DMAP FOR DETERMINING MODAL PARTICIPATION

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ABSTRACT

When performing eigenvalue analyses, it is usually necessary to establish the significance of individual modes. Parameters that are commonly used to assist in determining Modal Participation include Generalized Mass, Modal Participation Factors, and Effective Modal Mass. MSC/NASTRAN currently calculates only Generalized Mass when performing eigenvalue analysis (Sol 3). A DMAP alter package has been developed to provide MSC/NASTRAN users with additional information concerning Modal Participation. Features include: Modal Participation Factors; Effective Modal Mass; maximum values of eigenvectors; and Generalized Mass based on normalized eigenvectors of the physical structure. The last two items are particularly useful when Generalized Dynamic Reduction is used or when the "MASS" method of normalization is selected on the EIGR Bulk Data card.

The theory and procedure required for this DMAP alter package, as well as a verification problem, are discussed.

In addition, a method for calculating and plotting "Proportional Eigenvectors" is presented to provide a graphical representation of Modal Participation.

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1.0 INTRODUCTION

This DMAP alter package was developed because of the necessity of establishing the significance of individual modes when performing eigenvalue analysis. MSC/NASTRAN currently calculates only Generalized Mass when executing Solution 3. The inclusion of this alter package will provide the user with additional information concerning Modal Participation.

1.1 Features

Features of this alter package include calculations of:

a. Modal Participation Factors;
b. Effective Modal Mass;
c. Maximum value of eigenvectors;
d. Generalized Mass based on normalized eigenvectors (after removal of Q-set and R-set); and
e. "Proportional Eigenvectors"

Items (c) and (d) are particularly useful when Generalized Dynamic Reduction is used or when the "MASS" method of normalization is selected on the EIGR Bulk Data card.

1.2 Input

Besides the inclusion of this alter package in the Executive Control deck, the following PARAM card should be added to the Bulk Data deck.

PARAM, MDPF, V1

where; V1 = -1 - DO NOT EXECUTE ALTER (default)

= 0 - IF NORM = MASS ON EIGR BULK DATA CARD

= 1 - IF NORM = MAX ON EIGR BULK DATA CARD

1.3 Output

Besides the typical output produced by MSC/NASTRAN Solution 3 (Generalized Mass, eigenvalues, eigenvectors, mode shape plots, etc.), the following additional information is provided:

a. MODALPF - Printout of the Modal Participation Factors for each eigenvector

b. MAXDISP - Printout of the maximum displacements for each eigenvector after the Q-set has been removed

c. MDLWGHT - Printout of Effective Modal Mass for each eigenvector

d. MIMAX - Printout of the new Generalized Mass matrix created from the eigenvectors which were normalized after the removal of the Q-set

Item (d) is provided only for option PARAM, MDPF, 1 (NORM = MAX).

Additionally, the alter has the capability of producing plots of "Proportional Eigenvectors".

"Proportional Eigenvectors" are herein defined as eigenvectors scaled proportionally to their corresponding maximum Effective Modal Mass. This option is included to provide a graphical representation of Modal Participation.

1.4 Limitations

1.4.1 DMAP Limitations

The most significant limitation of this alter is that presently, Modal Participation Factor resultants do not yield valid rotational terms. The terms should be ignored when interpreting the results.

Another less significant limitation is that eigenvalue normalization is restricted to the "MASS" or "MAX" options as indicated on the EIGR Bulk Data card. The POINT option should not be selected when including this alter.

Finally, the Q-set is limited to scaler points and should not include any structural degress of freedom. This limitation is particularly applicable when including Generalized Dynamic Reduction.

An inconvenience rather than a limitation is that in order to obtain plots of "Proportional Eigenvectors", the user must also obtain plots of normalized eigenvectors.

This can produce improperly scaled plots if the maximum physical translation degree of freedom is not normalized to 1.0 as in the case when the MASS method of normalization or Generalized Dynamic Reduction is used. This problem can be alleviated by restarting and incorporating the modifications discussed in Section 4.0.

1.4.2 Theory Limitations

The concepts of Effective Modal Mass and "Proportional Eigenvectors" do not apply to all types of structural analyses.

2.0 EIGENVALVE ANALYSIS: THEORY AND APPLICATION

2.1 Theory

The theory applicable to this DMAP alter package is represented by basic relationships of eigenvalue analysis (Reference 4). These equations are cross-referenced to their corresponding data block names in Section 3.0.

2.1.1 Modal Extraction -

$$([K] - \omega_v^2 [M])\{\phi\}_v = 0 \qquad (1)$$

where $[K]$ = stiffness matrix

$[M]$ = mass matrix

$\{\phi\}_v$ = eigenvectors

ω_v^2 = eigenvalues

v = mode identification = 1 to V

The eigenvectors represent a deflected shape of the structure and are relative with respect to one another. This is commonly called the natural mode of vibration of the system. The associated frequency is defined as:

$$f_v = \frac{\omega_v}{2\pi} = \text{natural frequency (CPS)} \qquad (2)$$

2.1.2 Generalized Mass

The Generalized Mass associated with each eigenvector is defined by:

$$MI_{vv} = \{\phi\}_v^T [M] \{\phi\}_v \qquad (3)$$

where v = mode identification (1 to V)

The Generalized Mass is simply the Generalized Weight divided by gravity.

2.1.3 Participation Factors

Participation Factors are computed for each eigenvector. The translational components of the Participation Factors are defined as:

$$\Gamma_{iv} = \frac{\sum_{j=1}^{N} \phi_{ij} M_{ij}}{\{\phi\}_v^T [M] \{\phi\}_v} \qquad (4)$$

where i = component identification (1 to 6)

j = grid point identification (1 to N)

v = mode identification (1 to V)

N = total number of grid points

V = total number of modes

In other words, the Participation Factor is equal to the summation of the component of the eigenvector corresponding to the j^{th} node in the i^{th} direction, times the associated Mass, all divided by the Generalized Mass.

2.1.4 Effective Modal Mass

The Effective Modal Mass is defined as the square of the Participation Factor, (of a given eigenvector for a given component) times the associated Generalized Mass, i.e.,

$$MW_{iv} = \Gamma_{iv}^2 \cdot MI_{vv} \qquad (5)$$

where i = component identification (1 to 6)

v = mode identification (1 to V)

This concept has been derived in Reference 5 for problems with the following characteristics:

a. a unit static translation of the base of the structure produces directly a unit displacement of the entire structure

b. Masses are lumped along a vertical axis

However, the concept of Effective Modal Mass is usually a good indication of Modal Participation for most problems subjected to base excitation.

The Effective Modal Mass times gravity is commonly referred to as Modal Weight. The summation of Modal Weights for all modes in a given direction is equal to the corresponding "Base Shear" resulting from a "one g" base acceleration.

2.1.5 Proportional Eigenvectors

In order to present graphically, Modal Participation, the concept of "Proportional Eigenvectors" is introduced.

"Proportional Eigenvectors" are defined as eigenvectors which after being normalized to 1.0, are multiplied by the maximum of their corresponding Effective Modal Mass.

$$\{P\}_v = \{\phi\}_v \cdot MAX(MW_{iv};\ i = 1 \text{ to } 6) \qquad (6)$$

where i = component identification

v = mode identification (1 to V)

2.2 Application

The application of eigenvalue analysis in MSC/NASTRAN is accomplished by executing Solution 3.

2.2.1 Case Control

The Case Control deck (Reference 1) input includes a "METHOD" card which selects the Real Eigenvalue Paramaters as defined on a "EIGR" Bulk Data card.

If Dynamic Reduction is selected, a "DYNRED" card must be included to select the appropriate parameters as defined on the "DYNRED" Bulk Data card.

2.2.2. Bulk Data

The Bulk Data deck (Reference 1) includes an "EIGR" card. This card defines the method of eigenvalue extraction (INV, GIV, MGIV) and related parameters, as well as the method for normalizing eigenvectors. These methods, defined by the NORM parameter, are:

MASS - Normalized to unit value of Generalized Mass

MAX - Normalized to unit value of the largest component in the analysis set

POINT - Normalized to unit value of defined component

As discussed is Section 1.0, the alter is limited to the MASS or MAX options.

If Generalized Dynamic Reduction is used, a "DYNRED" card is also included. This card defines the highest frequency of interest and the number of Generalized coordinates.

This method uses Generalized coordinates to approximate the degrees of freedom which are free to vibrate. The user must define scaler points ("SPOINT" Bulk Data card) for these Generalized coordinates and must place them in the Q-set and A-set using the "QSET1" and "ASET1" Bulk Data cards (Reference 2).

2.3 Theory for Recommended Improvements

As discussed in Section 5.1, there are certain enhancements which will provide the user with information for both methods of normalization, regardless of which was selected.

This includes calculation of corresponding Modal Participation Factors as follows:

a. If NORM = MASS, the Modal Participation Factor for the MAX method is:

$$\Gamma_{MAX_{iv}} = \Gamma_{MASS_{iv}} \cdot \bar{\phi} \quad (7)$$

where $\bar{\phi}$ = maximum value of eigenvector

i = component identification (1 to 6)

v = mode identification (1 to V)

b. If Norm = MAX, the Modal Participation Factor for the MASS method is:

$$\Gamma_{MASS_{iv}} = (MW_{iv})^{1/2} \quad (8)$$

where i = component identification (1 to 6)

v = mode identification (1 to V)

Additionally, the Generalized Mass can be computed even if NORM = MASS using the relationship:

$$MI_{vv} = MW_{iv} \cdot (\Gamma^2_{MAX_{iv}})^{-1} \quad (9)$$

where i = component identification (1 to 6)

v = mode identification (1 to V)

3.0 THE MODAL PARTICIPATION ALTER

The Modal Participation Alter is shown in Table 1, and has been written in accordance with the DMAP rules as outlined in References 1 and 3. The solution of the matrix equations will be described as a series of steps through the alter. Since the solution requires multiple paths due to the two normalization methods ("MASS" and "MAX"), a number of parameters and data blocks must first be defined.

MDPF is the user defined parameter which is set to zero if the normalization method is "MASS" or to one if the normalization method is "MAX". The DMAP statement:

```
PARAM  //NOP/V,Y,MDPF = -1 $
```

sets a default of -1 for MDPF. The next parameter is NMDPF, which is defined by the DMAP statement:

```
PARAM  //SUB/V,N,NMDPF/MDPF/1 $
```

The equivalent algebric definition is:

```
NMDPF = MDPF -1
```

In other words, NMDPF equals -1 if the "MASS" option is specified or it equals zero if the "MAX" option is specified. The final parameter defined is MMDPF by the DMAP statement:

```
PARAM  //NE/V,N,MMDPF/MDPF/0 $
```

Which satisfied the following relationship:

If MDPF = 0, MMDPF = 1 (MASS option)

If MDPF $\neq$ 0, MMDPF = -1 (MAX option)

A condition statement is then specified to terminate the DMAP alter if the user did not specify MDPF. It reads:

```
COND  NOMP,MDPF  $
```

This statement will transfer control to:

```
LABEL  NOMP  $
```

at the end of the alter, in the event that MDPF equal -1 (default if no user specification of MDPF).

The next preliminary process is to set up a temporary V-size column vector (MITTT) with each row set equal to unity which will be used for various transformations. To define the vector, the Generalized Mass (MI) is inverted with the DMAP statement:

```
DIAGONAL  MI/MIT/SQUARE/-1.  $
```

The Generalized Mass is then multiplied by its invert (MIT) with the DMAP statement:

```
MPYAD MIT,MI,/MITT $
```

The column matrix of the diagonal of MITT is then formed with the DMAP statement:

```
DIAGONAL  MITT/MITTT/COLUMN/1.  $
```

3.1 Determining Modal Participation Factors

3.1.1 Data Block Definitions

As discussed in Section 2.1.3, Modal Participation Factors are defined by equation (4).

This matrix equation is represented by the following data blocks:

MDLPF = Modal Participation Factors

UGMQRV = Recalculated Eigenvector

MGG = G-size Mass Matrix

MIFF = Recalculated Generalized Mass

3.1.2 Recalculated Eigenvector

UGMQRV is a G-size vector containing null terms for the Q-set and R-set. To obtain such a data block, the Q-set terms must first be set equal to zero. A partitioning vector, CQ, is defined by the DMAP statement:

```
VEC USET/CQ/G/COMP/Q  $
```

The eigenvector (UGV) is then partitioned into a Q-set vector (UQV) and a vector made up of the compliment of the Q-set (UCQV) by the DMAP statement:

```
PARTN UGV,,CQ/UCQV,UQV,,/1  $
```

The recalculated eigenvector and Generalized Mass must remain consistant to one another and their structure will depend on the normalization method chosen. An intermediate vector, NUCQV, is defined which is equal to UCQV if NORM = MASS or it is equal to normalized UCQV if NORM = MAX.

If NORM = MASS, NUCQV is defined to be equivalent to UCQV by the DMAP statement:

EQUIV UCQV,NUCQV/NMDPF $

The next condition statement which follows:

COND NOMAX1,NMDPF $

Will then cause a transfer to the label:

LABEL NOMAX1 $

when NORM = MASS. If, instead, NORM = MAX, the DMAP statement:

NORM UCQV/NUCQV $

is processed.

A Q-size vector (UQVN) is now created, which is the negative of UQV with the DMAP statement:

ADD UQV,/UQVN/-1.0 $

Next, a Q-size vector of zero terms (UQVZ) is obtained by adding UQV to UQVZ with the DMAP statement:

ADD UQV,UQVN/UQVZ $

UQVZ is then merged with NUCQV to form the G-size vector, UGMQV, which has null Q-set terms. This is done with the DMAP statement:

MERGE NUCQV,UQVZ,,,,CQ/UGMQV/1 $

The same process that was used to null the Q-set is now used to null the R-set. A partitioning vector (CR) is defined by the DMAP statement:

VEC USET/CR/G/COMP/R $

Next, UGMQV is partitioned into a R-set vector (URV) and a compliment of R-set vector (UCRV) with the DMAP statement:

PARTN UGMQV,,CR/UCRV,URV,,/1 $

A negative R-set vector (URVN) is formed by the DMAP statement:

ADD URV,/URVN/-1.0 $

A null R-set vector (URVZ) is formed by the DMAP statement:

```
ADD URV,URVN/URVZ  $
```

The G-size vector with null Q-set and R-set terms (UGMQRV) is formed by the DMAP statement:

```
MERGE UCRV,URVZ,,,,CR/UGMQRV/1  $
```

3.1.3 Recalculated Generalized Mass

The Generalized Mass must be consistent with the eigenvector and the method of normalization. If NORM = MASS, the recalculated Generalized Mass (MIFF) is equivalenced to the standard Generalized Mass (MI) with the DMAP statement:

```
EQUIV MI,MIFF/NMDPF  $
```

In addition, if NORM = MASS, the condition statement:

```
COND NOMAX2,NMDPF  $
```

transfers control to the label:

```
LABEL NOMAX2  $
```

If NORM = MAX, a new Generalized Mass must be calculated, which is equal to the standard Generalized Mass divided by the maximum displacements of the compliment of the Q-set vector, squared. First the maximum displacements are created with the DMAP statement:

```
MATMOD UCQV,,,,,/MUCQV,/7  $
```

Next, MUCQV is squared forming SUCQV by the DMAP statement:

```
DIAGONAL MUCQV/SUCQV/WHOLE/2.0  $
```

Next, SUCQV is inverted forming IUCQV by the DMAP statement:

```
DIAGONAL SUCQV/IUCQV/WHOLE/-1.0  $
```

The standard Generalized Mass (MI) is then multiplied by IUCQV yielding MIF by the DMAP statement:

```
MPYAD IUCQV,MI,/MIF/1  $
```

MIF then has the proper terms for Generalized Mass, but is of the wrong form since it is a column matrix of V-size. To bring it to the proper form, (V by V) it is multiplied by the unit column matrix (MITTT) forming MIFF with the following DMAP statement:

```
MPYAD MITTT,MIF,/MIFF  $
```

Since the recalculated Generalized Mass could be of interest to the user, it is then printed. The printing of the column matrix MIF is more pleasing to the eye, thereby it is first renamed to MIMAX for proper titling by the DMAP statement:

```
MATMOD MIF,,,,,/MIMAX,/13  $
```

MIMAX is then printed by the DMAP statement:

```
MATPRT MIMAX//  $
```

3.1.4 Maximum Displacements

The maximum displacement of the original eigenvector with null terms substituted for the Q-set is an item of frequent interest. To obtain these values, the G-size vector is formed with the DMAP statement:

```
MERGE UCQV,UQVZ,,,,CQ/MAXDISP/1  $
```

followed by the printing of the maximum values of MAXDISP with the DMAP statement:

```
VECPLOT MAXDISP,BGPDT,EQEXIN,CSTM,CASECC,
        /MDIS/V,Y,GRDPNT/0/5/MAXDISP $
```

3.1.5 Modal Participation Factor

To obtain the numerator of the Modal Participation equation, the standard G-size Mass Matrix (MGG) must first be multiplied by its new G-size vector (UGMQRV) with the DMAP statement:

```
MPYAD UGMQRV,MGG,/UGMG/1  $
```

Before performing the summation, the data block UGMG will be divided by the new Generalized Mass MIFF. This requires a three-step process. First the new Generalized Mass is diagonalized with the DMAP statement:

```
DIAGONAL MIFF/MIDIAG/SQUARE  $
```

The diagonalized Generalized Mass (MIDIAG) is then inverted with the DMAP statement:

```
DIAGONAL MIDIAG/MIINV/SQUARE/-1.  $
```

followed by the multiplication of the data block UGMG by the invert of the new Generalized Mass with the DMAP statement:

```
MPYAD MIINV,UGMG,/MDLPF  $
```

The resulting data block (MDLPF), is a G-size vector of Modal Participation Factors. To obtain the summation for each of the six Basic Coordinate directions, MDLPF must first be transposed with the DMAP statement:

```
TRNSP MDLPF/MDLPFT  $
```

followed by summarizing and printing the resultant in the Basic Coordinate System with the DMAP statement:

```
VECPLOT MDLPFT,BGPDT,EQEXIN,CSTM,CASECC,
        /PFRT/V,Y,GRDPNT/O/1/MODALPF  $
```

3.2 Determining Effective Modal Mass

3.2.1 Data Block Definitions For Effective Modal Mass

Effective Modal Mass are defined by equation (5) of Section 2.1.4.

This matrix equation is represented by the following data blocks:

MDLWGHT = Effective Modal Mass

SUMPF = Summarized Modal Participation Factors

SQPF = SUMPF squared

3.2.2 Summarizing Modal Participation Factors

The earlier use of VECPLOT for printing the summation of the Modal Participation Factors provided only printed output. The computation of Effective Modal Mass will require that the summation of the Modal Participation Factors be put into data block form.

MDLPFT is in Global Coordinates, however to perform a summation the vector must be in Basic Coordinates. The resultant data block (PFRT) from the above VECPLOT statement provides this required vector.

The data block, PFRT is of G-size. To perform the summation over the six degrees of freedom, the Q-set must be partitioned out with the following DMAP statement:

```
PARTN PFRT,,CQ/PFCQ,PFQ,,/1  $
```

A pattern matrix whose size is the compliment of the Q-set by six is required for the summation. The matrix will consist of 6 by 6 identity matrices for each Grid Point in the structure. To provide such a matrix, a parameter (NCMDLPF) must be defined whose value is the number of terms in the compliment of the Q-set. NCMDLPF is determined with the DMAP statement:

```
PARAML PFCQ//TRAILER/2/V,N,NCMDLPF  $
```

A pattern matrix is then generated with the DMAP statement:

```
MATGEN ,/PATT1/4/NCMDLPF/6/0/1/6/1/1/6  $
```

PATT1 will consist of a series of 6 by 6 matrices with the row numbers on the diagonals. The summation process will require that the 6 by 6 matrices have ones on the diagonal, thereby a new matrix is formed with the DMAP statement:

```
NORM PATT1/PATT2  $
```

The summation is then obtained with the DMAP statement:

```
MPYAD PATT2,PFCQ,/SUMPF  $
```

SUMPF is then squared with the DMAP statement:

```
DIAGONAL SUMPF/SQPF/WHOLE/2.0  $
```

3.2.3 Effective Modal Mass

MDLWGHT is determined by multiplying the diagonal of the recalculated Generalized Mass (MIDIAG) by the squared summation of Modal Participation Factors (SQPF) with the DMAP statement:

```
MPYAD SQPF,MIDIAG,/MDLWGHT  $
```

The Effective Modal Mass is then printed with the DMAP statement:

```
MATPRT MDLWGHT//  $
```

3.3 "Proportional Eigenvectors"

Proportional Eigenvectors are defined in Section 2.1.5, equation (6).

The "Proportional Eigenvectors" should only be calculated if a PLOT request exists. The DMAP statement:

```
COND P3,JUMPPLOT  $
```

will cause a transfer to the label statement:

```
LABEL P3  $
```

at the end of the alter when no plots have been requested. JUMPPLOT is a standard MSC/NASTRAN parameter in SOL 3.

3.3.1 Data Block Definitions for Proportional Eigenvectors

MMW = Maximum Values of MDLWGHT

NUGMQRV = Normalized UGMQRV

MMWV = Proportional Eigenvector

3.3.2 Maximum Effective Modal Mass

The values of the Maximum Effective Modal Mass are obtained with the following DMAP statement:

```
MATMOD MDLWGHT,,,,,/MMW,/7  $
```

The resulting data block, MMW, is a V-size column vector. The form of this vector must be changed to a square diagonal matrix. This requires a three step process. First, the vector is transposed with the DMAP statement:

```
TRNSP MMW/MMWT  $
```

Next, the resultant data block, MMWT, is multiplied by the V-size unit column vector, MITTT, with the DMAP statement:

```
MPYAD MITTT,MMWT,/MMWS  $
```

Finally, the resultant square matrix, MMWS, is diagonalized with the DMAP statement:

```
DIAGONAL MMWS/MMWD/SQUARE  $
```

3.3.3 Normalized Eigenvector

A G-size by V-size vector is now required which has been normalized to 1.0 after the Q-set and R-set have been replaced with null terms. If the normalization method is "MAX", this vector is equivalent to UGMQRV, which is provided by the DMAP statement:

```
EQUIV UGMQRV,NUGMQRV/MMDPF  $
```

Also, if the normalization method is "MAX", control is transferred with the DMAP statement:

```
COND MAX,MMDPF  $
```

to the label statement:

```
LABEL MAX  $
```

If, on the other hand, the normalization method is "MASS", UGMQRV must be normalized with the DMAP statement:

```
NORM UGMQRV/NUGMQRV  $
```

3.3.4 Determining and Plotting the "Proportional Eigenvector"

The "Proportional Eigenvector" is determined with the DMAP statement:

```
MPYAD NUGMQRV,MMWD,/MMWV  $
```

The resulting vector, MMWV, is in the Global Coordinate system. Before it is plotted, it is transformed to the Basic Coordinate system with the DMAP statement:

```
SDR2 CASECC,CSTM,MPT,DIT,EQEXIN,,ETT,,
     BGPDT,LAMA,QG,MMWV,EST,XYCDB/OPG3,
     OQG3,OUGV3,OES3,OEF3,PMMWV/SOLTYPE/
     S,N,NOSORT2 $
```

The plotting vector, PMMWV, is then plotted with the DMAP statement:

```
PLOT PLTPAP,GPSETP,ELSETP,CASEXX,BGPDT,
     EQEXIN,SIL,PMMWV,PMMWV,GPECT,OES1/
     PLOTX3/DSIL/LUSET/JUMPPLOT/PLTFLG/
     S,N,PFILE  $
```

The plot messages, PLOTX3, are then printed with the DMAP statement:

```
PRTMSG PLOTX3//  $
```

4.0 <u>VERIFICATION AND RESULTS</u>

To verify the method, five MSC/NASTRAN analyses were performed. Figures 1,2,3, and 4 provide data which is applicable to all five analyses. Figure 1 is the mathematical model, Figure 2 is the element data, Figure 3 is the constraint data and Figure 4 is the Modal extraction data. This model was chosen since it could be verified by hand computations.

4.1 Verification

The five test runs were required to verify the different paths and options through the alter. Table 2 shows the characteristics which were varied between the five runs.

The Effective Modal Mass was used in the comparison of results in Table 3, since these values should be the same for all five runs. The magnitudes of the Participation Factors are dependent on the normalization method chosen and are thus not presented here. The results show that the significant Effective Modal Mass, which are in units of Mass for each Eigenvector, were identical with the exception of frequency 7.93 HZ. The value of the Effective Modal Mass for this mode is essentially a computational zero and can be ignored.

4.2 Sample Output

Samples of the printed output are provided in Tables 4, 5, 6 and 7.

Table 4 is the recalculated Generalized Mass provided when the normalization method is "MAX". The new Generalized Mass is based on the renormalization of the eigenvector after the Q-set and R-set terms are set to zero. Each column of INTERMEDIATE MATRIX MIMAX represents each eigenvector in the analysis. This printout is only provided when NORM = MAX (PARAM,MDPF,1).

Table 5 provides the values of maximum displacements (for each of the six components) after the Q-set and R-set terms have been set to zero. The terms are from the original eigenvector (not renormalized) thus providing a method of locating the structural maximum displacements by reviewing the standard eigenvalue printout.

Table 6 provides the Modal Participation Factors for each eigenvector. The rotational terms in this printout are not valid since the proper moment arms are not taken into consideration.

Table 7 is the Effective Modal Mass (over the three translational components) for each of the eigenvectors. The six rows of the Intermediate Matrix MDLWGHT represent the six basic component directions (T1, T2, T3, R1, R2 and R3) and the columns represent the eigenvectors.

4.3 Plotted Output

Figure 5 shows standard MSC/NASTRAN eigenvector plots for frequencies 28 HZ, 226 HZ, and 227 HZ respectively. The model used for these plots included a SUPORTed large Mass at grid point 600 with NORM = MASS (Run #2). The maximum "structural" displacements (from MAXDISP RESULTANT printout) where .7346 (T2), .5802 (T2) and .5802 (T2) respectively.

Figure 6 shows the "Proportional Eigenvector" plots of the same three modes with Effective Modal Mass being 1.913 (T2), 6.6E-6 (T1) and 2.911 (T2) respectively. The plots provide a visual contribution of each of the modes. This is accomplished by having all of the vectors scaled with respect to one another. This option is available by using the MAXIMUM DEFORMATION parameter on the MSC/NASTRAN PLOT card as shown in the following example:

PLOT MODAL DEFORMATION MAXIMUM DISPLACEMENT 1.0

This method provides a visual indication of the Effective Modal Mass.

The above PLOT card, which is required to produce "Proportional Eigenvector" plots, could produce undesirable standard eigenvector plots in some models. All PLOT MODAL DEFORMATION cards in the Case Control deck will be processed by the standard SOL 3 Deformed Plotter and the Deformed Plotter in the alter. With these facts in mind, three possible plotting options are provided.

1. To obtain eigenvector plots scaled to the maximum displacement of all eigenvectors and "Proportional Eigenvector" plots, use the alter as is.

2. To obtain only "Proportional Eigenvector" plots (Version 62) include in the Executive Control deck:

   ALTER 500, 500

3. To obtain eigenvector plots with each vector scaled to its maximum value and "Proportional Eigenvector" plots:

   - Obtain eigenvector plots first in a standard SOL 3 run (without the alter)

   - Restart for all Modal Participation output, including in the Executive Control deck:

     ALTER 500, 500

The plots shown in Figures 5 and 6 were produced with MSC/GRASP and are equivalent to the plots that would be produced by the above method.

5.0 SUMMARY

5.1 Recommended Improvements

Although this alter package provides the MSC/NASTRAN user with valuable information in an acceptable format, there are areas requiring modifications which, if incorporated, will enhance the alter as more user-friendly.

These improvements include:

a. Provide DMAP to internally determine the value of parameter MDPF;

b. provide user parameters to optionally suppress printing of all provided output;

c. determine Modal Participation Factors for both methods (NORM = MASS, MAX) regardless of method selected. Allow option to print both;

d. calculate and optionally print Generalized Mass based on normalized eigenvector when NORM = MASS;

e. summarize the Effective Modal Mass for all modes selected by dividing by the total Effective Modal Mass. This will provide a check of Modal representation;

f. include modification which will provide proper rotational terms of the Modal Participation Factors. (In the interim, these terms should be zeroed out);

g. include option to plot either/or eigenvectors and Proportional Eigenvectors;

h. include option to print renormalized eigenvector; and

i. include option to print "Proportional Eigenvectors"

5.2 Conclusions

Modal Participation is important to all analysts performing Normal Modes Analyses. This alter, by calculating Modal Participation parameters, will benefit analyses by providing:

- cost savings since more eigenvalues than required will not have to be incorporated into a frequency response analyses

- increased accuracy since it eliminates the risk of omitting significant modes

- faster and more accurate result interpretation by determining Effective Modal Mass and "Proportional Eigenvectors".

TABLE INDEX

TABLE 1 MODAL PARTICIPATION ALTER

N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O

```
ID DVSE,MSC
TIME 2
DIAG 14
SOL 3
$ RFALTER FOR RECOVERING MODAL PARTICIPATION FACTORS AND MODAL WEIGHT
$ FOR SOL 3
$
$
$     NOTE- Q-SET MAY NOT CONTAIN ANY GRID DOF (ONLY SPOINTS)
$
$
$ PARAMETERS-
$     MDPF - DEFAULT = -1 (NO ACTION)
$             O = MASS OPTION (NORM ON EIGR CARD)
$             1 = MAX OPTION  (NORM ON EIGR CARD)
$
$
$ ADDITIONAL PRINT OUT-
$     MAXDISP - MAXIMUM DISPLACEMENTS OF UNNORMAILIZED EIGENVECTORS
$               WITH Q-SET ZEROED OUT
$     MODALPF RESULTANT - THE MODAL PARTICIPATION FACTORS FOR
$                         EACH EIGENVECTOR. ONLY THE THREE
$                         TRANSLATIONAL VALUUES ARE VALID
$     IF PARAM,MDPF,1 - MIMAX - GENERALIZED MASS BASED ON
$                         NORMALIZATION OF THE EIGENVECTORS
$                         WITH Q-SET DISPLACEMENTS REMOVED
$
$
ALTER 509
PARAM //NOP/V,Y,MDPF=-1 $ SET MDPF = -1 WITH USER OPTION TO CHANGE
PARAM //SUB/V,N,NMDPF/MDPF/1 $ NMDPF = MDPF - 1 (FOR COND AND EQUIV LATE
PARAM //NE/V,N,MMDPF/MDPF/O $ MMDPF = 1 FOR MASS OPTION
COND NOMP,MDPF $ IF MDPF = -1  STOP
$
$
$     FORM V-SIZE COLUMN VECTOR OF 1.OS
$
$
DIAGONAL MI/MIT/SQUARE/-1. $ INVERT MI
MPYAD MIT,MI,/MITT $ FORM IDENTITY MATRIX
DIAGONAL MITT/MITTT/COLUMN/1. $ FORM COLUMN MATRIX
$
$
$     PARTITION OUT Q-SET
$
$
VEC USET/CQ/G/COMP/Q $ CREATE PARTITIONING VECTER FOR Q-SET
PARTN UGV,,CQ/UCQV,UQV,,/1 $ PARTITION EIGENVECTORS
$
```

N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O

```
$
$      DETERMINE UGMQRV
$
$
EQUIV UCQV,NUCQV/NMDPF $ EQUIV ONLY IF MASS OPTION USED
COND NOMAX1,NMDPF $ JUMP IF NORM = MASS
$
$
$      DETERMINE NUCQV FOR NORM=MAX
$
$
NORM UCQV/NUCQV $ NORMALIZE COMP-Q SIZE EIGENVECTORS
LABEL NOMAX1 $
$
$
$      FORM NEW G-SIZE EIGENVECTOR WITH Q-SET ZEROED OUT
$
$
ADD UQV,/UQVN/-1.0 $ GET NEGATIVE VALUES OF Q-SIZE EIGVEC
ADD UQV,UQVN/UQVZ $ CREATE ZEROED VECTOR OF Q-SIZE
MERGE NUCQV,UQVZ,,,,CQ/UGMQV/1 $ CREATE G-SIZE VECTOR WITH ZERO Q-SET
$
$
$      FORM NEW G-SIZE EIGENVECTOR WITH R-SET ZEROED OUT
$
$
VEC USET/CR/G/COMP/R $ CREATE PARTITIONING VECTOR FOR R-SET
PARTN UGMQV,,CR/UCRV,URV,,/1 $ PARTITION OUT R-SET
ADD URV,/URVN/-1.0 $ GET NEGATIVE VALUES OF R-SIZE EIGVEC
ADD URV,URVN/URVZ $ CREATE ZEROED VECTOR OF R-SIZE
MERGE UCRV,URVZ,,,,CR/UGMQRV/1 $CREATE G-SIZE VEC WITH ZERO R AND Q-SET
$
$
$      DETERMINE MIFF
$
$
EQUIV MI,MIFF/NMDPF $ EQUIV ONLY IF MASS OPTION USED
COND NOMAX2,NMDPF $ JUMP IF NORM = MASS
$
$
$      FIND MIFF FOR NORM = MAX
$           WHERE-NUCQV=NORMALIZED COMP-Q SIZE EIGENVECTORS
$
$                                   (GENERALIZED MASS)
$                 MIFF=-----------------------------------
$                                                        2
$                     (MAXIMUM VALUES OF COMP-Q EIGENVECTORS)
$
$
$
```

NASTRAN EXECUTIVE CONTROL DECK ECHO

```
$
$     FIND MAX VALUES FOR COMP-Q SIZE EIGENVECTORS
$
$
MATMOD UCQV,,,,,/MUCQV,/7 $ FIND MAX VALUES
DIAGONAL MUCQV/SUCQV/WHOLE/2.0 $ SQUARE MAX COMP-Q EIGENVECTORS
DIAGONAL SUCQV/IUCQV/WHOLE/-1.0 $ INVERT SQUARED VALUES
MPYAD IUCQV,MI,/MIF/1 $ SOLVE MIF = MI/(MAX COMP-Q EIGVEC) SQUARED
MPYAD MITTT,MIF,/MIFF $ BRING GEN MASS TO PROPER SIZE
MATMOD MIF,,,,,/MIMAX,/13 $ CHANGE NAME FOR PRINTING
MATPRT MIMAX// $ PRINT NEW GENERALIZED MASS
LABEL NOMAX2 $
$
$
$     PRINT MAX DISPLACEMENTS WITHOUT NORMALIZATION
$
$
MERGE UCQV,UQVZ,,,,CQ/MAXDISP/1 $CREATE G-SIZE VECTOR ZERO Q-SET
VECPLOT MAXDISP,BGPDT,EQEXIN,CSTM,CASECC,/MDIS/V,Y,GRDPNT/O/5/MAXDISP $
$
$
$     SOLVE FOR MODAL PARTICIPATION FACTORS (MDLPFT)
$       WHERE-
$                 SUMMATION OF (EIGVEC WITH ZERO R AND Q) (MGG)
$           MDLPFT=------------------------------------------------
$                            (NEW GENERALIZED MASS)
MPYAD UGMQRV,MGG,/UGMG/1 $ GET SUMMATION
DIAGONAL MIFF/MIDIAG/SQUARE $ DIAGIONALIZE NEW GEN WGHT
DIAGONAL MIDIAG/MIINV/SQUARE/-1. $ INVERT MIFF
MPYAD MIINV,UGMG,/MDLPF $ SOLVE FOR MDLPF
TRNSP MDLPF/MDLPFT $ TRANSPOSE FOR VECPLOT
VECPLOT MDLPFT,BGPDT,EQEXIN,CSTM,CASECC,/PFRT/V,Y,
GRDPNT/O/1/MODALPF $ SUMMARIZE AND PRINT
$
$
$     COMPUTE MODAL WEIGHTS (MDLWGHT)
$
$
PARTN PFRT,,CQ/PFCQ,PFQ,,/1 $ REMOVE Q-SET FROM MODAL PARTIC FACT
PARAML PFCQ//TRAILER/2/V,N,NCMDLPF $ FIND SIZE OF COMP-Q-SET
MATGEN ,/PATT1/4/NCMDLPF/6/O/1/6/1/1/6 $ CREATE PATTERN MATRIX
NORM PATT1/PATT2 $ NORMALIZE PATTERN MATRIX
MPYAD PATT2,PFCQ,/SUMPF $ SUM MDPF FOR 6 COMPONENTS
DIAGONAL SUMPF/SQPF/WHOLE/2.0 $ SQUARE MDPF SUMMATION
MPYAD SQPF,MIDIAG,/MDLWGHT $ CREATE MDL WGHT = ((MDPF)**2)*GEN WGHT)
MATPRT MDLWGHT// $ PRINT MODAL WGHT
$
$
$     PLOT MODAL WGHT VECTOR
$
```

N A S T R A N   E X E C U T I V E   C O N T R O L   D E C K   E C H O

```
$
COND P3,JUMPPLOT $
MATMOD MDLWGHT,,,,,/MMW,/7 $ FIND MAX MDL WGHT
TRNSP MMW/MMWT $ FORM MAX MDL WGHT TRANSPOSE
MPYAD MITTT,MMWT,/MMWS $ MAKE MAX MDL WGHT A SQUARE MATRIX
DIAGONAL MMWS/MMWD/SQUARE $ FORM MAX MDL WGHT DIAGONAL MATRIX
EQUIV UGMQRV,NUGMQRV/MMDPF $ EQUIV IF MAX OPTION
COND MAX,MMDPF $ JUMP IF MAX OPTION
NORM UGMQRV/NUGMQRV $
LABEL MAX $
MPYAD NUGMQRV,MMWD,/MMWV $ FORM MAX MDL WGHT VECTOR
SDR2     CASECC,CSTM,MPT,DIT,EQEXIN,,ETT,,BGPDT,LAMA,QG,MMWV,EST,XYCDB/
                   OPG3,OQG3,OUGV3,OES3,OEF3,PMMWV/SOLTYPE/S,N,NOSORT2 $
PLOT   PLTPAP,GPSETP,ELSETP,CASEXX,BGPDT,EQEXIN,SIL,PMMWV,PMMWV,GPECT,
         OES1/PLOTX3/DSIL/LUSET/JUMPPLOT/PLTFLG/S,N,PFILE $
PRTMSG   PLOTX3// $
LABEL    P3 $
LABEL NOMP $
CEND
```

TABLE 2

Test Runs

Run Number	Normalization Method	Base Condition*	Base Weight**
1	MAX	SUPORT	1.0E11
2	MASS	SUPORT	1.0E11
3	MAX	SPC	0.0
4	MAX	SPC	1.0E11
5	MASS	SPC	0.0

* Grid Point 600 - 123

** Weight in pounds grid point 600-123

TABLE 3

Comparison of Results

Maximum Values of Effective Modal Mass

Frequency	NORM = MASS	NORM = MAX
4.40	4.822 (T3)	4.822 (T3)
7.42	4.824 (T3)	4.824 (T3)
7.93	1.4-22 (T1)	1.5-24 (T1)
27.75	2.07-3 (T3)	2.07-3 (T3)
28.49	1.913 (T2)	1.913 (T2)
226.40	6,67-6 (T1)	6.67-6 (T1)
227.32	2.911 (T2)	2.911 (T2)

INTERMEDIATE MATRIX ... MIMAX

```
1                    COLUMN      1
                       2.588000E+08                    1
1                    COLUMN      2
                       2.588000E+08                    1
1                    COLUMN      3
                       2.588000E+08                    1
1                    COLUMN      4
                       4.582463E+00                    1
1                    COLUMN      5
                       4.822045E+00                    1
1                    COLUMN      6
                       2.971024E+00                    1
1                    COLUMN      7
                       3.111002E+00                    1
1                    COLUMN      8
                       1.853313E+00                    1
1                    COLUMN      9
                       2.971028E+00                    1
1                    COLUMN     10
                       2.971525E+00                    1
```

BY D.V. SCHIAVELLO AND J.E. SINKIEWICZ

MAXDISP RESULTANT

	T1	T2	T3	R1	R2	R3
1	1.0000000E+00	3.6531210E-15	0.	0.	0.	1.2267964E-14
2	1.0691960E-14	1.0000000E+00	0.	0.	0.	4.4408921E-16
3	0.	0.	1.0000000E+00	3.7192471E-15	1.6960325E-15	0.
4	3.7466220E-13	2.8715809E-14	7.9945371E-01	9.5782949E-03	7.9169123E-04	9.4884665E-15
5	7.1052875E-01	1.0644522E-03	1.5479089E-12	1.4192221E-14	3.0217152E-14	3.5620960E-03
6	6.9872226E-13	5.1199579E-13	6.7371309E-01	7.0631211E-03	1.1566761E-02	1.0661786E-14
7	7.7604736E-14	2.4715983E-11	6.0865661E-01	4.9507230E-03	2.3965666E-02	8.0314661E-13
8	1.1548617E-03	9.2674494E-01	2.0577073E-11	1.7108019E-13	8.1254949E-13	1.5295240E-02
9	6.6724189E-04	5.8390050E-01	3.1678134E-13	1.2661769E-08	6.9416654E-08	1.1679161E-02
10	1.4954855E-03	5.8383106E-01	2.2540682E-11	3.7408862E-09	2.4041835E-08	9.8935937E-03

BY D.V. SCHIAVELLO AND J.E. SINKIEWICZ

MODALPF RESULTANT

	T1	T2	T3	R1	R2	R3
1	2.2959999E-08	-9.5483932E-24	0.	0.	0.	-2.2367999E-06
2	-1.9896123E-22	2.2959999E-08	0.	0.	0.	2.4415991E-20
3	0.	0.	2.2959999E-08	2.2367999E-06	5.7598240E-20	0.
4	4.9254756E-13	-8.4917325E-15	-1.0257993E+00	-1.2309591E+02	1.3983481E-11	-5.9129025E-11
5	-1.0002053E+00	-3.5131647E-13	-4.9049929E-13	-5.8859915E-11	-6.2393959E-11	1.2008002E+02
6	1.6820752E-12	-7.3263126E-13	-3.5815241E-13	-4.2779337E-11	-6.0000000E+01	-2.0257297E-10
7	-1.0491713E-14	1.5665183E-11	2.5799289E-02	3.0959147E+00	9.0949470E-13	3.3806264E-11
8	8.1427403E-15	1.0159559E+00	9.2761101E-13	1.1131332E-10	5.5354885E-13	-5.2425919E-11
9	1.4983742E-03	1.0301860E-11	-1.4543651E-14	-1.7452381F-12	-6.3048751E-13	5.9820109E+01
10	6.1405500E-13	-9.8978042E-01	1.0327088E-12	1.2392506E-10	4.4881199E-11	5.1719341E-10

TABLE 6 MDLPF RESULTANT PRINTOUT

BY D.V. SCHIAVELLO AND J.E. SINKIEWICZ

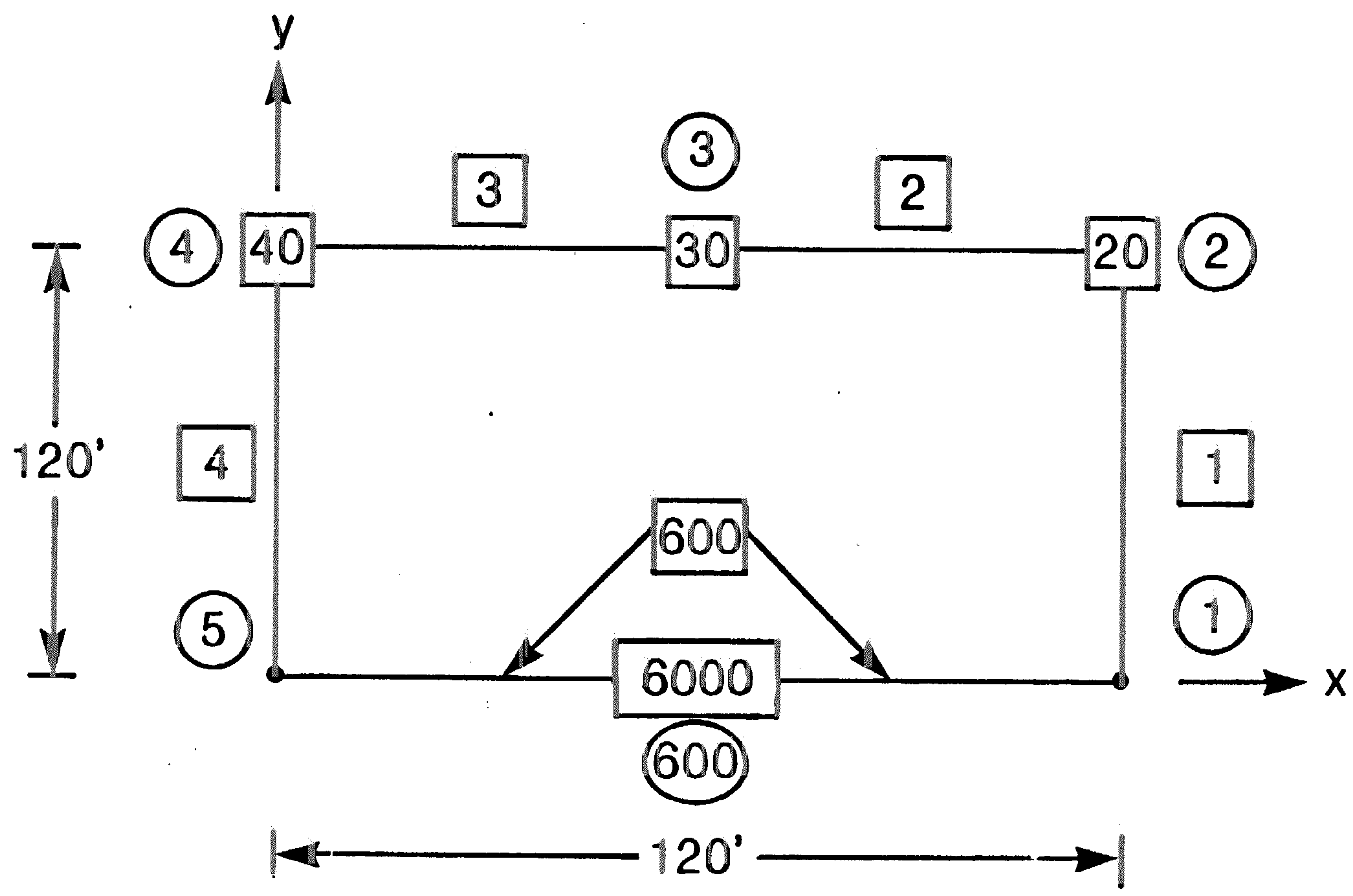
INTERMEDIATE MATRIX ... MDLWGHT

				COLUMN 1				
1	1.364294E-07	2.359527E-38	0.		0.	0.	0.	6
				COLUMN 2				
1	1.024475E-35	1.364294E-07	0.		0.	0.	0.	6
				COLUMN 3				
1	0.	0.	1.364294E-07		0.	0.	0.	6
				COLUMN 4				
1	1.111720E-24	3.304392E-28	4.821961E+00		0.	0.	0.	6
				COLUMN 5				
1	4.824025E+00	5.951574E-25	1.160134E-24		0.	0.	0.	6
				COLUMN 6				
1	8.406147E-24	1.594693E-24	3.825334E-25		0.	0.	0.	6
				COLUMN 7				
1	3.424468E-28	7.634336E-22	2.070694E-03		0.	0.	0.	6
				COLUMN 8				
1	1.225701E-28	1.912927E+00	1.594706E-24		0.	0.	0.	6
				COLUMN 9				
1	6.670331E-06	3.151546E-22	6.284253E-28		0.	0.	0.	6
				COLUMN 10				
1	1.120412E-24	2.911100E+00	3.169094E-24		0.	0	0.	6

FIGURE INDEX

FIGURE 1

Mathematical Model



where □ = element IDs

○ = grid point IDs

FIGURE 2

General Model Data

Elements

- CBAR

  A = 36.0 in^2
  I1 = 108.0 in^4
  I2 = 108.0 in^4
  J = 108.0 in^4
  E = 1.0E 7 psi
  NU = 0.3
  RHO = 0.1 lbs/in^3

- CONM2

  ID 20 - 250.0 lbs
  ID 30 - 500.0 lbs
  ID 40 - 250.0 lbs

FIGURE 3

General Model Data

Constraints

- SPC

  Grid Point 600 - 456

- RBE2 - 123456

  Independent - 600

  Dependent - 1 and 5

FIGURE 4

General Model Data

Modal Extraction

- Eigenvalues

  Method - MGIV

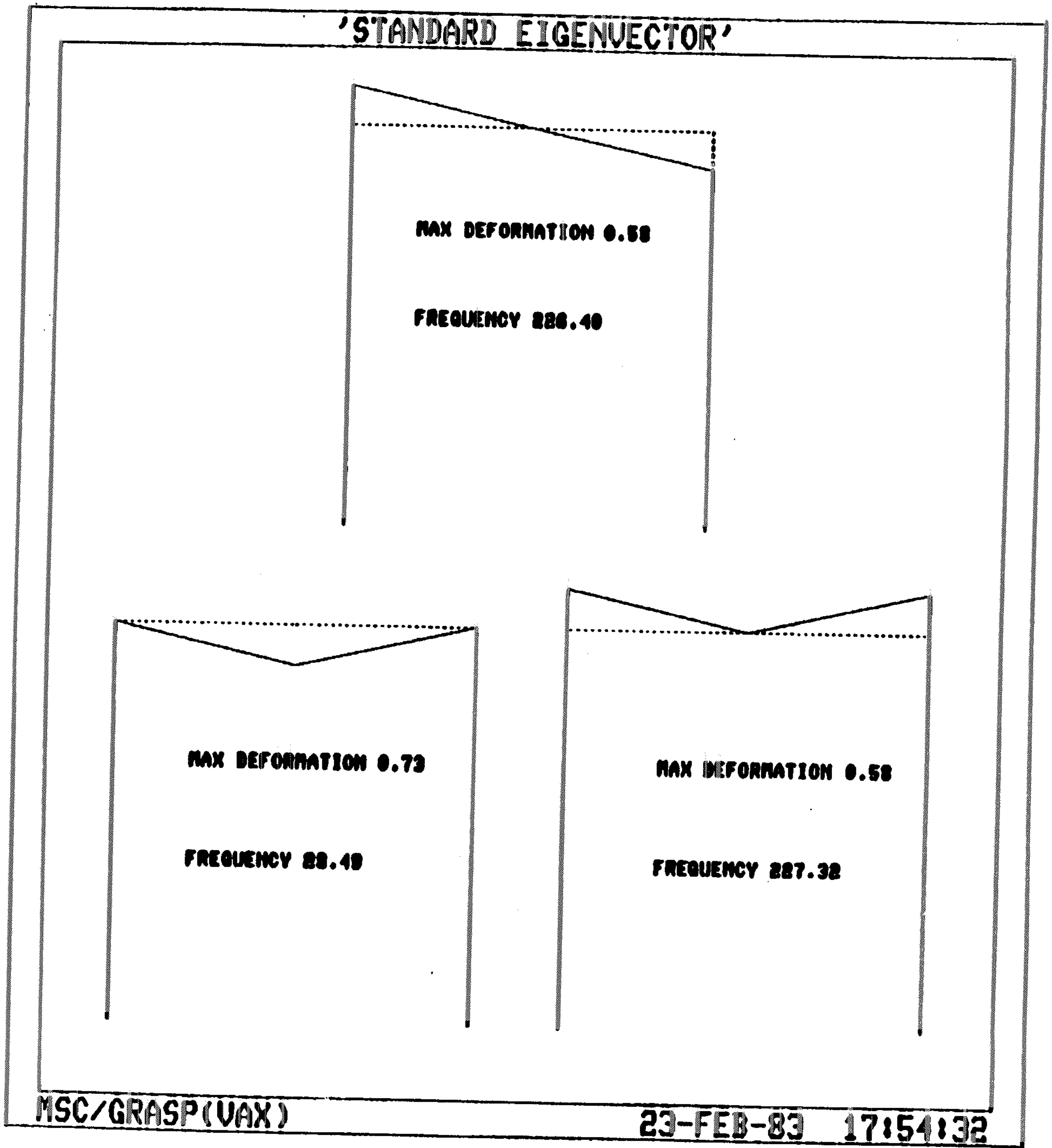
  Number of Roots - 10

- Generalized Dynamic Reduction

  FMAX = 200.0 hertz

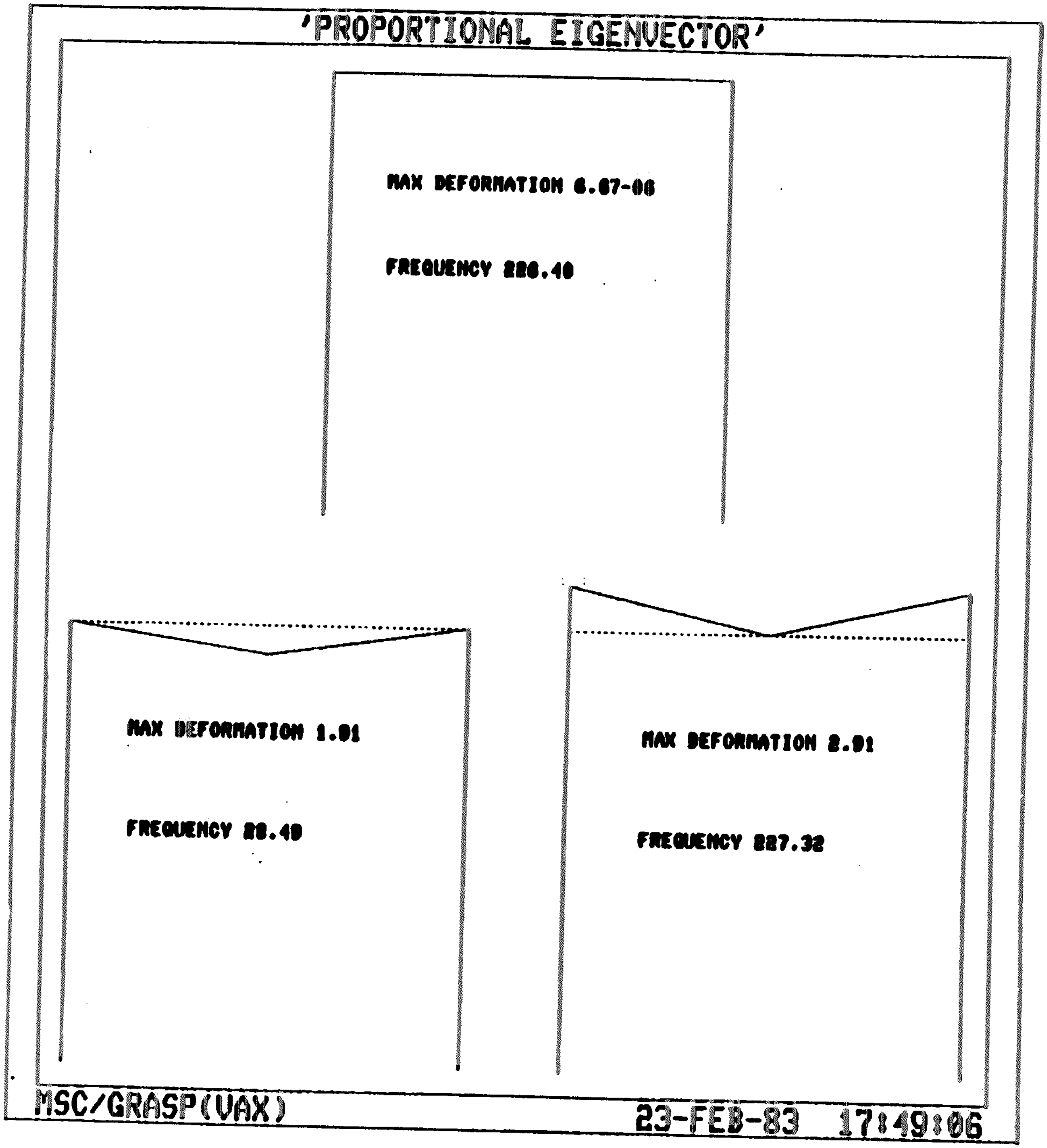
  ASET and QSET = 99000 thru 99050

FIGURE 5



'STANDARD EIGENVECTOR'
MAX DEFORMATION 0.58
FREQUENCY 288.40
MAX DEFORMATION 0.73
FREQUENCY 28.40
MAX DEFORMATION 0.58
FREQUENCY 287.32
MSC/GRASP(VAX)
23-FEB-83 17:54:32

FIGURE 6


'PROPORTIONAL EIGENVECTOR'
MAX DEFORMATION 6.87-06
FREQUENCY 226.40
MAX DEFORMATION 1.01
FREQUENCY 28.40
MAX DEFORMATION 2.01
FREQUENCY 227.32
MSC/GRASP(VAX)
23-FEB-83 17:49:06

REFERENCES

1) MSC/NASTRAN USER'S MANUAL

2) MSC/NASTRAN APPLICATIONS MANUAL

3) MSC/NASTRAN PROGRAMMER'S MANUAL

4) MSC/NASTRAN THEORETICAL MANUAL

5) CLOUGH, R. and PENZIEN, J., "DYNAMICS OF STRUCTURES", McGRAW-HILL, INC., NEW YORK, 1975