

DMAP Alters For Nonlinear Craig-Bampton Component Modal Synthesis

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ABSTRACT

A set of DMAP (Direct Matrix Abstraction Program) alters for MSC/NASTRAN have been developed for generating reduced matrices for nonlinear structures using the Craig-Bampton [1] method. These DMAP alters are currently being used in conjunction with the standard MSC/NASTRAN component modal synthesis approach to create a system model for coupled loads analysis of Space Station Freedom (SSF) on-orbit configurations. Nonlinear Craig-Bampton models of the Photo Voltaic (PV) arrays are created and combined with the linear Craig-Bampton models of the various other SSF components using the external superelement approach. In addition, a modal selection DMAP Alter is provided. This alter is used in combination with an external FORTRAN program to select a reduced set of component modes based on the modal strain energy criteria. The procedure is illustrated with an example problem.

INTRODUCTION

Dynamic analysis of large space structures such as the Space Station Freedom (SSF) usually involve assembling system dynamic models from components supplied by many different contractors. The contractors usually provide component models, either as conventional finite element models or as reduced Craig-Bampton models. The finite element models are then reduced to Craig-Bampton component mode models. The MSC/NASTRAN superelement technique is then used to combine all the various Craig-Bampton component mode models into a system model assembly.

The Space Station is powered utilizing Photo Voltaic (PV) arrays, consisting of a deployable truss mast and blanket substrates (Figure 1). The stiffness of the split-blanket array is a function of the rigidity of the mast as well as the tension in the blankets. The solar arrays are deployed in orbit, and the blanket is stretched into position as the mast is extended.

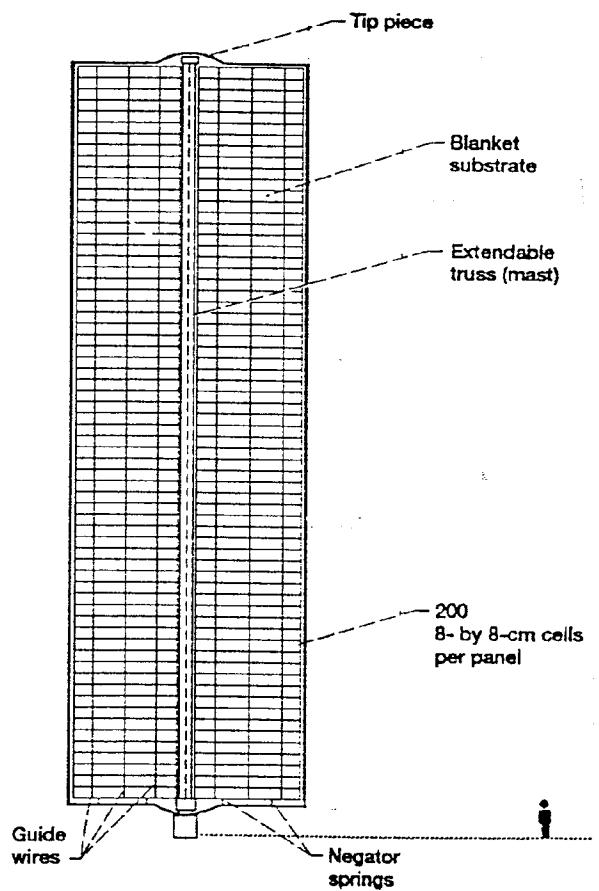


Figure 1 : Space Station Freedom Split Blanket Photo Voltaic Solar Array

The Space Station will be subjected to various dynamic loads during Space Shuttle docking, solar tracking, attitude adjustments, astronaut extra vehicular activities, etc. Accurate prediction of the natural frequencies and mode shapes of the space station components, including the solar arrays, is critical for determining the structural loads of the components.

The Craig-Bampton component mode reduction, which is the default method used in MSC/NASTRAN, consists of reducing a finite element model into a set of generalized mass and stiffness matrices which can then be connected to physical boundary points. The generalized coordinates used in the creation of the boundary mass and stiffness matrices consists of both the constraint modes and fixed interface elastic modes [1].

The Craig-Bampton component mode models of various space station components are assembled into a system model using external superelement techniques. External superelements are substructure models which may be generated using either MSC/NASTRAN or other finite element analysis packages. Data recovery is performed using a combination of Load Transformation Matrices (LTM), and Displacement Transformation Matrices (DTM). The development of an external superelement from an internal superelement with the benefit of the complete finite element model is presented in Reference [2].

Coupled loads analysis involving external superelements presents a true challenge due to the absence of the complete finite element model geometry. Procedures have been developed based on the MSC/NASTRAN external superelement technique for system solution, system mode shape plotting and coupled loads analysis [3,4]. These techniques have been successfully implemented and shown to provide an efficient technique for the coupled loads analysis of various space station configurations [5].

Craig-Bampton component mode reduction for nonlinear structures is more involved than linear Craig-Bampton component mode reduction. Structural nonlinearities could be either due to material or geometric nonlinearity. An example of such a nonlinearity is the space station PV arrays, where the arrays are preloaded in tension resulting in geometric stiffening effects. Geometric stiffness due to preload make this an interesting nonlinear problem. One of the problems associated with nonlinear structures is the so called "Grounding Effect" [6]. Due to the limitations inherent in the geometric stiffness matrix in most finite element codes, including MSC/NASTRAN, pseudo-forces are developed when a rigid body rotation is applied to the structure. These pseudo-forces are generated at the element level, making it difficult to correct. If not corrected, the geometric stiffness matrix would lack the capability for rigid body rotations, especially when the rotations are large. This results in the calculation of incorrect rigid body modes.

A set of DMAP alters for MSC/NASTRAN have been developed for generating reduced matrices for nonlinear structures using the Craig-Bampton method. A correction for the "Grounding Effect" has also been incorporated in these DMAPS. In the nonlinear Craig-Bampton approach, correct rigid body modes are appended to the Craig-Bampton matrices, thus enabling full rigid body capability. These DMAP alters are used in conjunction with the standard MSC/NASTRAN component modal synthesis approach to create a system model for coupled loads analysis of various space station on-orbit configurations. Nonlinear Craig-Bampton models of the PV arrays are created and combined with the linear Craig-Bampton models of the various other space station components using the external superelement approach [5].

Figure 2 shows the SSF Permanently Manned On-Orbit Configuration which includes six PV Solar Arrays. The Craig-Bampton models of each PV array include approximately 850 fixed interface modes which were calculated below 7.5 Hz. The coupled system solution for this configuration would therefore include approximately 5100 component modes (6×850). In order to be cost-effective and be able to perform the coupled loads analysis cycle in a timely manner, some form of reduction has to be performed on the PV array Craig-Bampton component mode model. Experience has shown that a modal selection based on a strain energy criteria is the most effective means of reducing the number of component modes while maintaining sufficient accuracy in the coupled system response.

For the SSF Solar Arrays, a modal selection DMAP alter was also developed and integrated into the nonlinear Craig-Bampton DMAP alters. As part of the modal selection technique, a FORTRAN program is also included which is used in conjunction with the DMAP alters to create a Craig-Bampton component mode model using a reduced set of modes which are selected based on a strain energy criteria. A simple example problem is included to illustrate the operations involved in the creation of the Craig-Bampton component mode model for a nonlinear structure. The effectiveness of the modal selection technique as applied to the SSF PV Solar Array is also demonstrated.

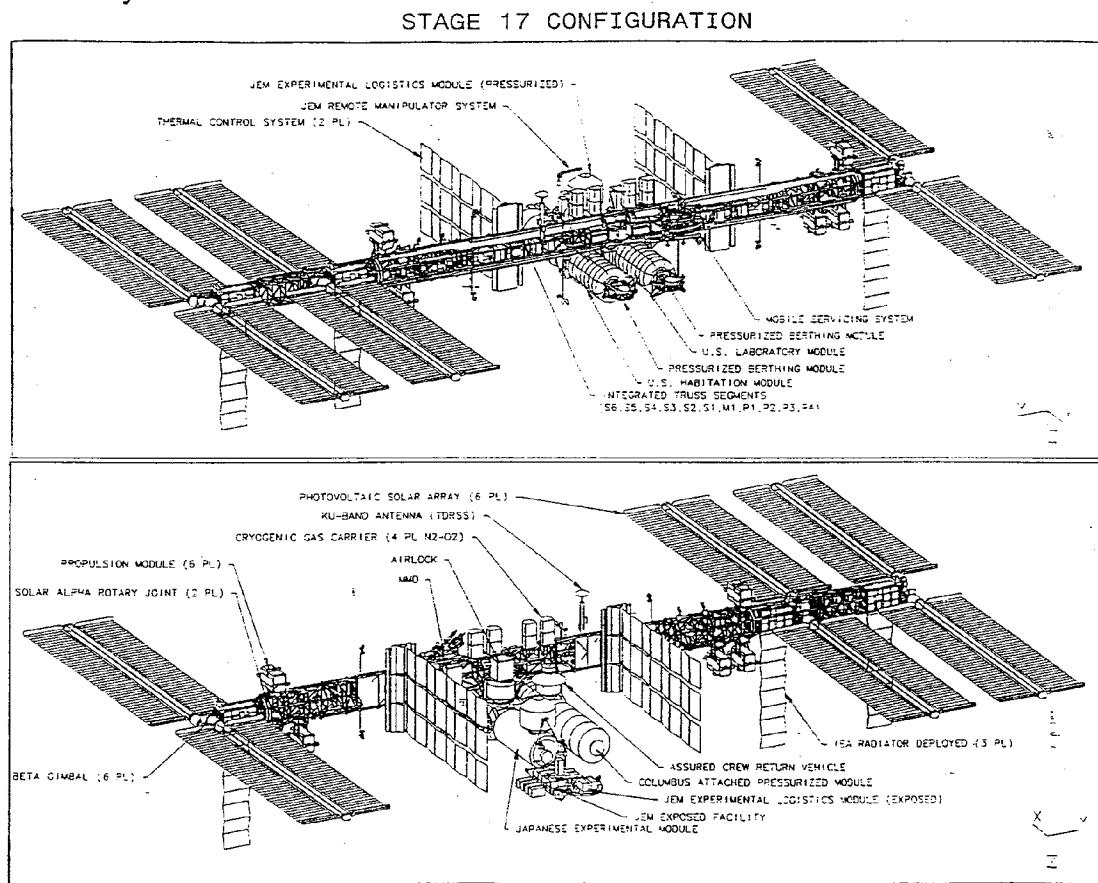


Figure 2 : Space Station Freedom Stage 17 Permanently Manned On-Orbit Configuration

Creation of Nonlinear Craig-Bampton Component Mode Model

Creating a Craig-Bampton component mode model for a nonlinear structures includes 3 steps. The reason for the three steps is that because of the requirement to perform a modal selection for the space station solar arrays, it was easier to perform the modal selection process using an external FORTRAN program. The reason to use an external FORTRAN program as opposed to using DMAP language was that the strain energy datablocks which are created by GPFDR module were found to be in a table format and could not be easily operated on. If modal selection is not a requirement, the two DMAP alters could be easily combined into a single DMAP alter.

In the first step, using DMAP alter " ALTERNL1 " (Appendix A) in conjunction with solution 106, the finite element model of each nonlinear component is first reduced to a Craig-Bampton model and then all the necessary data blocks are saved in the database. A punched file containing the strain energies for all the elements as defined in a ESE=SET ID is also created. The following additional input cards are required in step 1 :

Step 1 :

- Add USET1/USET entries in bulk data to define the interface d.o.f's (USERSET U1)
- Add PARAM,NMLOOP,LOOPID
where LOOPID = loopid of nonlinear solution to use as input to CMS
- In the Case Control, define the data recovery items and add a METHOD request card.
- In the Case Control, define a ESE=SET ID for modal selection.
- Define a User set U2 and specify the set of d.o.f's which will be used to apply external loads or will be used for plotting.
- Define a number of scalar points for eigenvalue analysis. The total number of scalar points should be greater than or equal to the number of calculated modes.

Add PARAM,NSPOINT,NS
where NS = Total number of SCALAR points

- In addition, define the following PARAM cards:

MAKEMAT = ID of the superelement (SEID).

MATFILE = OUTPUT4 file ID (Default : write to DMIG punch file only).

SEPARATE= Integer

= (Default=-1) separate the mass and stiffness matrices

= Otherwise : Combine matrices KEXT = KAA + KLAA

MEXT = MAA + MLA

In step 2, the strain energies which were created in step 1 are then used as part of input to the FORTRAN program "ENERGY" (Appendix B) which performs the modal selection based on a modal strain energy criteria. The strain energies in the user defined ESE=SET ID are summed for each mode and then compared with the total strain energy in each mode. The modes are selected if they exceed a certain user defined percentage. The output from the program is in the form of a summary table identifying the selected modes and a punched DMI file for the subsequent step 3 processing.

In step 3, using the database from step 1 and the DMAP alter " ALTERNL2 " (Appendix C), a restart is performed using solution 106. The nonlinear Craig-Bampton component mode model is then created and all the necessary datablocks such as the mass and stiffness matrices and output transformation matrices are then created. These datablocks are then partitioned based on the selected modes as defined on the DMI cards. The partitioned datablocks are then written in a file in the form of either DMIG cards or OUTPUT4 format. The following additional input cards are required in step 3:

- Step 3 :

 - Add DMI entries in bulk data.
 - Add PARAM,PERCNT,VAL
where VAL = Percent of strain energy in the ESE = SET ID, to be used for modal selection.
 - In addition define the following :
 - MAKEMAT = ID of the superelement (SEID).
 - MATFILE = OUTPUT4 file ID (Default : write to DMIG punch file only).
 - SEPARATE= Integer
 - = (Default=-1) separate the mass and stiffness matrices
 - = Otherwise : Combine matrices KEXT = KAA + KLAA
MEXT = MAA + MLAA

Example Problem

The nonlinear Craig-Bampton procedure is illustrated by using an example problem of a simple cantilevered beam model. As shown in figure 3, the model consists of 4 beam elements and 5 nodes.

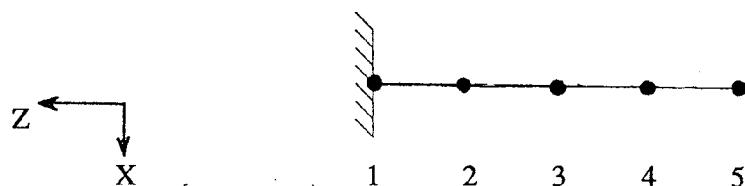


Figure 3 : Simple Cantilevered Beam Model Test Case

Appendix D shows the input deck for step 1. In this example problem, solution 106 is used in conjunction with the DMAP alter "ALTERNL1" of appendix A. Node 1 is constrained in all six directions and a point load is applied to grid 5 in the axial direction to simulate a pre-load. Elements 1 and 2 are used in the strain energy modal selection process. A total of 4 iterations are requested on the NLPARM card and also defined on PARAM,NMLOOP. A tension load of magnitude 10,000 Lbs. is applied to grid 5. As a result of this, grid 5 is also defined on USET,U2 entry. The boundary point (Grid 1) is also defined on USET,U1 entry. Although only 5 eigenvalues are requested, a total of 10 scalar points are defined. The number of scalar points are also defined using PARAM,NSPOINT,10.

Step 2 involves the execution of the FORTRAN program ENERGY (Appendix B) which reads a file containing the strain energies for all the modes and for elements in SET = 101. For this example problem, only elements 1 and 2 were defined in SET 101. The variable PERCNT should be defined in the program prior to execution of the program. This variable is only used to identify the selected modes for the summary table only. The punched DMI cards contain two columns of data. The first column contains the strain energy in SET 101 and the second column contains the total strain energy for each mode. The actual modal selection of partitioning is actually performed in step 3 using DMAP alter "ALTERNL2" (Appendix C).

Appendix E shows the input deck for step 3. As shown, the case control for step 3 is very similar to step 1. Step 3 is a restart using the database from step 1. The DMI cards which were created in step 2 are used as part of the input to this run. PARAM,PERCNT,60.0 defines the percent strain energy to be used for modal selection. This means that if the strain energies in elements defined by SET=101 are higher than 60% of the total strain energy in that mode, that mode is then selected to be included in the Craig-Bampton component mode model. As shown in appendix F , for this example modes 4 and 5 were excluded because the total strain energy was found to be less than 60% of total.

Appendix G shows the DMIG cards which were created from step 3. It contains all the necessary datablocks for integration with other Craig-Bampton component mode models for the system solution and coupled loads analysis using external superelement techniques [2,3,5]. The nonlinear Craig-Bampton component mode generalized mass and stiffness matrices are MEXT and KEXT respectively. Datablocks PHIXQ, PHIXT, DIS, SPCF and FORC are used for data recovery using external superelements. As shown, these datablocks are all in the reduced form depicting only the selected modes. In order to bypass the modal selection process and use all the modes in the Craig-Bampton model, the user simply runs step 1 and step 3 without the DMI cards and defines a PARAM,PERCNT,0.0.

To illustrate the " Grounding Effect" [6], the beam example problem was first analyzed in a free-free mode using standard nonlinear solution 106 without the corrections and was then analyzed using the nonlinear Craig-Bampton component mode procedure which has been incorporated with a correction for rigid body modes.

As shown in table 1, for the standard nonlinear solution without the correction the free-free beam problem lacks the capability for full rigid body motion and only four rigid body modes are calculated. The same free-free beam problem when analyzed using the Craig-Bampton component mode procedure with the correction shows full rigid body translation as well as rotation capability.

R E A L E I G E N V A L U E S (WITH GROUNDING)

MODE NO.	EXTRACTION ORDER	EIGENVALUES	CYCLES
1	1	-3.445894E-08	2.954412E-05
2	2	-3.160676E-08	2.829503E-05
3	3	2.671732E-08	2.601456E-05
4	4	5.276641E-05	1.156109E-03
5	5	8.284701E+03	1.448634E+01
6	6	8.284701E+03	1.448634E+01

R E A L E I G E N V A L U E S (WITHOUT GROUNDING)

MODE NO.	EXTRACTION ORDER	EIGENVALUE	CYCLES
1	1	3.492460E-10	2.974307E-06
2	2	9.604264E-10	4.932331E-06
3	3	1.862645E-09	6.868868E-06
4	4	4.889444E-09	1.112884E-05
5	5	1.180160E-08	1.728983E-05
6	6	1.789941E-05	6.733478E-04

TABLE 1 : Effect Of Grounding On The Rigid Body Modes.

Space Station Freedom Photo Voltaic Array Component Mode Model

To demonstrate the application of the nonlinear Craig-Bampton component mode reduction procedure to a more realistic structure such as the SSF PV array, the current Solar Array model was selected for component mode reduction. The six degrees of freedom at the base of the mast were taken as interface degrees of freedom. In step 1, a total of 844 fixed interface vibration modes were calculated below 7.5 Hz. Each mode in which the combined total strain energy in selected areas of the PV array was found to be at least 1% of the total strain energy for the mode was selected to be included in the component mode model. Based on this, only 72 modes were selected out of the total of 844 modes.

To validate the modal selection criteria, a stand-alone model of the PV array was analyzed for a typical dynamic loading such as Space Shuttle orbiter plume impingement loads. The array transient responses were calculated both with and without the modal selection. Figure 4 shows a typical plot comparing the array mast base bending moment response for both the reduced component mode model (72 modes) versus the full component mode model (844 modes). The results are almost identical, with the maximum variation between the two responses calculated to be only 0.3 %.

For the SSF Permanently Manned Capability On-Orbit Configuration (figure 2) which includes six PV Solar Arrays, the total number of component modes in the system model would therefore only be 432 (6x72), as opposed to 5064 (6x844) if a modal selection was not performed. This has proven to be a cost-effective and efficient approach for the coupled loads analysis of various space station configurations.

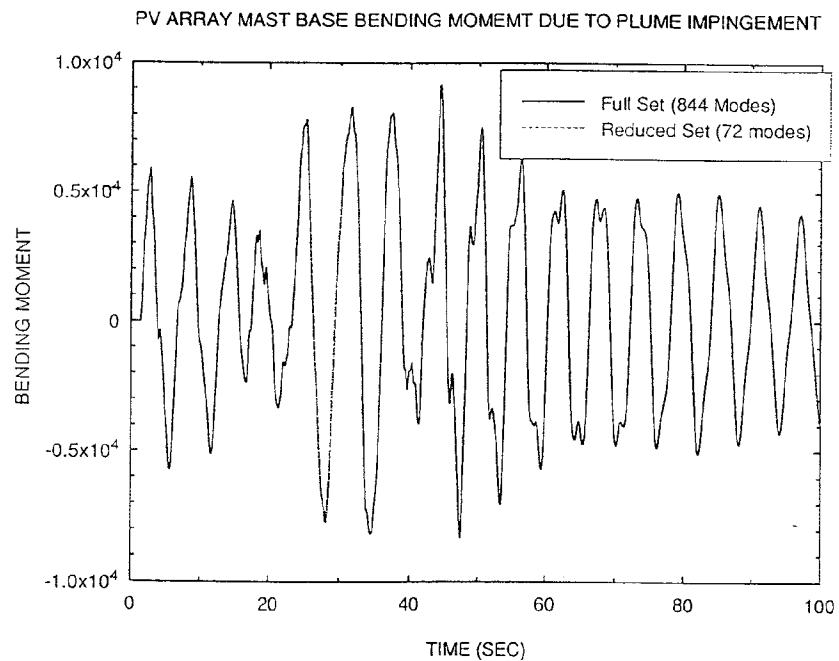


Figure 4 :Comparison Between Full FEM and Reduced Component Mode Model

SUMMARY

This paper demonstrates how to create a Craig-Bampton component mode model for nonlinear structures. A set of MSC/NASTRAN version 67 DMAP alters and a FORTRAN program are provided. An example problem was also included to illustrate the procedure. A modal selection process based on strain energy criteria is also included within the DMAP alters. A simple fix to the so-called "Grounding Effect" problem has also been included in the nonlinear Craig-Bampton component mode DMAP alters.

REFERENCES

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5. Bedrossian, H., "MSC/NASTRAN External Superelement Coupled Loads Analysis ", June 18, 1992, Rocketdyne Internal Document.
6. Bosela, P.A., Fertis, D.G., and Shaker, F.J., " Grounding of Space Structures", Computers and Structures, Vol 45, No 1, 1992.

ACKNOWLEDGEMENT

The material presented here is based on work performed for the Space Station Freedom program at the Rocketdyne Division of Rockwell International under NASA contract NAS3-25082.

APPENDIX A

DMAP ALTER "ALTERNL1" FOR NONLINEAR CRAIG-BAMPTON (STEP-1)

```
$-----  
$ DMAP ALTER FOR SOL 106 TO PERFORM CRAIG-BAMPTON CMS  
$ ON THE FINAL MATRICES -  
$ CREATE A 'CRAIG-BAMPTON' MODEL OF A NONLINEAR MODEL -  
$-----
```

| P H A S E 1 |

N O T E

```
$-----  
$ PLACE 'BOUNDARY' POINTS IN THE U1-SET WHICH MUST BE A  
$ SUBSET OF THE S SET AND THE DMAP WILL DO THE REST  
$-----
```

- 1) SET UP DECK TO PERFORM NONLINEAR ANALYSIS AS USUAL
- 2) ADD PARAM,NMLOOP,## TO BULK DATA
- 3) ADD METHOD IN CASE CONTROL BEFORE SUBCASES
- 4) ADD USET OR USET1 ENTRIES IN BULK DATA TO DEFINE
THE INTERFACE DOF - SINCE STABILITY IS NECESSARY
FOR A NONLINEAR SOLUTION, THE USET (I/F DOF) MUST
BE A SUBSET OF THE S-SET (SPCS)
- 5) SELECT U2 SET AND SPECIFY IN BULK DATA -
SET OF DOF WHICH WILL BE USED IN PLOTING THE
'INTERIOR' AND FOR LOAD APPLICATION
- 6) DEFINE ADEQUATE NO OF SCALAR POINTS TO COVER THE NUMBER
OF CALCULATED MODES. USE OF PARAM,AUTOSPC WILL CONSTRAIN
LEFT OVER SCALAR POINTS.

=====NOTE=====

```
$-----  
$ THE DMAP CREATES DMIG ENTRIES FOR PHIXQ AND PHIXT WHICH MAY BE  
$ INTERPRETED IMPROPERLY. THE PROGRAM WRITES THE DMIG AS TYPE '9'  
$ BUT DOES NOT FILL IN 'NCOL' ON THE HEADER ENTRY. IN ORDER TO  
$ PROPERLY USE THESE MATRICES 'NCOL' SHOULD BE ADDED BY THE USER  
$-----
```

```
$-----  
$ DMAP PROGRAM WRITTEN BY :
```

```
$-----  
$ HERAND BEDROSSIAN  
$ ROCKETDYNE DIVISION
```

AND

```
$-----  
$ TED ROSE  
$ MACNEAL SCHWENDLER CORP.
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$      ROCKWELL INTERNATIONAL
$-----  

$-----  

$      COMPILE SEMG, SOUIN=MSCSOU, NOREF,LIST $  

$      ALTER 23  

$      IF (NMLOOP <=0 ) THEN          $  

$        EMA      GPECT,KDICT,KELM,BGPDTS,SILS,CSTMS/KJJL,    $  

$        CALL DBSTORE KJJL,///0/0/'DBALL'/0 $  

$      ENDIF                          $  

$      EQUIVX   KELM/KELMHB/ALWAYS $  

$      TABEDIT  KDICT,///KDICTHB/      $  

$      CALL DBSTORE KELMHB,KDICTHB,///0/0/'DBALL'/0 $  

$      ALTER 51  

$      ADD5     KELMNL,KDELMNL,///KELMH $  

$      CALL DBSTORE KJJZ,KELMH,///0/0/'DBALL'/0 $  

$      CALL DBSTORE KELMNL,KDICTNL,KDELMNL,KDDICTNL,///0/0/'DBALL'/0 $  

$      COMPILE NLSTATIC, SOUIN=MSCSOU, NOREF,LIST $  

$      ALTER 287  

$      CALL DBSTORE PSNL,///0/0/'DBALL'/0 $  

$      COMPILE SEKR, SOUIN=MSCSOU, NOREF,LIST $  

$      ALTER 15  

$      TYPE PARM,,I,N,FINE           $  

$      CALL DBFETCH /KJJL,///0/0/0/0/S,FINE $  

$      EQUIVX   KJJL/KGGL/NOUP       $  

$      ALTER 42  

$      EQUIVX   KGGL/KNNL/NOMSET   $  

$      CALL DBSTORE KNNL,///0/0/'DBALL'/0 $  

$      ALTER 46  

$      MCE2     USETB,GM,KGGL,///KNNL,,, $  

$      CALL DBSTORE KNNL,///0/0/'DBALL'/0 $  

$      ALTER 64  

$      CALL DBSTORE KNN,///SEID/PEID/'DBALL'/0 $  

$      COMPILE SEMR2, SOUIN=MSCSOU, NOREF,LIST $  

$      ALTER 8  

$      CALL DBSTORE MNN,///0/0/'DBALL'/0 $  

$      COMPILE MODERS, SOUIN=MSCSOU, NOREF , LIST $  

$      ALTER 2  

$      TYPE DB ZUZR01,ZUZR02,ZUZR03,ZUZR04,ZUZR05 $  

$      TYPE PARM,,I,Y,(NSPOINT=0) $  

$      TYPE PARM,,I,Y,(MATFILE=12) $  

$      ALTER 5  

$      TYPE PARM,,I,N,NOASET,NOBSET,NOCSET,NOGSET,NOLSET,NOOSET $  

$      TYPE PARM,,I,N,NOQSET,NORSET,NOSSET,NOTSET,NOVSET,NOA,NOSET $  

$      TYPE PARM,,I,N,NORC,NOMSET,NOU1SET,SUCCESS           $  

$      CALL PMLUSET   USET//S,NOASET/S,NOBSET/S,NOCSET/S,NOGSET/S,NOLSET/  

$                    S,NOOSET/S,NOQSET/S,NORSET/S,NOSSET/S,NOTSET/  

$                    S,NOVSET/S,NOA/S,NOSET/S,NORC/S,NOMSET/O $  

$      PARAML USET//USET///S,N,NOUSET//U1//S,N,NOU1SET $  

$      CALL DBFETCH /MNN,KNN,///0/0/0/0/S,SUCCESS $  

$      CALL DBFETCH /KNNL,///0/0/0/0/S,SUCCESS $  

$-----  

$      PARTITION N-SET MATRICES INTO F AND S SUBSETS  

$      UPARTN   USET,MNN/MSS,MSF,MFS,MFFL/'N'/'S'/'F'      $  

$      UPARTN   USET,KNN/KSS,KSF,KFS,KFFL/'N'/'S'/'F'      $  

$      UPARTN   USET,KNNL/KSSH,KSFH,KFSH,KFFLH/'N'/'S'/'F' $  

$      VEC     USET/UPART9/'S'/'U1'/'COMP'/$  

$      PARTN    KSS,UPART9,/KU1,,,/$  

$      PARTN    KFS,,UPART9/KFU1,,,/1 $  

$      PARTN    KSF,UPART9,/KU1F,,,/1 $  

$      PARTN    KSFH,UPART9,/KU1FH,,,/1 $

```

```

PARTN  MSS, UPART9,,/MU1,,,/   $
PARTN  MFS,, UPART9/MFU1,,,/1   $
PARTN  MSF, UPART9,,/MU1F,,,/1   $
DCMP   USET,SILS,EQEXINS,KFFL/LFF,UFF/-1/0/BAILOUT/
       MAXRATIO/'O'/1.E-20////////S,N,SING/
       S,N,NBRCHG/S,N,ERR $
       IF (ERR<0) MESSAGE //*** WARNING *** EXCESSIVE'/
         ' PIVOT RATIOS FOUND DURING PREPARATION FOR'/
         ' CMS - THIS MAY RESULT IN INCORRECT RESULTS' $
FBS    LFF,UFF,KU1F/GOATNL/-1/-1/0/0 $
DCMP   USET,SILS,EQEXINS,KFFLH/LFFFH,UFFH/-1/0/BAILOUT/
       MAXRATIO/'O'/1.E-20////////S,N,SING/
       S,N,NBRCHG/S,N,ERR $
       IF (ERR<0) MESSAGE //*** WARNING *** EXCESSIVE'/
         ' PIVOT RATIOS FOUND DURING PREPARATION FOR'/
         ' CMS - THIS MAY RESULT IN INCORRECT RESULTS' $
FBS    LFFH,UFFH,KU1FH/GOATLL/-1/-1/0/0 $
$      $
$      $ PERFORM EIGENSOLUTION ON LEFT OVER-SET FOR CONSTRAINED MODES
$      $
ALTER 80,80 $ 78,78
MESSAGE //''SOLVING FOR RESIDUAL STRUCTURE MODES WITH U1-SET'/
  ' DOF HELD FIXED' $
MESSAGE //'' NOTE DMAP NOT SET UP TO HANDLE MASS MATRIX WITH ZEROS'/
  ' ON THE DIAGONALS - USE LANCZOS IF INFINITE ROOTS EXIST' $
READ KFFL,MFFL,,,EED,,CASES/LAMA,PHIX,MI,OEIGS/
  READAPP/S,N,NEIGV/NSKIP $
ALTER 82,82 $ 80,80
MESSAGE //''SOLVING FOR RESIDUAL STRUCTURE MODES WITH A-SET'/
  ' DOF HELD FIXED' $
REIGL KFFL,MFFL,DYNAMICS,CASES,,,./LAMA,PHIX,MI,EIGVMAT,/
  READAPP/S,N,NEIGV/NSKIP $
ALTER 84 $82
$      $
$      $ CREATE CRAIG-BAMPTON CMS MODEL
TYPE PARM,,I,N,TOTCOL,NOLEFT,TOTCOT,NSPC      $
TOTCOL = NOU1SET+NEIGV $
NOLEFT = NEIGV $
MATGEN /MERGU1/6/NOU1SET/NOU1SET      $
MATGEN /MERGCB/6/TOTCOL/NOU1SET/NOLEFT $
MATGEN /MERGCT/6/TOTCOL/NEIGV/NOU1SET $
MATGEN /IDENT/1/NOU1SET/ $
UMERGE USET,IDENT,/IDENTS/'S'/'U1'/'SB' $
UMERGE USET,IDENTS,GOATNL/GNNNL/'N'/'S'/'F' $
UMERGE USET,IDENTS,GOATLL/GNN/'N'/'S'/'F' $
$      NORMALIZE PHIX
MATMOD PHIX,,,,,/BMAX,,/7 $
MATMOD BMAX,,,,,/BMAXD,,/28 $
MATGEN /ID5/1/NEIGV/ $
ADD ID5,BMAXD/BMAXINV/1.0/1.0/2 $
MPYAD PHIX,BMAXINV,,/PHIXNEW
FILE PHIX=OVRWRT $
EQUIVX PHIXNEW/PHIX/ALWAYS $
$      $
UMERGE USET,PHIX,/PHIN/'N'/'F'/'S' $
MERGE GNN,,PHIN,,MERGCB,/PHIGEN/1 $
MERGE GNNNL,,PHIN,,MERGCB,/PHIGNL/1 $
MPYAD PHIGEN,KNNL,/PTK/1 $
MPYAD PTK,PHIGEN,/KGEN $ GENERALIZED STIFFNESS ( SIZE U1+NEIGV )
MPYAD PHIGNL,MNN,,/PTM/1 $

```

```

MPYAD PTM,PHIGNL,/MGEN $ GENERALIZED MASS ( SIZE U1+NEIGV )
PARTN KGEN,MERGCB,/KGEN1,,,KGEN2/-1 $
MPYAD PHIX,KFFL,/GG1/1 $
MPYAD GG1,PHIX,/KGEN9 $
FILE KGEN=OVRWRT $
MERGE KGEN1,,,KGEN9,MERGCB,/KGEN/-1 $
CALL DBFETCH /INTEXT1,,,/,0/0/0/0/S,SUCCESS $
VEC USET/VECXXX/'G'/'COMP'/'U1'/$
VEC USET/VECXXT/'G'/'U1'/'COMP'/$
MPYAD INTEXT1,VECXXX,/VECYYY/1 $
MPYAD INTEXT1,VECXXT,/VECYYT/1 $
TOTCOL = NOGSET $
TOTCOT = NOGSET - NSPOINT $
NOLEFT = TOTCOL-TOTCOT-NEIGV $
MATGEN /VECZZY/6/TOTCOL/TOTCOT/NEIGV/NOLEFT $
MPYAD INTEXT1,VECZZY,/VECZI/$ G SIZE EIGV SET, INTERNAL ORDER VECTOR
ADD VECZZY,VECYYY/VECZZ/ $ G SIZE EIGV+U1 SET, EXTERNAL ORDER VECTOR
ADD VECZI,VECXXX/VECCPP/$ G SIZE EIGV+U1 SET, INTERNAL ORDER VECTOR
VEC USET/VECZZJ/'G'/'N'/'COMP'/$
PARTN VECZI,,VECZZJ/VECZZK,,,/1 $
PARTN VECYYT,,VECZZY/VECTT1,,,/1 $
MERGE VECTT1,,,VECZZY/VECTTT/1 $
VEC USET/HBINT/'G'/'S'/'COMP'/$
MPYAD INTEXT1,HBINT,/HBEXT/1 $
ADD VECZZZ,HBEXT/VEC899/$
MPYAD INTEXT1,VEC899,/VEC999/$
MERGE ,,,MGEN,VECZZZ,/MEXT/-1 $
MERGE ,,,KGEN,VECZZZ,/KEXT/-1 $
MODTRL KEXT///6 $
MODTRL MEXT///6 $
$ CALL DBSTORE PHIGEN,VEC999,MERGCB,VECCPP,VECZI//0/0/'DBALL'/0 $
CALL DBSTORE MERGCT,MERGU1,PHIN,KEXT,MEXT//0/0/'DBALL'/0 $
CALL DBSTORE VECTTT,EQEXINS,VECZZY,KGEN,MGEN//0/0/'DBALL'/0 $
$ CREATE G-SIZE TRANSFORMATION MATRICES WITH TERMS FOR U2 SET ONLY
$ THESE MATRICES WILL BE USED FOR PLOTTING AND LOAD APPLICATION
$ TOTCOL = NOU1SET+NEIGV $
TOTCOT = NOU1SET $
NOLEFT = TOTCOL - TOTCOT $
MATGEN /VEC888/6/TOTCOL/TOTCOT/NOLEFT $
PARTN PHIGEN,VEC888,/PHIXT1,,PHIXQ1,,/1 $
MERGE PHIXT1,,,VEC888,/PHIXT2/+1 $
MERGE ,,,PHIXQ1,,VEC888,/PHIXQ2/+1 $
VEC USET/VU2/'N'/'COMP'/'U2'/$
PARTN PHIXQ2,,VU2,,GOGQNL,,,/+1 $
PARTN PHIXT2,,VU2,,GOGTNL,,,/+1 $
MERGE ,,,GOGTNL,,,VU2/PHIXT3/+1 $
MERGE ,,,GOGQNL,,,VU2/PHIXQ3/+1 $
IF (NOMSET>0) THEN $
UMERGE USET,PHIXT3,/PHIXT4/'G'/'N'/'M' $
UMERGE USET,PHIXQ3,/PHIXQ4/'G'/'N'/'M' $
ELSE $
EQUIVX PHIXQ3/PHIXQ4/ALWAYS $
EQUIVX PHIXT3/PHIXT4/ALWAYS $
ENDIF $
MPYAD INTEXT1,PHIXQ4,/PHIXQ/1 $
MPYAD INTEXT1,PHIXT4,/PHIXT/1 $
CALL DBSTORE PHIXQ,PHIXT,,,/,0/0/'DBALL'/0 $

```

```

COMPILE PHASE1 SOUIN=MSCSOU,NOREF,LIST  $
ALTER 2
TYPE PARM,,I,Y,(MATFILE=12) $
TYPE PARM,,I,Y,(SEPARATE=-1) $
TYPE PARM,,I,N,NDIF,NBOND   $
ALTER 96 $ 101 IN V66A
TYPE DB ZUZR01,ZUZR02,ZUZR03,ZUZR04,ZUZR05 $
TYPE PARM NDDL I N ZUZR1 $
$
MESSAGE //'*'*****$ MESSAGE //'*'CREATING CRAIG-BAMPTON MATRICES FOR SUPERELEMENT'/SEID $ MESSAGE //'*'*****$ $
ZUZR1=SEID $
MATGEN EQEXINS/INTEXT1/9/0/LUSETS $
CALL DBSTORE INTEXT1,,,,,/SEID/PEID/'DBALL'/0 $
COMPILE SEDISP SOUIN=MSCSOU, LIST, NOREF $
$
$ CREATE OTM
$ ALTER 2
TYPE DB,ZUZR06,ZUZR07 $
TYPE PARM,,I,N,EXIT8,EXIT9  $
TYPE PARM,NDDL,I,N,ZUZR1      $
TYPE PARM,,I,N,NOASET,NOBSET,NOCSET,NOGSET,NOLSET,NOOSET $
TYPE PARM,,I,N,NOQSET,NORSET,NOSSET,NOTSET,NOVSET,NOA,NOSET $
TYPE PARM,,I,N,NORC,NOMSET,NOU1SET,NOU3SET,SUCCESS  $
TYPE PARM,,I,Y,(MATFILE=12) $
ALTER 137 $
$
$ ALTER TO CREATE LTM, ATM, AND/OR DTM
$ MESSAGE //'*'CREATING OTM REQUESTED IN CASE CONTROL FOR SE '/SEID $
$ CALCULATE AND STORE OUTPUT QUANTITIES FOR S.E. FOR UNIT BOUNDARY DISP
$ CALL PMLUSET USET//S,NOASET/S,NOBSET/S,NOCSET/S,NOGSET/S,NOLSET/
          S,NOOSET/S,NOQSET/S,NORSET/S,NOSSET/S,NOTSET/
          S,NOVSET/S,NOA/S,NOSET/S,NORC/S,NOMSET/0 $
CALL DBFETCH /KNN,MNN,,,/0/0/0/0/S,SUCCESS $
CALL DBFETCH /PHIGEN,VEC999,MERGCB,VECCPP,VECZZI/0/0/0/0/S,EXIT8    $
CALL DBFETCH /MERGCT,PHIN,KJJZ,,,/0/0/0/0/S,EXIT9   $
PARTN PHIGEN,MERGCB,/PHI1,,PHI2,/1 $
VEC     USET/VEC8//S//U1//COMP// $
MERGE   PHI1,,,VEC8//PHI3/1 $
VEC     USET/VEC9//G//COMP//S// $
PARTN   VEC999,,VEC9/VECT,VECB,,/1 $
PARTN   PHI3,VECB,/PHI4,,PHI5,/1 $
MERGE   PHI2,,,MERGCT,/PHI6/1 $
ADD     PHI5,PHI6/PHI7/  $
UPARTN USET,PHI7/GOA,,,'N'//F//S//1 $
PARAML GOA//TRAILER//1/S,N,NGOA $ NUMBER OF DOF IN GOA
PRTPARM //0//NGOA' $
MATGEN /UNITDISP/1/NGOA $ UNIT BOUNDARY + SPOINT DISP
ZUZR1 = SEID $
IF (NOMSET>0) THEN $
UPARTN USET,VEC999/VEC989,,,'G'//N//M//1  $
ELSE $
EQUIVX VEC999/VEC989/ALWAYS $
ENDIF $

```

```

PARTN KNN,VEC989,/KSS1,KSF1,KFS1,KFF1/   $
MPYAD GOA,UNITDISP,/DISPA//    $ 
MERGE ,,UNITDISP,,,VECCPP/UNITG/1 $ 
UMERGE USET,DISPA,/DISPN/'N'/'F'/'S'   $ 
IF(NOMSET>0) THEN $ 
MPYAD GM,DISPN,/DISPM//    $ 
UMERGE USET,DISPN,DISPM/ZHBR06/'G'/'N'/'M'   $ 
ELSE $ 
EQUIVX DISPN/ZHBR06/ALWAYS $ 
ENDIF $ 
ADD ZHBR06,UNITG/ZUZR06/   $ 
PARTN DISPN,,VEC989/,DISP11,,,1 $ 
MPYAD KFS1,DISP11,/QSS1///-1//   $ 
MERGE QSS1,,,,VEC989/ZUBR07/1 $ 
UMERGE USET,ZUBR07,/ZUZR07/'G'/'N'/'M'   $ 
$ 
IF(NOMSET>0) THEN 
MPYAD GM,PHIN,/PHIGM $ 
UMERGE USET,PHIN,PHIGM/PHIGG/'G'/'N'/'M' $ 
ELSE $ 
EQUIVX PHIN/PHIGG/ALWAYS $ 
ENDIF $ 
$ 
COMPILE SEDRCVR SOUIN=MSCSOU, LIST, NOREF 
$ 
ALTER 2 
TYPE DB,ZUZR06,ZUZR07 $ 
TYPE PARM,NDDL,I,N,ZUZR1 $ 
TYPE PARM,,I,N,EXIT7   $ 
$ FLAG FOR CREATION OF EXTERNAL S.E. MATRICES 
$ 
TYPE PARM,,I,Y,(MATFILE=12) $ 
$ 
ALTER 42 $ 
$ 
ZUZR1 = SEID $ 
$ 
SDR2 CASEDR,CSTMS,MPTS,DIT,EQEXINS,,ETT,OLB1,BGPDTS,, 
      ZUZR07,ZUZR06,EST,XYCDBDR/ IOPG1,IOQG1,IOUGV1,IOES1,IOEF1, 
      IPUGV/APP1/S,N,NOSORT2/NOCOMPS $ 
$ 
$ CREATE OTM 
$ 
DRMS1 IOUGV1,IOQG1,IOES1,IOEF1/TABDIS,DIS,TABSPCF,SPCF,TABSTR, 
      STRESS,TABFOR,FORC/LMODES $ 
TABPT TABDIS,TABSPCF,TABSTR,TABFOR// $ *** 
$ TABPCH TABDIS,TABSPCF,TABSTR,TABFOR// $ *** 
CALL DBSTORE DIS,STRESS,SPCF,FORC,//0/0/'DBALL'/0 $ 
CALL DBSTORE TABDIS,TABSPCF,TABSTR,TABFOR,//0/0/'DBALL'/0 $ *** 
$ MATPRN DIS,STRESS,SPCF,FORC// $ 
$ IF (MATFILE=-1) THEN $ PUNCH OTM 
IF(APP='REIG') THEN $ 
ALTER 258 
MESSAGE //'' '$ 
MESSAGE //'*'*****' / 
      ' L I N E A R - S T R A I N - E N E R G Y'/
      '*****' '$ 
MESSAGE //'' '$ 
MESSAGE //'' '$ 
CALL DBFETCH /KELMHB,KDICTHB,KELMHH,,/0/0/0/0/S,EXIT7 $ 

```

```

CALL DBFETCH /KELMNL,KDICTNL,KDELMNL,KDDICTNL,/0/0/0/0/S,EXIT7 $
GPFDR CASEDR,UGVS,KELMHB,KDICTHB,ECTS,EQEXINS,GPECT,PG1,QGS,
BGPDTS,SILS,CSTMS,VELEM,PTELEM/
ONGRY6,OGPFB6/APP2/TINY   $
OFP ONGRY6//S,N,CARDNO/1   $
MESSAGE //'/ '$
MESSAGE //'/ '$
MESSAGE //'*'*/'
' N O N L I N E A R - S T R A I N - E N E R G Y'/
'*'*/'
MESSAGE //'/ '$
MESSAGE //'/ '$
GPFDR CASEDR,UGVS,KELMNL,KDICTNL,ECTS,EQEXINS,GPECT,PG1,QGS,
BGPDTS,SILS,CSTMS,VELEM,PTELEM/
ONGRY7,OGPFB7/APP2/TINY   $
OFP ONGRY7//S,N,CARDNO/5   $
MESSAGE //'/ '$
MESSAGE //'/ '$
MESSAGE //'*'*/'
' N O N L I N E A R - D I F F - S T R A I N - E N E R G Y'/
'*'*/'
MESSAGE //'/ '$
MESSAGE //'/ '$
GPFDR CASEDR,UGVS,KDELMNL,KDDICTNL,ECTS,EQEXINS,GPECT,PG1,QGS,
BGPDTS,SILS,CSTMS,VELEM,PTELEM/
ONGRY8,OGPFB8/APP2/TINY   $
OFP ONGRY8//S,N,CARDNO/5   $
ENDIF $

```

APPENDIX B

MODAL SELECTION FORTRAN COMPUTER PROGRAM (STEP 2)

```

NDAT=NDATA/NSET-NCOM
WRITE(6,1661)NCOM,NTCOM,NSET,NDATA,NDAT
1661 FORMAT(//,' NCOM =',I5,/
*,      ' NTCOM=',I5,/
*,      ' NSET =',I5,/
*,      ' NDATA=',I5,/
*,      ' NDAT =',I5,/)
C     WRITE(13,4999)
C4999 FORMAT(3X,'MODE NO',4X,' TOTAL STRAIN ENERGY ',,
C      *        4X,' STRAIN ENERGY IN SET',
C      *        4X,' PERCENT',/)
      WRITE(13,4999)
4999 FORMAT(3X,'MODE      MODES',,           TOTAL STRAIN ',
*          6X,' STRAIN ENERGY',
*          6X,' PERCENT',/,4X,'NO      SELECTED',10X,'ENERGY',
*          13X,' IN SET',13X,'ENERGY',/)
C
C       READ NONLINEAR STRAIN ENERGIES
C
      NSET2=NSET/2
      DO 1100 K=1,NSET2
      DO 101 JJ=1,NCOM
101  READ(11,1)DOLLAR
      ENSUM=0.0
      ENPCT=0.0
      DO 102 KK=1,NDAT
      READ(11,103)X(KK),Y(KK)
103  FORMAT(18X,2F18.0)
      ENSUM=ENSUM+X(KK)
      ENPCT=ENPCT+Y(KK)
      ENTOT=ENSUM*100.0/ENPCT
102  CONTINUE
      V(K)=ENSUM
C     Z(K)=ENPCT
      W(K)=ENTOT
1100 CONTINUE
C
C       READ NONLINEAR DIFFERENTIAL  STRAIN ENERGIES
C
      IK=0
      DO 2100 K=1,NSET2
      DO 201 JJ=1,NCOM
201  READ(11,1)DOLLAR
      ENSUM=0.0
      ENPCT=0.0
      DO 202 KK=1,NDAT
      READ(11,203)X(KK),Y(KK)
203  FORMAT(18X,2F18.0)
      ENSUM=ENSUM+X(KK)
      ENPCT=ENPCT+Y(KK)
      ENTOT=ENSUM*100.0/ENPCT
202  CONTINUE
      V(K)=V(K)+ENSUM
C     Z(K)=Z(K)+ENPCT
      W(K)=W(K)+ENTOT
      Z(K)=V(K)*100.0/W(K)
      ENPCT=Z(K)
      IF(ENPCT.GT.PERCNT) IK=IK+1
      IF(ENPCT.GT.PERCNT)
C     *WRITE(13,3999)K,W(K),V(K),Z(K)

```

```

*WRITE(13,3999)K,IK,W(K),V(K),Z(K)
C3999 FORMAT(1X,I5,' * ',10X,1PE12.4,15X,1PE12.4,7X,1PE12.4)
3999 FORMAT(I5,I11,9X,1PE12.4,9X,1PE12.4,7X,1PE12.4)
   IF(ENPCT.LT.PERCNT)
C   *WRITE(13,3998)K,W(K),V(K),Z(K)
C3998 FORMAT(1X,I5,'      ',10X,1PE12.4,15X,1PE12.4,7X,1PE12.4)
   *WRITE(13,3998)K,W(K),V(K),Z(K)
3998 FORMAT(I5,20X,1PE12.4,9X,1PE12.4,7X,1PE12.4)
2100 CONTINUE
C
C      WRITE DMI TABLE
C
I1=0
I2=2
I3=1
I4=0
M=1
N=NSET2
C
      WRITE(12,211)I1,I2,I3,I4,M,N
211 FORMAT('DMI      ENERGY      ',4I8,8X,2I8)
DO 1200 J=1,NSET2
ID1=ID+1
      WRITE(12,212)J,I3,Z(J)
212 FORMAT('DMI*      ENERGY      ',2I16,1PE16.8)
1200 CONTINUE
STOP
END

```

APPENDIX C

DMAP ALTER "ALTERNL2" FOR NONLINEAR CRAIG-BAMPTON (STEP-3)

```
$-----  
$ DMAP ALTER FOR SOL 106 TO PERFORM CRAIG-BAMPTON CMS  
$ ON THE FINAL MATRICES -  
$ CREATE A 'CRAIG-BAMPTON' MODEL OF A NONLINEAR MODEL -  
$-----  
| P H A S E      2 |  
$-----  
$----- N O T E -----  
$-----  
$ PARAMETERS USED IN THIS DMAP  
$-----  
$ MATFILE = OUTPUT4 FILE ID TO WRITE MATRICES IN  
$     DEFAULT = 12  
$-----  
$ PERCNT = PERCENT STRAIN ENERGY FOR MODAL SELECTION  
$         = 0.0 , MEANS SELECT ALL MODES (SKIP MODAL SELECTION)  
$         >= 100., MEANS SELECT NO MODES  
$         = 30.0, MEANS SELECT MODES WHICH CONTAIN 30 PERCENT OF  
$             TOTAL STRAIN ENERGY.  
$-----  
$ =====NOTE=====  
$-----  
$ THE DMAP CREATES DMIG ENTRIES FOR PHIXQ AND PHIXT WHICH MAY BE  
$ INTERPRETED IMPROPERLY. THE PROGRAM WRITES THE DMIG AS TYPE '9'  
$ BUT DOES NOT FILL IN 'NCOL' ON THE HEADER ENTRY. IN ORDER TO  
$ PROPERLY USE THESE MATRICES 'NCOL' SHOULD BE ADDED BY THE USER  
$-----  
$-----  
$ DMAP PROGRAM WRITTEN BY :  
$-----  
$ HERAND BEDROSSIAN          TED ROSE  
$ ROCKETDYNE DIVISION        AND      MACNEAL SCHWENDLER CORP.  
$ ROCKWELL INTERNATIONAL  
$-----  
$-----  
$ COMPILE IFPL, SOUIN=MSCSOU, LIST, NOREF  
$     ALTER 24  
$     CALL DBSTORE DMI,DMINDEX,,,//0/0/'DBALL'/0 $  
$-----
```

```

$COMPILE SEMODES SOUIN=MSCSOU REF LIST  $
$ALTER 1
$TYPE PARM,NDDL,I,N,NLOOP   $
$NLOOP=4                      $      <<<  DEFINE NLOOP FROM SOL106
$ 
$COMPILE PHASE1DR SOUIN=MSCSOU REF LIST   $
$ALTER 38,42
$ 
COMPILE SEDISP SOUIN=MSCSOU, LIST, NOREF $
  ALTER 2
  TYPE DB,ZUZR01,ZUZR02,ZUZR03 $
  TYPE PARM,NDDL,I,N,ZUZR1 $
  TYPE DB DMI,DMINDX $
  TYPE PARM,,I,N,EXITS  $
  TYPE PARM,,I,Y,(MATFILE=12) $
  TYPE PARM,,RS,Y,(PERCNT=0.0) $
$ 
$  ALTER 137 $
$.....$          STRAIN ENERGY MODAL SELECTION$.....$ 
$.....$          CALL DBFETCH /KEXT,MEXT,PHIXT,PHIXQ,/0/0/0/0/S,EXITS    $
$.....$          CALL DBFETCH /KGEN,MGEN,,,/0/0/0/0/S,EXITS    $
$.....$          CALL DBFETCH /VECTTT,MERGU1,VECZZY,MERGCT,/0/0/0/0/S,EXITS  $ ***$.....$ 
$.....$          CALL DBFETCH /KNN,MNN,PHIGEN,MERGCB,EQEXINS/0/0/0/0/S,EXITS $
$.....$          ZUZR1=SEID
$.....$          EQUIVX MERGCT/ZUZR01/ALWAYS    $
$.....$          EQUIVX MERGCB/ZUZR02/ALWAYS    $
$ 
$ IF (PERCNT>0.0) THEN $
$   CALL DBFETCH /DMI,DMINDX,,,/0/0/0/0/S,EXITS    $
$   DMIIN DMI,DMINDX/ENERGY,,,,$
$   TRNSP ENERGY/ENERGYT $
$   MESSAGE //'
$   MESSAGE //'
$   MESSAGE //'
$ ENDIF $
$ IF (PERCNT>0.0)THEN $
$   MATPRN ENERGYT// $
$   MATMOD ENERGYT,,,/SEDIAG,/28 $
$   MATMOD SEDIAG,,,/SEFILT,/2///PERCNT    $
$   MATMOD SEFILT,,,/SELMOD,/12 $
$   MESSAGE //'
$   MESSAGE //'
$   MESSAGE //'
$   MATPRN SELMOD// $
$   MERGE MERGU1,SELMOD,,,MERGCB/MERGNEW/1 $
$   MERGE SELMOD,MERGU1,,,MERGCT/MERGOLD/1 $ ***$ 
$   EQUIVX MERGNEW/ZUZR03/ALWAYS    $
$   PARTN KGEN,MERGNEW,/KGEN1,,,,$
$   PARTN MGEN,MERGNEW,/MGEN1,,,,$
$   FILE MEXT=OVRWRT
$   FILE KEXT=OVRWRT
$   MERGE ,,SELMOD,,,VECZZY/SEXXG/1 $
$   ADD SEXXG,VECTTT/VEC99/ $
$   MERGE KGEN1,,,VEC99,/KEXT/-1 $
$   MERGE MGEN1,,,VEC99,/MEXT/-1 $
$   MODTRL KEXT///6 $
$   MODTRL MEXT///6 $
$   PARTN PHIXT,MERGNEW,/PHIXT1,,,/1 $

```

```

PARTN    PHIXQ,MERGNEW,/PHIXQ1,,,/1 $
FILE     PHIXT=OVRWRT
FILE     PHIXQ=OVRWRT
EQUIVX   PHIIXQ1/PHIXQ/ALWAYS $
EQUIVX   PHIIXT1/PHIXT/ALWAYS $
EQUIVX   KEXT/KAAEXT/ALWAYS $
EQUIVX   MEXT/MAAEXT/ALWAYS $
ELSE $
EQUIVX   KEXT/KAAEXT/ALWAYS $
EQUIVX   MEXT/MAAEXT/ALWAYS $
MESSAGE //'. . . . . '$
MESSAGE //'. ALL THE MODES ARE USED IN THE COMPONENT MODE REDUCTION'$
MESSAGE //'. . . . . '$
ENDIF $
$      K E X T      &      M E X T
MATMOD KAAEXT,EQEXINS,,,./MATP,/16/1//////////KA $
MATMOD MAAEXT,EQEXINS,,,./MATP1,/16/1//////////MA $
OUTPUT4 KAAEXT,MAAEXT,,./0/MATFILE/-1 $
$      W R I T E      P H I X Q      &      P H I X T
MATMOD PHIXQ,EQEXINS,,,./MATP5,/16/1//////////PQ $
MATMOD PHIXT,EQEXINS,,,./MATP6,/16/1//////////PT $
OUTPUT4 PHIXQ,PHIXT,,./0/MATFILE/-1 $
$      C O M P I L E      S E D R C V R      S O U I N = M S C S O U ,      L I S T ,      N O R E F
      A L T E R      2
      T Y P E      D B , Z U Z R 0 1 , Z U Z R 0 2 , Z U Z R 0 3 $
      T Y P E      P A R M , N D D L , I , N , Z U Z R 1      $
      T Y P E      P A R M , , I , N , E X I T T      $
      T Y P E      P A R M , , R S , Y , ( P E R C N T = 0 . 0 ) $
      T Y P E      P A R M , , I , Y , ( M A T F I L E = 1 2 ) $
      T Y P E      P A R M , , I , N , E X I S T S = 1 $
$      A L T E R      4 2 $
I F ( A P P = ' N L S T ' )      T H E N $
$      D O      N O T H I N G
E L S E $
C A L L      D B F E T C H      / D I S , S T R E S S , F O R C , S P C F / 0 / 0 / 0 / 0 / S , E X I T T $
C A L L      D B F E T C H      / T A B D I S , T A B S P C F , T A B S T R , T A B F O R , / 0 / 0 / 0 / 0 / S , E X I T T $
$      E Q U I V X      Z U Z R 0 1 / M E R G C T / A L W A Y S      $
      E Q U I V X      Z U Z R 0 2 / M E R G C B / A L W A Y S      $
      E Q U I V X      Z U Z R 0 3 / M E R G N E W / A L W A Y S      $
$      P A R A M L      D I S / / ' P R E S E N C E ' / / / S , N , E X I S T S      $
I F ( E X I S T S <>-1 ) T H E N $
P A R T N      D I S , M E R G C T , / D I S 1 , , D I S 2 , / 1 $
F I L E      D I S = O V R W R T
M E R G E      D I S 2 , , D I S 1 , , M E R G C B , / D I S / + 1 $
E N D I F $
$      P A R A M L      S T R E S S / / ' P R E S E N C E ' / / / S , N , E X I S T S      $
I F ( E X I S T S <>-1 ) T H E N $
P A R T N      S T R E S S , M E R G C T , / S T R E S S 1 , , S T R E S S 2 , / 1 $
F I L E      S T R E S S = O V R W R T
M E R G E      S T R E S S 2 , , S T R E S S 1 , , M E R G C B , / S T R E S S / + 1 $
E N D I F $
$      P A R A M L      F O R C / / ' P R E S E N C E ' / / / S , N , E X I S T S      $
I F ( E X I S T S <>-1 ) T H E N $
P A R T N      F O R C , M E R G C T , / F O R C 1 , , F O R C 2 , / 1 $

```

```

FILE      FORC=OVRWRT
MERGE    FORC2,,FORC1,,MERGCB,/FORC/+1 $
ENDIF   $

$ PARAML SPCF//'PRESENCE'///S,N,EXISTS $
IF (EXISTS<>-1)THEN $
PARTN    SPCF,MERGCT,/SPCF1,,SPCF2,/1 $
FILE     SPCF=OVRWRT
MERGE    SPCF2,,SPCF1,,MERGCB,/SPCF/+1 $
ENDIF $

$ PARAML MERGNEW//'PRESENCE'///S,N,EXISTS $
MESSAGE //'' DATABLOCK MERGENEW '/EXISTS $
IF (EXISTS<>-1)THEN $          PARTITION DATABLOCKS
$

PARAML DIS//'PRESENCE'///S,N,EXISTS $
IF (EXISTS<>-1)THEN $
FILE     DIS1=OVRWRT
PARTN    DIS,MERGNEW,/DIS1,,,/1 $
FILE     DIS=OVRWRT
EQUIVX   DIS1/DIS/ALWAYS $
ENDIF $

$ PARAML STRESS//'PRESENCE'///S,N,EXISTS $
IF (EXISTS<>-1)THEN $
FILE    STRESS1=OVRWRT
PARTN   STRESS,MERGNEW,/STRESS1,,,/1 $
FILE    STRESS=OVRWRT
EQUIVX  STRESS1/STRESS/ALWAYS $
ENDIF $

$ PARAML FORC//'PRESENCE'///S,N,EXISTS $
IF (EXISTS<>-1)THEN $
FILE    FORC1=OVRWRT
PARTN   FORC,MERGNEW,/FORC1,,,/1 $
FILE    FORC=OVRWRT
EQUIVX  FORC1/FORC/ALWAYS $
ENDIF $

$ PARAML SPCF//'PRESENCE'///S,N,EXISTS $
IF (EXISTS<>-1)THEN $
FILE     SPCF1=OVRWRT
PARTN   SPCF,MERGNEW,/SPCF1,,,/1 $
FILE     SPCF=OVRWRT
EQUIVX  SPCF1/SPCF/ALWAYS $
ENDIF $

$ ENDIF $      END PARTITION
$

MATPCH  DIS// $
MATPCH  SPCF// $
MATPCH  STRESS// $
MATPCH  FORC// $
TABPCH  TABDIS,TABSPCF,TABSTR,TABFOR// $
$ OUTPUT2 TABDIS,TABSPCF,TABSTR,TABFOR,///MATFILE $
$ OUTPUT2 DIS,SPCF,STRESS,FORC,///MATFILE $
$ OUTPUT2 ,,,/-9/MATFILE $ WRITE EOF
$ OUTPUT4 TABDIS,TABSPCF,TABSTR,TABFOR,/-0/MATFILE/-1 $
OUTPUT4 DIS,SPCF,STRESS,FORC,/-2/MATFILE/-1 $
ENDIF $

```

APPENDIX D

INPUT DECK FOR THE EXAMPLE PROBLEM (PHASE 1)

```
ID SOL106,NASTRAN
SOL 106
TIME 5
INCLUDE ALTERNL1
CEND
TITLE =      NONLINEAR CRAIG BAMPTON COMPONENT MODE REDUCTION
SUBTITLE = SIMPLE CANTILEVERED BEAM MODEL RUN 1 PHASE 1
SUBCASE 100
DISP(PLOT)= ALL
SET 101=1,2
STRESS(PLOT)= 101
FORCE(PLOT) = 101
SPCF =ALL
ESE = 101
SPC = 1
METHOD = 888
LOAD = 1
NLPARM = 1
BEGIN BULK
PARAM,TINY,0.0
PARAM,DBDICT,2
PARAM,LGDISP,1
PARAM,NMLOOP,4
PARAM,USETPRT,11
PARAM,NSPOINT,10
EIGRL,888,,,5
FORCE,1,5,0,1E+3,0.,0.,-10.
NLPARM,1,4,,AUTO,1,20,UPW,NO
SPC1,1,123456,1
USET,U1,1,123456
SPOINT,10101,THRU,10110
DEFUSET,U2,U2
USET,U2,5,123
GRID      1          3.0    0.0   -1.0
GRID      2          3.0    0.0   -2.0
GRID      3          3.0    0.0   -3.0
GRID      4          3.0    0.0   -4.0
GRID      5          3.0    0.0   -5.0
CBEAM     1          1          1          2          1.0
CBEAM     2          1          2          3          1.0
CBEAM     3          1          3          4          1.0
CBEAM     4          1          4          5          1.0
MAT1      1          1.E+7        0.3    2.6E-4
PBEAM     1          1          0.10       0.1         0.1    0.8000+A1
+A1      YESA      1.
+A2      0.5        0.5
ENDDATA
```

APPENDIX E

INPUT DECK FOR THE EXAMPLE PROBLEM (PHASE 2)

```
RESTART VERSION= 1,KEEP
ID   SOL106,NASTRAN
SOL 106
TIME   5
DIAG 8,13,14
INCLUDE ALTERNL2
CEND
TITLE    = NONLINEAR CRAIG BAMPTON COMPONENT MODE
SUBTITLE = GENERATE A REDUCED SET OF COMPONENT MODES
LABEL    = USE 60% STRAIN ENERGY CRITERIA
SUBCASE 100
DISP(PLOT) = ALL
SET 101=1,2
STRESS(PLOT) = 101
FORCE(PLOT) = 101
SPCF(PLOT)=ALL
ESE(PLOT) = 101
SPC = 1
METHOD = 888
LOAD = 1
$ NLPARM = 1
NLPARM = 2
BEGIN BULK
$
PARAM,LOOPID,4
PARAM,SUBID,1
PARAM,LOADINC,4
PARAM,PERCNT,60.0      $ 40 PERCENT STRAIN ENERGY USED IN SET 101
PARAM,MATFILE,12        $ OUTPUT4 TAPE ID
$
NLPARM,2,1,,AUTO,1,20,UPW,NO
INCLUDE DMI            $ DMI PUNCHED FILE FROM STRAIN ENERGY PROGRAM
$
ENDDATA
```

APPENDIX F

MODAL SELECTION SUMMARY LIST PRINTED BY PROGRAM "ENERGY"

MODE NO	MODES SELECTED	TOTAL STRAIN ENERGY	STRAIN ENERGY IN SET	PERCENT ENERGY
1	1	1.2546E+04	1.0566E+04	8.4216E+01
2	2	1.2546E+04	1.0566E+04	8.4222E+01
3	3	9.5147E+04	7.8653E+04	8.2664E+01
4		1.1485E+05	6.7532E+04	5.8801E+01
5		1.1485E+05	6.7535E+04	5.8803E+01

DMI TABLE PUNCHED BY PROGRAM "ENERGY"

DMI	ENERGY	0	2	1	0	1	5
DMI*	ENERGY			1		1	8.42163839E+01
DMI*	ENERGY			2		1	8.42215011E+01
DMI*	ENERGY			3		1	8.26640800E+01
DMI*	ENERGY			4		1	5.88008644E+01
DMI*	ENERGY			5		1	5.88034854E+01

APPENDIX G

PUNCHED FILE FROM STEP 3 CONTAINING ALL THE DATABLACKS FOR
CRAIG-BAMPTON COMPONENT MODE SYNTHESIS USING EXTERNAL SUPERELEMENTS

DMIG	KEXT	0	6	1	0
DMIG*	KEXT			1	1
*		1		1	1.169193544E-09
DMIG*	KEXT			1	2
*		1		2	1.169193544E-09
DMIG*	KEXT			1	3
*		1		3	2.117582368E-22
DMIG*	KEXT			1	4
*		1		2	5.942906819E-10
*		1		4	2.374872565E-08
DMIG*	KEXT			1	5
*		1		1-5.942906819E-10	
*		1		5	2.374872565E-08
DMIG*	KEXT			1	6
*		1		6	3.725290298E-09
DMIG*	KEXT			10101	0
*		10101		0	2.509146843E+04
DMIG*	KEXT			10102	0
*		10101		0	1.746700757E-09
*		10102		0	2.509146843E+04
DMIG*	KEXT			10103	0
*		10101		0	1.395752055E-08
*		10102		0	-3.337465755E-08
*		10103		0	1.902949842E+05
DMIG	MEXT	0	6	1	0
DMIG*	MEXT			1	1
*		1		1	3.200104000E+00
DMIG*	MEXT			1	2
*		1		2	3.200104000E+00
DMIG*	MEXT			1	3
*		1		3	3.200104000E+00
DMIG*	MEXT			1	4
*		1		2	5.863859356E+00
*		1		4	1.466965691E+01
DMIG*	MEXT			1	5
*		1		1-5.863859356E+00	
*		1		5	1.466965691E+01
DMIG*	MEXT			1	6
*		1		6	2.080000000E-04
DMIG*	MEXT			10101	0
*		1		1-1.498929405E-01	
*		1		2	1.520394639E+00
*		1		3-2.037436142E-15	
*		1		4	3.809789150E+00
*		1		5	3.756001790E-01
*		1		6-1.542018908E-11	
*		10101		0	1.000000000E+00
DMIG*	MEXT			10102	0
*		1		1	1.520394639E+00

*		1		2	1.498929405E-01	
*		1		3	7.061876402E-15	
*		1		4	3.756001790E-01	
*		1		5	-3.809789150E+00	
*		1		6	-1.130553925E-11	
*		10101		0	-1.332037302E-15	
*		10102		0	1.000000000E+00	
DMIG*	MEXT		10103	0		
*		1		1	-3.068822574E-13	
*		1		2	-2.312963161E-13	
*		1		3	-1.589810170E+00	
*		1		4	-1.125293096E-14	
*		1		5	-6.364738790E-14	
*		1		6	-8.430593121E-10	
*		10101		0	1.043960435E-15	
*		10102		0	-3.590243412E-15	
*		10103		0	1.000000000E+00	
DMIG	PHIXQ	0	9	1	0	9
DMIG*	PHIXQ			7	0	
*		5		1	-8.977659517E-02	
*		5		2	9.106222983E-01	
*		5		3	-2.299264040E-14	
DMIG*	PHIXQ			8	0	
*		5		1	9.106222983E-01	
*		5		2	8.977659517E-02	
*		5		3	-1.585203460E-14	
DMIG*	PHIXQ			9	0	
*		5		1	1.082614765E-12	
*		5		2	1.681682928E-13	
*		5		3	-7.905565686E-01	
DMIG	PHIXT	0	9	1	0	9
DMIG*	PHIXT			1	0	
*		5		1	1.000000000E+00	
DMIG*	PHIXT			2	0	
*		5		2	1.000000000E+00	
DMIG*	PHIXT			3	0	
*		5		3	1.000000000E+00	
DMIG*	PHIXT			4	0	
*		5		2	4.000000000E+00	
DMIG*	PHIXT			5	0	
*		5		1	-4.000000000E+00	
DMI	DIS	0	2	1	0	90
DMI*	DIS			1	7	-2.23206176E-02
*		2.26402573E-01	7.05119290E-15	7	7.75860949E-02	7.64907190E-03
*		-6.83701787E-08	-4.81191479E-02	4	8.80802323E-01	-2.55381598E-14
*		1.21763891E-01	1.20044804E-02	-7	5.8763211E-08	-7.20320233E-02
*		7.30635490E-01	2.74365747E-14	1	3.9779325E-01	1.37805893E-02
*		-9.71157887E-08	-8.97765952E-02	9	1.0622298E-01	-2.29926404E-14
*		1.43446254E-01	1.41421051E-02	-1	1.0359618E-07	1.000000000E+00
DMI*	DIS			2	7	2.26402573E-01
*		2.23206176E-02	8.47593183E-15	7	6.4907190E-03	-7.75860949E-02
*		-5.91506080E-08	4.880802323E-01	4	8.1191479E-02	-1.42861248E-14
*		1.20044804E-02	-1.21763891E-01	-5	3.9596539E-08	7.30635490E-01
*		7.20320233E-02	2.25632689E-14	1	3.7805893E-02	-1.39779325E-01
*		-6.41681430E-08	9.10622298E-01	8	9.7765952E-02	-1.58520346E-14
*		1.41421051E-02	-1.43446254E-01	-8	0.2716230E-08	37
*		1.000000000E+00				
DMI*	DIS			3	7	-4.26755138E-13
*		-3.52389525E-13	-3.02532901E-01	2	5.1899493E-14	-8.99907580E-14
*		7.61639051E-07	1.32401472E-13	-7	6.0687575E-14	-5.59007911E-01

*		6.23541079E-14	-1.87324308E-13	-5.17066339E-06	-6.30544072E-13
*		5.52631365E-14	-7.30379033E-01	7.03352736E-14	-3.43994476E-13
*		-8.71931885E-06	1.08261476E-12	1.68168293E-13	-7.90556569E-01
*		7.30944965E-14	-4.68226821E-13	-6.16867177E-06	43
*		1.00000000E+00			
DMI*	DIS	4		7	-3.97837501E-01
*		5.60578529E-01	-5.02872815E-13	-5.91067103E-02	-4.19474965E-02
*		-2.45718335E-07	-3.70900199E-01	5.22622146E-01	4.28070005E-12
*		-1.82522747E-01	-1.29534739E-01	1.10838713E-05	6.80428635E-02
*		-9.58767544E-02	-4.17434326E-12	-2.76695139E-01	-1.96368032E-01
*		1.68857757E-05	4.86231743E-01	-6.85131680E-01	2.19400097E-12
*		-3.05200641E-01	-2.16598129E-01	1.30484418E-05	49
*		1.00000000E+00			
DMI*	DIS	5		7	-5.60578529E-01
*		-3.97837501E-01	1.48041968E-12	4.19474965E-02	-5.91067103E-02
*		-1.17237008E-05	-5.22622146E-01	-3.70900199E-01	-3.04072385E-12
*		1.29534739E-01	-1.82522747E-01	-1.06915208E-05	9.58767544E-02
*		6.80428635E-02	4.41544981E-12	1.96368032E-01	-2.76695139E-01
*		-1.23787243E-05	6.85131680E-01	4.86231743E-01	-3.20663691E-12
*		2.16598129E-01	-3.05200641E-01	-1.53682435E-05	55
*		1.00000000E+00			
DMI*	DIS	6		1	1.00000000E+00
*		7	1.00000000E+00	11	1.77635684E-15
*		13	1.00000000E+00	17	2.66453526E-15
*		19	1.00000000E+00	23	2.88657986E-15
*		25	1.00000000E+00	29	3.72529030E-15
DMI*	DIS	7		2	1.00000000E+00
*		8	1.00000000E+00	10	-1.77635684E-15
*		14	1.00000000E+00	16	-2.66453526E-15
*		20	1.00000000E+00	22	-2.88657986E-15
*		26	1.00000000E+00	28	-3.72529030E-15
DMI*	DIS	8		3	1.00000000E+00
*		9	1.00000000E+00	15	1.00000000E+00
*		21	1.00000000E+00	27	1.00000000E+00
DMI*	DIS	9		4	1.00000000E+00
*		8	1.00000000E+00	10	1.00000000E+00
*		14	2.00000000E+00	16	1.00000000E+00
*		20	3.00000000E+00	22	1.00000000E+00
*		26	4.00000000E+00	28	1.00000000E+00
DMI*	DIS	10		5	1.00000000E+00
*		7	-1.00000000E+00	11	1.00000000E+00
*		13	-2.00000000E+00	17	1.00000000E+00
*		19	-3.00000000E+00	23	1.00000000E+00
*		25	-4.00000000E+00	29	1.00000000E+00
DMI*	DIS	11		6	1.00000000E+00
*		12	1.00000000E+00	18	1.00000000E+00
*		24	1.00000000E+00	30	1.00000000E+00
DMI	SPCF	0	2	1	0
					90
					6