COMPONENT MODE SYNTHESIS AND LARGE DEFLECTION VIBRATION OF COMPLEX STRUCTURES
VOLUME 1: EXAMPLES OF NASTRAN® MODAL SYNTHESIS CAPABILITY

By
Chuh Mei, Principal Investigator
and
Mo-How Shen

Final Report
For the period ended January 31, 1987

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, VA 23665

Under
Research Grant NAG-1-301
Mr. Joseph E. Walz, Technical Monitor
SDD—Structural Dynamics Branch

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SUMMARY

This report illustrates the use of NASTRAN® modal synthesis capability for some small examples. A classical truss problem is examined and the results for accuracy are compared to existing results from other methods. This problem is examined using both fixed interface modes and free interface modes. The solution is carried out for an applied dynamic load down as far as recovery or forces in individual members as a function of time. Another small beam problem is used to compare different means of "combining" substructures.

INTRODUCTION

During the past twenty years, a body of technology has developed within the general field of structural dynamics that has been identified by the term modal synthesis. Modal synthesis is a Rayleigh-Ritz approach using systematically derived displacement functions. It is used to formulate and solve the large eigen problems which arise in dynamic analysis of complex structural systems. Solutions are approximate in the sense that the motion of the structure is constrained to linear combinations of a limited number of modes or displacement functions characterizing the behavior of independent substructures.
Several researchers have formulated various modal synthesis procedures in an attempt to reduce computation errors and minimize computer costs. Hurty developed the first modal synthesis method capable of analyzing structures with redundant interface connections in references 1 and 2. He treated the structure as an assembly of connected components, or substructures, each of which is analyzed separately to derive a set of modes or displacement shapes from which a set of generalized coordinates applicable to the complete structure is synthesized. Craig and Bampton (ref. 3) simplified Hurty's formulation by combining two groups of coordinate functions which Hurty had defined separately. A number of survey papers have been written by Hou, Goldman, Benfield and Hruda in references 4 to 7. Some methods are found to be more suitable for certain applications than others. Yet, experience has shown that no single approach is generally preferred over the others.

The complexity of aerospace structures increased enormously during the last two decades. A new challenge is presented by the proposed space station (ref. 8) in that it is an evolving structure that cannot be ground tested because final configuration may not be known when the first component is put into space. Therefore, the component mode synthesis method may be applied for the dynamic analysis of such large structure system in space. A widely used tool for structural analysis, the NASTRAN® computer program, contains a modal synthesis capability but, other than the demonstration problem presented in reference 5, little is publicly known about its capabilities.

The purpose of the present report is to examine some of the capabilities of this program. This is done by examining two simple problems, a truss and a beam.

**NUMERICAL EXAMPLES**

The modal synthesis procedure in NASTRAN® is applied to two simple structures. One is a redundant truss confined to lie in a plane but free to move in this plane. It is composed entirely of ROD elements (no bending stiffness for all). This example is used to examine convergence character-
istics of the modal synthesis procedure and also to illustrate the transient response capability all the way down to obtaining stresses in rod members as a function of time. The second example is a free-free beam. It is used to examine different ways to "combine" substructures to yield frequency for the total structure.

Truss Example

The redundant truss example is the one used in reference 5 to compare eight different modal synthesis procedures. The full truss model is shown in figure 1(a) and its two components shown in figure 1(b). Component A consists of five equal bays and has a total of 18 joints. Component B consists of four equal bays and has a total of 15 joints. All members in the components have identical properties. At the interface of the components in the full truss model, the vertical member has twice the area of other members. Basic geometric and material properties are presented in table I along with the prescribed load for a transient response analysis. An additional run was made with the full model subdivided into three components with three bays in each component.

The basic run sequence and substructure operation are shown in figure 2. In the figure capitalized letters inside of rectangular blocks indicate names of pseudostructures used in the analysis. Capitalized letters adjacent to, or on, the flow diagram indicate the names of modules that perform a certain function in the computer program. At the top of figure 2, the Phase 1 operations formulate the finite element stiffness and mass matrices using Rigid Format 2. For the convergence study the Phase 2 runs on Rigid Format 3 were repeated using a different number of modes from the individual components. Also Phase 2 runs were using free interface modes as well as the fixed interface modes. A limited amount of data is presented for three components and naturally a Phase 1 run must be made for this component.

A transient response analysis was made on this free-free truss structure for an axial load applied to the right end of the truss. The load was applied for 0.12 seconds and then removed. In order to apply a load at grid point 42 in component B, this grid point must be included on a BOUNDARY
card. Thus, additional degrees of freedom are created corresponding to this point. The structure was represented by eight modes from component A, six modes from component B, and the eight interface modes for a total of twenty-two modes. The modes for the individual component were determined with the interface fixed. The standard procedure will obtain displacements back in the individual component. However, member forces and stresses are not determined automatically, but can be obtained through a simple procedure in a few steps. In the first step a run is made with DIAG 17 turned on to put the DMAP sequence on the punch file with an EXIT scheduled after statement 1. A small substructure deck is included to allow the appropriate commands that interface to the Substructures Operating File (SOF) to be generated. This punch file is subsequently saved and altered to replace the RECOVER module with the SDR2 module which can recover element forces and stresses. The listing of this DMAP sequence and run stream is contained in Appendix A.

Beam Example

This example consists of a beam composed of seven components as shown in figure 3(a). All subbeams have a constant length, area and uniform mass properties. Each component consists of ten equal elements and has a total of 11 joints as shown in figure 3(b). Basic geometric and material properties for each subbeam are presented in Table II. A lumped mass formulation is used (no rotary inertia) and, therefore, there are 213 stiffness degrees of freedom in the problem, but only 142 eigenvalues.

Three different ways of "combining" substructures are illustrated in figures 3(c), 3(d), and 3(e). The basic run sequences and substructure operations for each case are shown in figures 4 thru 6. For all cases, the substructuring Phase 1 operations formulate the finite element stiffness and mass matrices for subbeam A using Rigid Format 3. The structural matrices contained in BBASIC, CBASIC, ..., FBASIC are generated as needed by using EQUIV operation. The basic subbeams are reduced to modal coordinates and combined together following the procedures shown in figures 4 thru 6. The eigenvalues of the total beam are obtained by using the MRECOVER command. The driver decks and sample bulk data for cases 1, 2 and 3 are listed in Appendices B, C and D. Only fixed interface modes were used but two sets of runs were made using a different number of modes from the subbeams.
RESULTS

For assessing the accuracy of the modal synthesis procedure, two and three truss components with fixed or free interface connection are run to determine frequencies and compared to results for full model. Percentage errors in frequency for the combined systems of 12, 20, 28 and 36 degrees of freedom are shown in tables III thru VI. Here degrees of freedom include not only the number of flexible modes used but also any interface modes. Thus, for example, for 12 degrees of freedom results, since there are six interface modes, only six flexible modes can be shown. Based on the lowest frequency criterion then four modes were chosen from component A and two modes from component B.

Figures 7 thru 11 are nondimensional plots that indicate the relative accuracy obtained by modal synthesis procedures. Also shown on the figures are results taken directly from reference 5 in which several other procedures are compared. From figures 7 to 10 it can be seen that modes derived with the interfaces fixed yield better results than modes derived with the interface free.

For the transient response run the percentage error in displacement for grid points 41, 42, and 43 of component B are shown in table VII. These results were produced from the 20 degrees of freedom model. The axial force in elements 111-113 and 143 of component B are shown in table VIII.

The full beam shown in figure 2 was run to determine its natural frequencies and used as a comparison of results obtained with the various "combination" procedures. Table IX shows the percentage error in frequency for the various "combination" procedures when 62 degrees of freedom are used. These 62 degrees of freedom correspond to approximately 47% of the total degrees of freedom in the full model. All three "combination" procedures yield good results. However, case 1 uses considerably less CYBER 75 CPU time than the other two cases (53.8 CPU seconds corresponds to 65.3 seconds, 59.1 seconds, respectively). Another run for case 1 was made using 19% of total degrees of freedom, and 55% frequencies were obtained with less than 1% error in frequency.
ACKNOWLEDGEMENT

This work was sponsored by the NASA-Langley Research Center under Grant NAG-1-301. The work was monitored under the supervision of Dr. Jerrold M. Housner and Mr. Joseph E. Walz, Structural Dynamics Branch, Structures and Dynamics Division. Mr. Mo-How Shen, a graduate student in the Department of Mechanical Engineering and Mechanics, Old Dominion University, carried out most of the detailed studies. The author would like to thank Mr. Joe Walz for many valuable suggestions and assistance.
REFERENCES


Table I. Truss Geometric and Material Properties

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<td>(2.5x10^-4 \text{ lbf-sec}^2)</td>
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Table III. Frequency for Full Truss and Percent Error in Frequency for Two Modal Synthesis Models Using 12 Degrees of Freedom

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Table VI. Frequency for Full Truss and Percent Error in Frequency for Two Modal Synthesis Models using 36 Degrees of Freedom
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Table VII: Transient Response and Percent Error in Displacement
Table VIII. The Axial Force in Elements of B Substructure

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Table IX. Percent Frequency Error Using 62 Degrees of Freedom

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<th>Case 2 (Hz)</th>
<th>(%)</th>
<th>Case 3 (Hz)</th>
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Table IX. Percent Frequency Error Using 62 Degrees of Freedom (concluded)

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Figure 2. Substructure Formulation Tree and Solution Sequence
Figure 3. Total Beam Model and Various Subdivided Representations.
Figure 4. Case 1 Subbeam Formulation Tree and Solution Sequence
Figure 5. Case 2 Subbeam Formulation Tree and Solution Sequence.
Figure 6. Case 3 Subbeam Formulation Tree and Solution Sequence
Figure 7. Comparison of Methods with Frequency Error of 0.1%.
Figure 8. Comparison of Methods with Frequency Error of 0.5%.
Figure 9. Comparison of Methods with Frequency Error of 1.0%.

Legend:
NR1 = Free-interface NASTRAN
NR2 = Fixed-interface NASTRAN
BH1 = Benfield-Hruda, Free-Free
BH2 = Benfield-Hruda, Constrained
BH3 = Benfield-Hruda, Free-Free, Interface Loading
BH4 = Benfield-Hruda, Constrained, Interface Loading
H = Hurty
BF = Bajan-Feng
CB = Craig-Bampton
HO = Hou
G = Goldman
Figure 10. Comparison of Methods with Frequency Error of 5.0%.
Figure 11. Comparison of Methods with Frequency Error of 10.0%.
APPENDICES
APPENDIX A. Driver decks and sample bulk data for two components truss problem.

NASTRAN FILES = UMF & CDC AND IBM
ID = DEM2031, NASTRAN
APP DISP SUBS
SOL 2, 0
TIME 3
CEND
SUBSTRUCTURE PHASE 1
PASSWORD = MOLSYN
SOF(1) = FT19, 500, NEW & CDC AND IBM
NAME = ABASIC
SOFPRTN TOC
ENDSUBS
TITLE = TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
LABEL = SUBSTRUCTURE 1, RUN 1, PHASE 1, RF 2
SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 2-3-1
BEGIN BULK
CROD 1 1 1 2
CROD 2 1 1 1 1 2
CROD 3 1 1 1 2 1 3
CROD 4 1 1 1 2 1 3 1 4
CROD 5 1 1 1 2 1 3 1 4 1 5
CROD 6 1 1 1 2 1 3 1 4 1 5 1 6
CROD 7 1 1 1 2 1 3 1 4 1 5 1 6 1 7
CROD 8 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8
CROD 9 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9
CROD 10 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10
CROD 11 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11
CROD 12 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12
CROD 13 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13
CROD 14 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14
CROD 15 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15
CROD 16 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16
CROD 17 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17
CROD 18 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18
CROD 19 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18 1 19
CROD 20 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18 1 19 1 20
CROD 21 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18 1 19 1 20 1 21
CROD 22 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18 1 19 1 20 1 21 1 22
CROD 23 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18 1 19 1 20 1 21 1 22 1 23
CROD 24 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18 1 19 1 20 1 21 1 22 1 23 1 24
CROD 25 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18 1 19 1 20 1 21 1 22 1 23 1 24 1 25
CROD 26 1 1 1 2 1 3 1 4 1 5 1 6 1 7 1 8 1 9 1 10 1 11 1 12 1 13 1 14 1 15 1 16 1 17 1 18 1 19 1 20 1 21 1 22 1 23 1 24 1 25 1 26
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GRID 26 .0 .0 .0

3456
GRID 22 80.0 30.0 0.0
GRID 23 80.0 30.0 0.0
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GRID 33 120.0 0.0 0.0
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GRID 53 200.0 -30.0 0.0
MAT1 1 10.0 6 3
PROD 1 1
ENDDATA

NASTRAN FILES = UMF $ CDC AND IBM
ID £ DEM2032$ NASTRAN
APP DISP, SUBS
SOL 2, 0
TIME 3
CEND
SUBSTRUCTURE PHASE1
PASSWORD = MOLSYN
SOF(1$ FTLY, 500 $ CDC AND IBM
NAME = BBASIC
SOFRINT TOC
ENSUBS
TITLE = TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 2-3-2
LABEL = SUBSTRUCTURE 2, RUN 2, PHASE 1, RF 2
BEGIN BULK
CROD 1 1 1 2
CROD 11 1 1 2
CROD 12 1 1 2
CROD 21 1 2 2
CROD 22 1 2 2
CROD 31 1 3 3
CROD 32 1 3 3
CROD 41 1 4 4
CROD 42 1 4 4
CROD 111 1 1 1
CROD 112 1 1 1
CROD 113 1 1 1
CROD 114 1 1 1
CROD 115 1 1 1
CROD 116 1 1 1
CROD 117 1 1 1
CROD 211 1 2 2
CROD 212 1 2 2
CROD 221 1 2 2
CROD 222 1 2 2
CROD 231 1 3 3
CROD 232 1 3 3
CROD 241 1 4 4
CROD 242 1 4 4
GROSET 1
GRID 1 30.0 0.0
GRID 5 -30.0 0.0
GRID 11 30.0 40.0 0.0
GRID 12 0.0 40.0 0.0

3456
GRID  13  -30.0  40.0  .0
GRID  21  30.0  80.0  .0
GRID  22  0.0  80.0  .0
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GRID  33  -30.0  120.0  .0
GRID  41  30.0  160.0  .0
GRID  42  0.0  160.0  .0
GRID  43  -30.0  160.0  .0
MAT1  43  10.0E6  .3  3.2E-4

& NASTRAN FILES = UMF $ CDC AND IBM
ID DEMO33,NASTRAN
APP DISP, SUBS
SOL 3, 0
END
SUBSTRUCTURE PHASE 2
PASSWORD = MDLSYN
SOF(1) = FT19,*300 $ CDC AND IBM
OPTIONS K* M* P
SOFPRINT TOC
MREDUCE A* BASIC
NAME MA
BOUNDARY 5
FIXED 5
METHOD 19
OUTPUT 1,5, 6, 9, 10
SOFPRINT TOC
MREDUCE B* BASIC
NAME MB
BOUNDARY 4
FIXED 4
METHOD 29
OUTPUT 1,5, 6, 9, 10
SOFPRINT TOC
MREDUCE C* BASIC
NAME MC
BOUNDARY 7
FIXED 7
METHOD 39
OUTPUT 1,5, 6, 9, 10
SOFPRINT TOC
COMBINE MA* MB* MC
NAME MCOMB
TOLERANCE 0.001
OUTPUT 2, 7, 12
COMPONENT MB
TRANSFORMATION 20
COMPONENT MC
TRANSFORMATION 40
SOFPRINT TOC
MREDUCE MC* COMB
NAME TRUSS
BOUNDARY 42
METHOD 90
NMAX 18
OUTPUT 1, 5, 6, 9, 10
SOFPRINT TOC
ENDSUBS
TITLE = TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
SUBTITLE = NASTRAN DEMONSTRATION PROBLEM NO. 2-3-4
LABEL = MODAL REDUCE, COMBINE, MODAL RECOVERY, RUN 4, PHASE 2, RF 3
BEGIN BULK
NASTRAN FILES = UMF $ CDC AND IBM
ID DEM2035*NASTRAN
APP DMAP*SUBS
BEGIN DISP 09 - DIRECT TRANSIENT RESPONSE ANALYSIS - APR. 1982 $
PRECHK ALL $
FILE UDV=APPEND/TOL=APPEND $
PARAM //*MPY*/CARDNO/0/0 $
GP1 GEOM2,GEOM3,GPL,GEQEXIN,GPDT,CTST,BGPD,T,SIL/S,N,LUSET/ S,N, 
NOGPDT/ALWAYS=-1 $
PLTTRAN BGPD,T,SIL/BGPD,P,SIP/LUSET/S,N,LUSEP $
PURGE USEG,GM,GQ,KAA,BAA,MAA,K4AA,PSA,PSL,EST,ECT,PLTSETX,PLTPAR, 
GPSET,ELSET/NOGPDT $
COND LBL5,NOGPDT $
GP2 GEOM2,GEQEXIN,ECT $
PARAM PCB*/*PRES=///JUMPPLOT $
PURGE PLTSETX,PLTPAR,GPSET,ELSET,JUMPPLOT $
COND P1,JUMPPLOT $
PLTSET PCB*,GEQEXIN,ECT,PLTSETX,PLTPAR,GPSET,ELSET,S,N,NSIL/S,N, 
JUMPPLOT=-1 $
PRTMSG PLTSETX/ $
PARAM //*MPY*/PLTFLG/1/1 $
PARAM //*MPY*/PFILE/0/0 $
COND P1,JUMPPLOT $
PLOT PLTPAR,GPSET,ELSET,CASECC,BGPD,T,GEQEXIN,SIL**,ECT,,/PLOTX1/ 
NSIL/LUSET/S,N,JUMPPLOT/S,N,PLTFLG/S,N,PFILE $
PRTMSG PLOTX1/ $
LABEL P1 $
GP3 GEOM3,GEQEXIN,GEOM2,SLT,GPPT,/NOGRAV $
TAL ECT,EPT,BGPD,T,SIL,GPTT,CTST,EST,GEI,GPCEX,/*/LUSET/S,N,NOSIMP= 
-1/1/S,N,NOGENL=-1/S,N,GENEL $
PURGE K4GG,GPST,OGPT*O,PPG,KGX,K4NN,K4FF,K4AA,MNN,MFF,MAA,BNN,BFF,BAA, 
KGEX/NOSIMP/OPGPT/GENEL $
COND LBL1,NOSIMP
JUMP FINIS $  
LABEL ERROR1 $  
PRTPARM //1/DIRTRO* $  
LABEL ERROR3 $  
PRTPARM //3/DIRTRO* $  
LABEL FINIS $  
PURGE DUMMY/ALWAYS $  
END  $

TIME 3  
DIAG 14  
END  
SUBSTRUCTURE PHASE 3  
PASSWORD = MOLSYN  
SOR (1) = FT19.500 $ CDC AND IBM  
ENDSUBS  
TITLE = TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS  
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QLOAD = ALL  
DISP = ALL  
FORCE = ALL  
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CROD 11 1 11 12  
CROD 12 1 12 13  
CROD 21 1 21 22  
CROD 22 1 22 23  
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CROD 32 1 32 33  
CROD 41 1 41 42  
CROD 42 1 42 43  
CROD 111 1 1 11  
CROD 112 1 2 12  
CROD 113 1 3 13  
CROD 121 1 11 21  
CROD 122 1 12 22  
CROD 123 1 13 23  
CROD 131 1 21 31  
CROD 132 1 22 32  
CROD 133 1 23 33  
CROD 141 1 31 41  
CROD 142 1 32 42  
CROD 143 1 33 43  
CROD 212 1 2 13  
CROD 211 1 2 11  
CROD 221 1 12 21  
CROD 222 1 12 23  
CROD 231 1 22 31  
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CROD 241 1 32 41  
CROD 242 1 32 43  

36
APPENDIX A. (concluded)

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ENDDATA
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11.30.27.UCLP, DDL00948, 0.423KINS.
APPENDIX B. Driver decks and sample bulk data for beam problem of case 1.

NASTRAN FILES = UMF & CDC AND IBM
ID DEM2031*NASTRAN
APP DISP, SUBS
SOL 3, 0
TIME 3
CEND
SUBSTRUCTURE PHASE1
PASSWORD = MOLSYN
SOF(1) = FT17, 500, NEW & CDC AND IBM
NAME = ABASIC
SOFPRINT TOC
ENDSUBS
TITLE = BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
LABEL = SUBSTRUCTURE 1, RUN 1, PHASE 1, RG 2
BEGIN BULK
BAROR 1 1 1 2
BAR 2 1 2 3
BAR 3 1 3 4
BAR 4 1 4 5
BAR 5 1 5 6
BAR 6 1 6 7
BAR 7 1 7 8
BAR 8 1 8 9
BAR 9 1 9 10
BAR 10 1 10 11
GRIDSET
GRID 1 0. 0. 0.
GRID 2 0. 0. 0.
GRID 3 0. 0. 0.
GRID 4 0. 0. 0.
GRID 5 0. 0. 0.
GRID 6 0. 0. 0.
GRID 7 0. 0. 0.
GRID 8 0. 0. 0.
GRID 9 0. 0. 0.
GRID 10 0. 0. 0.
GRID 11 0. 0. 0.
PBAR 1 1 10.0 10.0 0.0 1
MAT 1 1 10.0 6.56 63. 2.591-4
ENDDATA

NASTRAN FILES = UMF & CDC AND IBM
ID DEM2032*NASTRAN
APP DISP, SUBS
SOL 3, 0
TIME 5
CEND
SUBSTRUCTURE PHASE2
PASSWORD = MOLSYN
SOF(1) = FT17, 500, NEW & CDC AND IBM
EQUIV ABASIC, BBASIC
PREFIX B
EQUIV ABASIC, GBASIC
PREFIX G
MREDUCE ABASIC
NAME MA
BOUNDARY 20
FIXED 20
METHOD 1
MREDUCE BBASIC
NAME MB
BOUNDARY 2
APPENDIX B. (concluded)

FIXED 2
METHOD 2
MREDUCE GBASIC
NAME MG
BOUNDARY 3
FIXED 3
METHOD 3
EQUIV MB, MC
PREFIX C
EQUIV MB, MD
PREFIX D
EQUIV ME, ME
PREFIX E
EQUIV MB, MF
PREFIX F
COMBINE MA*MB*MC*MD*ME*MF*MG
NAME ABCDEF
TOLERANCE 0.01
OUTPUT 2, 7, 12
COMPONENT MB
TRANSFORM 2
COMPONENT MC
TRANSFORM 3
COMPONENT MD
TRANSFORM 4
COMPONENT ME
TRANSFORM 5
COMPONENT MF
TRANSFORM 6
COMPONENT MG
TRANSFORM 7
MREDUCE ABCDEF
NAME BEAM
BOUNDARY 20
METHOD 22
OUTPUT 1, 5, 6, 9, 10
SOFPRINT TOC
ENDSUBF
TITLE=BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
SUBTITLE=NASTRAN DEMONSTRATION PROBLEM NO. 2-3-2
LABEL=MODAL REDUCE, COMBINE, MODAL, RECOVERY, RUN2, PHASE2
BEGIN BULK
BDYC 6 50
BDYC 3 40
BDYC 20 30
BDYS 30 126 11
BDYS 40 126 1
BDYS 50 126 1 11
TRANS 2 150.
TRANS 3 250.
TRANS 4 350.
TRANS 5 450.
TRANS 6 550.
TRANS 7 650.
EIGR 1 INV 0 3000.00 10 100
EIGR 2 INV 0 3000.00 10 100
EIGR 3 INV 0 3000.00 10 100
EIGR 22 INV 0 2000.00 40 100
ENDDATA
#
APPENDIX C. Driver decks and sample bulk data for beam problem of case 2.

**NASTRAN FILES = UMF & CDC AND IBM**

**ID** = DEM2031, NASTRAN

**APP DISP** = SUBS

**SOL** = 3, 0

**TIME** = 3

**SEND**

**SUBSTRUCTURE PHASE1**

**PASSWORD = MDSYN**

**SOF (1) = FT17500, NEW & CDC AND IBM**

**NAME = ABASIC**

**SOFRINT TOC**

**ENDSUBS**

**TITLE = BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS**

**LABEL = SUBSTRUCTURE 1, RUN 1, PHASE 1, R6 2**

**BEGIN BULK**

**BAROR**

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**NASTRAN FILES = UMF & CDC AND IBM**

**ID** = DEM2032, NASTRAN

**APP DISP** = SUBS

**SOL** = 3, 0

**TIME** = 3

**SEND**

**SUBSTRUCTURE PHASE 2**

**PASSWORD = MDSYN**

**SOF (1) = FT17500, NEW & CDC AND IBM**

**EQUIV ABASIC, CBASIC**

**PREFIX B**

**EQUIV ABASIC, DBASIC**

**PREFIX C**

**EQUIV ABASIC, EBASIC**

**PREFIX D**

**EQUIV ABASIC, FBASIC**

**PREFIX E**

**EQUIV ABASIC, GBASIC**

**PREFIX F**

**EQUIV ABASIC, HBASIC**

**PREFIX G**

**HREDUCE ABASIC**

**NAME MA**

40
BOUNDARY 20
FIXED 20
METHOD 1
MREDUCE EBASIC
NAME MB
BOUNDARY 2
FIXED 2
METHOD 2
MREDUCE EBASIC
NAME MC
BOUNDARY 7
FIXED 7
METHOD 2
MREDUCE EBASIC
NAME MD
BOUNDARY 8
FIXED 8
METHOD 2
MREDUCE EBASIC
NAME ME
BOUNDARY 9
FIXED 9
METHOD 2
MREDUCE EBASIC
NAME MF
BOUNDARY 11
FIXED 11
METHOD 2
MREDUCE EBASIC
NAME MG
BOUNDARY 3
FIXED 3
METHOD 3
COMBINE MB, MB
NAME AB
TOLERANCE 0.01
OUTPUT 2, 7, 12
COMPONENT MD
TRANSFORM 2
MREDUCE AB
NAME MAB
BOUNDARY 10
FIXED 10
METHOD 22
COMBINE MAB, MB
NAME ABC
TOLERANCE 0.01
OUTPUT 2, 7, 12
COMPONENT MC
TRANSFORM 3
MREDUCE ABC
NAME MABC
BOUNDARY 21
FIXED 21
METHOD 22
COMBINE MABC, MB
NAME ABCD
TOLERANCE 0.01
OUTPUT 2, 7, 12
COMPONENT MD
TRANSFORM 4
MREDUCE ABCD
NAME MABCD
BOUNDARY 22
FIXED 22
METHOD 22
COMBINE MBCDEF,ME
NAME ABCDE
TOLERANCE 0.01
OUTPUT 2*7,12
COMPONENT ME
TRANSFORM 5
MREDUCE ABCDE
NAME MABCDFE
BOUNDARY 23
FIXED 23
METHOD 22
COMBINE MABCDEF, MF
NAME ABCD EF
TOLERANCE 0.01
OUTPUT 2*7,12
COMPONENT MF
TRANSFORM 6
MREDUCE ABCDEF
NAME MABCDEF
BOUNDARY 24
FIXED 24
METHOD 22
COMBINE MABCDEF, MG
NAME ABCDEFG
TOLERANCE 0.01
OUTPUT 2*7,12
COMPONENT MG
TRANSFORM 7
MREDUCE ABCDEFG
NAME BEAM
BOUNDARY 20
METHOD 22
OUTPUT 1*5, 8, 9, 10
STOP
PRINT TOC
ENDSUB
TITLE BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
SUBTITLE NASTRAN DEMONSTRATION PROBLEM NO. 2-3-2
LABEL=MODAL REDUCE,COMBINE,MODAL,RECOVRY, RUN2,P8 S52
BEGIN BULK
BDYC  7  CBASIC  50
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BDYC 21  CBASIC  30
BDYC 22  DBASIC  30
BDYC 23  EBASIC  30
BDYC 24  FBASIC  30
BDYC 11  FBASIC  50
BDYC  8  DBASIC  50
BDYC 10  BBASIC  30
BDYC 15  CBASIC  40
BDYC  2  BBASIC  50
BDYC 32  GBASIC  40
BDYC 30  ABASIC  30
BDYS 30  126  11
BDYS 40  126  1
BDYS 50  126  1
TRANS  4  0  0  0  0  0  0  300.0  0.0  0.0  0.0  300.0  0.0  1.0  +T4
TRANS  6  0  0  0  0  0  0  500.0  0.0  0.0  0.0  500.0  0.0  1.0  +T6
TRANS  2  100.0  0.0  0.0  0.0  100.0  0.0  1.0  +T2
TRANS  3  0  0  0  0  0  0  200.0  0.0  0.0  200.0  0.0  1.0  +T3
TRANS  5  0  0  0  0  0  0  400.0  0.0  0.0  400.0  0.0  1.0  +T5
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42
APPENDIX C. (concluded)

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<td>INV</td>
<td>0.0</td>
<td>3000.00</td>
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<td>10</td>
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<td>E3</td>
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<tr>
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<td>INV</td>
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<td>E22</td>
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APPENDIX D. Driver decks and sample bulk data for beam problem of case 3.

NASTRAN FILES = UMF $ CDC AND IBM
ID DEM2031.NASTRAN
APP DISP.SUBS
SOL 3,0
TIME 3
CEND
SUBSTRUCTURE PHASE1
PASSWORD = MDSLSTN
SOF(1) = FT17,YU00 $ CDC AND IBM
NAME = ABASIC
SOPPRINT TOC
ENDSUBS
TITLE = BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
LABEL = SUBSTRUCTURE 1, RUN 1, PHASE 1, R6 2
BEGIN BULK 10,0 10,0 0,0 1
BARR 1 1 1 2
BARR 2 1 1 2 3
BARR 3 1 1 3 4
BARR 4 1 1 4 5
BARR 5 1 1 5 6
BARR 6 1 1 6 7
BARR 7 1 1 7 8
BARR 8 1 1 8 9
BARR 9 1 1 9 10
BARR 10 1 1 10 11
GRIDSET 345
GRID 1 0,0 0,0 0,0
GRID 2 10,0 0,0 0,0
GRID 3 20,0 0,0 0,0
GRID 4 30,0 0,0 0,0
GRID 5 40,0 0,0 0,0
GRID 6 50,0 0,0 0,0
GRID 7 60,0 0,0 0,0
GRID 8 70,0 0,0 0,0
GRID 9 80,0 0,0 0,0
GRID 10 90,0 0,0 0,0
GRID 11 100,0 0,0 0,0
PBAR 1 1 0,56 63,0 2,591-4
ENDDATA

NASTRAN FILES = UMF $ CDC AND IBM
ID DEM2032.NASTRAN
APP DISP.SUBS
SOL 3,0
TIME 10
CEND
SUBSTRUCTURE PHASE2
PASSWORD = MDSLSTN
SOF(1) = FT17,YU00 $ CDC AND IBM
EQUIV ABASIC,BBASIC
PREFIX B
EQUIV ABASIC,CBASIC
PREFIX C
EQUIV ABASIC,DBASIC
PREFIX D
EQUIV ABASIC,EBASIC
PREFIX E
EQUIV ABASIC,FBASIC
PREFIX F
EQUIV ABASIC,GBASIC
PREFIX G
MREDUCE ABASIC
NAME MA
BOUNDARY 20
FIXED 20
METHOD 1
MREDUCE E BASIC
NAME MB
BOUNDARY 2
FIXED 2
METHOD 2
MREDUCE E BASIC
NAME MC
BOUNDARY 7
FIXED 7
METHOD 2
MREDUCE E BASIC
NAME MD
BOUNDARY 8
FIXED 8
METHOD 2
MREDUCE E BASIC
NAME ME
BOUNDARY 9
FIXED 9
METHOD 2
MREDUCE E BASIC
NAME MG
BOUNDARY 3
FIXED 3
METHOD 3
COMBINE MA+MB
NAME AB
TOLERANCE 0.01
OUTPUT 2, 7, 12
COMPONENT MB
TRANSFORM 2
MREDUCE AB
NAME MBA
BOUNDARY 10
FIXED 10
METHOD 22
COMBINE MC+MD
NAME CD
TOLERANCE 0.01
OUTPUT 2, 7, 12
COMPONENT MD
TRANSFORM 2
MREDUCE CD
NAME MCD
BOUNDARY 15
FIXED 15
METHOD 22
COMBINE ME+MF
NAME EF
TOLERANCE 0.01
OUTPUT 2, 7, 12
COMPONENT MF
TRANSFORM 2
MREDUCE EF
NAME MEF
BOUNDARY 25
FIXED 25
METHOD 22
COMBINE MBA+MCD
NAME ABCD
TOLERANCE 0.01
OUTPUT 27,12
COMPONENT MCD
TRANSFORM 3
MREDUCE ABCD
NAME MABCD
BOUNDARY 30
FIXED 30
METHOD 25
COMBINE MEF*MG
NAME EFG
TOLERANCE 0.01
OUTPUT 27,12
COMPONENT MG
TRANSFORM 3
MREDUCE EFG
NAME MEFG
BOUNDARY 35
FIXED 35
METHOD 25
COMBINE MABCD*MCEF
NAME ABCDEFG
TOLERANCE 0.01
OUTPUT 27,12
COMPONENT MEF
TRANSFORM 5
MREDUCE ABCDEFG
NAME BEAM
BOUNDARY 20
METHOD 25
OUTPUT 1,5,6,9,10
SOPRINT TOC
ENDSUBS
TITLE=BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
SUBTITLE=NASTRAN DEMONSTRATION PROBLEM NO. 2-3-2
LABEL=MODAL REDUCE,COMBINE,MODAL,RECOVERY,RUN2,PHASE2
BEGIN BULK
BDY 30 DBASIC 30
BDY 39 EBASIC 40
BDY 7 DBASIC 50
BDY 9 EBASIC 50
BDY 11 FBASIC 50
BDY 25 EBASIC 40
BDY 8 DBASIC 50
BDY 10 BBASIC 30
BDY 15 CBASIC 40
BDY 22 BBASIC 40
BDY 33 EBASIC 40
BDY 20 ABASIC 30
BDYS 30 126 11
BDYS 40 126 1
BDYS 50 126 1
TRANS 250.0 0.0 0.0 100.0 0.0 1
+T2
TRANS 3 0.0 0.0 200.0 0.0 1
+T3
TRANS 5 0.0 0.0 400.0 0.0 1
+T5
TRANS 7 0.0 0.0 600.0 0.0 1
+T7
EI 1 INV 3000.00 10
+EI
EI 2 INV 3000.00 10
+EI
END BULK

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APPENDIX D. (concluded)

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<td>3000.00</td>
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<tr>
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<td>INV</td>
<td>.0</td>
<td>2000.0</td>
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</table>

ENDDATA
This report compares the accuracy between NASTRAN modal synthesis, full structure NASTRAN and several other modal synthesis results (truss only). The results are based on a truss or beam having redundant or point interface connections. Each component substructure is reduced to modal and boundary degrees of freedom prior to the substructure combine operation. The combination structure, formulated in terms of the component modes, is also reduced to modal degrees of freedom for solution by the transient analysis rigid format.