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

August 1987
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

Submitted by the
Old Dominion University Research Foundation
P.O. Box 6369
Norfolk, Virginia 23508

August 1987
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 tree interface modes. The solution is carried out for an applied dynamic load down as far as recovery of 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

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical frame width (see fig. 1(b))</td>
<td>$a = 1.015 \text{ m (40&quot;)}$</td>
</tr>
<tr>
<td>Typical frame height (see fig. 1(b))</td>
<td>$h = 0.762 \text{ m (30&quot;)}$</td>
</tr>
<tr>
<td>Cross-sectional area of members</td>
<td>$A = 1.935 \text{ cm}^2 (0.3 \text{ in}^2)$</td>
</tr>
<tr>
<td>Young's modulus</td>
<td>$E = 1.422 \times 10^4 \frac{\text{Kg}}{\text{m}^2} (10^7 \text{ psi})$</td>
</tr>
<tr>
<td>Density</td>
<td>$\rho = 272.517 \frac{\text{Kg-sec}^2}{\text{m}^4}$ $(2.5 \times 10^{-4} \frac{\text{lbf-sec}^2}{\text{in}^4})$</td>
</tr>
<tr>
<td>Transient loads</td>
<td>$P_{42} = 2.2 \times 10^3 \text{Kg}(10^3 \text{lbf}) \ 0 &lt; t &lt; 0.12s$</td>
</tr>
<tr>
<td></td>
<td>$0 \quad t &gt; 0.12s$</td>
</tr>
</tbody>
</table>
### Table II. Beam Geometric and Material Properties

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typical component length (see fig. 3(b))</td>
<td>( l = 2.54 \text{ m (100&quot;)} )</td>
</tr>
<tr>
<td>Cross section of beam</td>
<td>( A = 3.613 \text{ cm}^2 (0.56 \text{ in}^2) )</td>
</tr>
<tr>
<td>Young's modulus</td>
<td>( E = 1.422 \times 10^4 \frac{\text{Kg}}{\text{m}^2} (10^7 \text{psi}) )</td>
</tr>
<tr>
<td>Density</td>
<td>( \rho = 282.437 \frac{\text{Kg-sec}^2}{\text{m}^4} ) ( (2.591 \times 10^{-4} \frac{\text{lbf-sec}^2}{\text{in}^4}) )</td>
</tr>
<tr>
<td>Total beam length</td>
<td>( L = 15.78 \text{ m (700&quot;)} )</td>
</tr>
</tbody>
</table>
Table III. Frequency for Full Truss and Percent Error in Frequency for Two Modal Synthesis Models Using 12 Degrees of Freedom

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Full Truss (Hz)</th>
<th>Free Interface (%)</th>
<th>Fixed Interface (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65.7771</td>
<td>29.88</td>
<td>0.0015</td>
</tr>
<tr>
<td>2</td>
<td>136.3306</td>
<td>4.32</td>
<td>0.0022</td>
</tr>
<tr>
<td>3</td>
<td>175.5505</td>
<td>21.9</td>
<td>0.0314</td>
</tr>
<tr>
<td>4</td>
<td>202.7780</td>
<td>7.35</td>
<td>0.0198</td>
</tr>
<tr>
<td>5</td>
<td>260.3387</td>
<td>3.49</td>
<td>0.0536</td>
</tr>
<tr>
<td>6</td>
<td>316.2614</td>
<td>5.12</td>
<td>0.0227</td>
</tr>
<tr>
<td>7</td>
<td>334.1522</td>
<td>61.41</td>
<td>4.21</td>
</tr>
<tr>
<td>8</td>
<td>347.1668</td>
<td>142.05</td>
<td>6.439</td>
</tr>
<tr>
<td>9</td>
<td>388.1286</td>
<td>183.78</td>
<td>0.97</td>
</tr>
</tbody>
</table>
Table IV. Frequency for Full Truss and Percent Error in Frequency for Two Modal Synthesis Models Using 20 Degrees of Freedom

| Mode No. | Full Truss (Hz) | Free Interface (%) | Fixed Interface (%) | 3 Components
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65.7771</td>
<td>19.23</td>
<td>0.00074</td>
<td>0.00351</td>
</tr>
<tr>
<td>2</td>
<td>136.3306</td>
<td>2.82</td>
<td>0.00044</td>
<td>-0.03425</td>
</tr>
<tr>
<td>3</td>
<td>175.5505</td>
<td>8.2</td>
<td>0.0087</td>
<td>-0.00915</td>
</tr>
<tr>
<td>4</td>
<td>202.7780</td>
<td>2.67</td>
<td>0.0087</td>
<td>0.02232</td>
</tr>
<tr>
<td>5</td>
<td>260.3387</td>
<td>2.23</td>
<td>0.0091</td>
<td>-0.00355</td>
</tr>
<tr>
<td>6</td>
<td>316.2614</td>
<td>2.0</td>
<td>0.0078</td>
<td>-0.03588</td>
</tr>
<tr>
<td>7</td>
<td>334.1522</td>
<td>0.65</td>
<td>0.75</td>
<td>0.00521</td>
</tr>
<tr>
<td>8</td>
<td>347.1668</td>
<td>3.9</td>
<td>0.088</td>
<td>0.00469</td>
</tr>
<tr>
<td>9</td>
<td>388.1286</td>
<td>0.3</td>
<td>0.23</td>
<td>-0.01105</td>
</tr>
<tr>
<td>10</td>
<td>394.1834</td>
<td>0.3</td>
<td>0.1</td>
<td>-0.00029</td>
</tr>
<tr>
<td>11</td>
<td>414.9853</td>
<td>1.9</td>
<td>0.18</td>
<td>-0.00924</td>
</tr>
<tr>
<td>12</td>
<td>451.2226</td>
<td>8.57</td>
<td>0.078</td>
<td>-0.00182</td>
</tr>
<tr>
<td>13</td>
<td>466.3475</td>
<td>8.5</td>
<td>0.14</td>
<td>0.00130</td>
</tr>
<tr>
<td>14</td>
<td>504.7402</td>
<td>7.8</td>
<td>0.41</td>
<td>0.01524</td>
</tr>
<tr>
<td>15</td>
<td>507.2363</td>
<td>39.7</td>
<td>1.32</td>
<td>0.03394</td>
</tr>
<tr>
<td>16</td>
<td>537.3632</td>
<td>58.4</td>
<td>2.0</td>
<td>0.01038</td>
</tr>
<tr>
<td>17</td>
<td>575.3048</td>
<td>114.65</td>
<td>0.7</td>
<td>0.00005</td>
</tr>
<tr>
<td>Full Truss (Hz)</td>
<td>Fixed Interface</td>
<td>Free Interface</td>
<td>Full Truss (Hz)</td>
<td>Fixed Interface</td>
</tr>
<tr>
<td>----------------</td>
<td>-----------------</td>
<td>----------------</td>
<td>----------------</td>
<td>-----------------</td>
</tr>
<tr>
<td>1</td>
<td>65.7771</td>
<td>0.00035</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>136.3306</td>
<td>0.00037</td>
<td>19</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>275.5105</td>
<td>0.00017</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>292.7780</td>
<td>0.00039</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>260.3387</td>
<td>0.00067</td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>366.7214</td>
<td>0.0029</td>
<td>23</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>394.1522</td>
<td>0.0029</td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>388.1286</td>
<td>0.006</td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>394.1834</td>
<td>0.003</td>
<td>26</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>414.9853</td>
<td>0.004</td>
<td>27</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>451.2226</td>
<td>0.006</td>
<td>28</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>499.9602</td>
<td>0.006</td>
<td>29</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>507.3632</td>
<td>0.007</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>537.3048</td>
<td>0.007</td>
<td>31</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>575.3048</td>
<td>0.008</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>16</td>
<td>597.3632</td>
<td>0.007</td>
<td>33</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>600.7099</td>
<td>0.010</td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>18</td>
<td>628.5009</td>
<td>0.013</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>19</td>
<td>659.4299</td>
<td>0.015</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>668.5250</td>
<td>0.016</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>678.8447</td>
<td>0.018</td>
<td>38</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>681.8918</td>
<td>0.020</td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>690.5944</td>
<td>0.022</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>750.0817</td>
<td>0.024</td>
<td>41</td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>770.3</td>
<td>0.026</td>
<td>42</td>
<td></td>
</tr>
</tbody>
</table>

Table V: Frequency for Full Truss and Percent Error in Frequency for Two Modal Synthesis Models Using 28 Degrees of Freedom
Table VI. Frequency for Full Truss and Percent Error in Frequency for Two Modal Synthesis Models Using 36 Degrees of Freedom

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Full Truss (Hz)</th>
<th>Free Interface (%)</th>
<th>Fixed Interface (%)</th>
<th>Mode No.</th>
<th>Full Truss (Hz)</th>
<th>Free Interface (%)</th>
<th>Fixed Interface (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>65.7771</td>
<td>6.71</td>
<td>0.00023</td>
<td>18</td>
<td>600.7099</td>
<td>0.011</td>
<td>0.0565</td>
</tr>
<tr>
<td>2</td>
<td>136.3306</td>
<td>0.809</td>
<td>0.00015</td>
<td>19</td>
<td>628.5009</td>
<td>0.183</td>
<td>0.0151</td>
</tr>
<tr>
<td>3</td>
<td>175.5505</td>
<td>1.185</td>
<td>0.00034</td>
<td>20</td>
<td>659.4299</td>
<td>0.029</td>
<td>0.0154</td>
</tr>
<tr>
<td>4</td>
<td>202.7780</td>
<td>0.84</td>
<td>0.00252</td>
<td>21</td>
<td>668.5250</td>
<td>1.574</td>
<td>0.1027</td>
</tr>
<tr>
<td>5</td>
<td>260.3387</td>
<td>0.713</td>
<td>0.00161</td>
<td>22</td>
<td>678.8447</td>
<td>0.495</td>
<td>0.021</td>
</tr>
<tr>
<td>6</td>
<td>316.2614</td>
<td>0.689</td>
<td>0.0019</td>
<td>23</td>
<td>681.8918</td>
<td>1.650</td>
<td>0.00062</td>
</tr>
<tr>
<td>7</td>
<td>334.1522</td>
<td>0.092</td>
<td>0.0676</td>
<td>24</td>
<td>690.5944</td>
<td>1.085</td>
<td>0.0622</td>
</tr>
<tr>
<td>8</td>
<td>347.1668</td>
<td>1.096</td>
<td>0.0159</td>
<td>25</td>
<td>750.0817</td>
<td>0.220</td>
<td>0.0673</td>
</tr>
<tr>
<td>9</td>
<td>388.1286</td>
<td>0.072</td>
<td>0.0301</td>
<td>26</td>
<td>757.5138</td>
<td>0.202</td>
<td>0.186</td>
</tr>
<tr>
<td>10</td>
<td>394.1834</td>
<td>0.012</td>
<td>0.00822</td>
<td>27</td>
<td>788.2198</td>
<td>0.642</td>
<td>0.552</td>
</tr>
<tr>
<td>11</td>
<td>414.9853</td>
<td>0.651</td>
<td>0.0244</td>
<td>28</td>
<td>792.7149</td>
<td>4.107</td>
<td>0.0786</td>
</tr>
<tr>
<td>12</td>
<td>451.2226</td>
<td>1.969</td>
<td>0.00734</td>
<td>29</td>
<td>824.4077</td>
<td>3.734</td>
<td>0.149</td>
</tr>
<tr>
<td>13</td>
<td>466.3475</td>
<td>0.592</td>
<td>0.00442</td>
<td>30</td>
<td>840.6797</td>
<td>2.215</td>
<td>0.0964</td>
</tr>
<tr>
<td>14</td>
<td>504.7402</td>
<td>0.039</td>
<td>0.0139</td>
<td>31</td>
<td>854.6771</td>
<td>7.767</td>
<td>0.1146</td>
</tr>
<tr>
<td>15</td>
<td>507.2363</td>
<td>0.047</td>
<td>0.0255</td>
<td>32</td>
<td>883.3126</td>
<td>9.033</td>
<td>0.268</td>
</tr>
<tr>
<td>16</td>
<td>537.3632</td>
<td>0.443</td>
<td>0.160</td>
<td>33</td>
<td>909.3136</td>
<td>41.970</td>
<td>0.794</td>
</tr>
<tr>
<td>17</td>
<td>575.3048</td>
<td>0.147</td>
<td>0.0730</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table VII. Transient Response and Percent Error in Displacement

<table>
<thead>
<tr>
<th>Grid Pts. Times</th>
<th>Full Truss</th>
<th>B Substr.</th>
<th>F-B % F</th>
<th>Full Truss</th>
<th>B. Substr.</th>
<th>F-B % F</th>
<th>Full Truss</th>
<th>B Substr.</th>
<th>F-B % F</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>28</td>
<td>41</td>
<td>0.0</td>
<td>29</td>
<td>42</td>
<td>0.0</td>
<td>30</td>
<td>43</td>
<td>0.0</td>
</tr>
<tr>
<td>0.0015</td>
<td>0.4786243</td>
<td>0.4785015</td>
<td>0.02566</td>
<td>0.499332</td>
<td>0.4993054</td>
<td>0.00533</td>
<td>0.4786243</td>
<td>0.4785015</td>
<td>0.02566</td>
</tr>
<tr>
<td>0.0030</td>
<td>2.070906</td>
<td>2.070847</td>
<td>0.00285</td>
<td>2.089915</td>
<td>2.089938</td>
<td>-0.00110</td>
<td>2.070906</td>
<td>2.070847</td>
<td>0.00285</td>
</tr>
<tr>
<td>0.0045</td>
<td>4.794056</td>
<td>4.793882</td>
<td>0.00363</td>
<td>4.813719</td>
<td>4.813558</td>
<td>0.00334</td>
<td>4.794056</td>
<td>4.793882</td>
<td>0.00363</td>
</tr>
<tr>
<td>0.0060</td>
<td>8.662573</td>
<td>8.662563</td>
<td>0.00012</td>
<td>8.682871</td>
<td>8.683060</td>
<td>-0.00218</td>
<td>8.662573</td>
<td>8.662563</td>
<td>0.00012</td>
</tr>
<tr>
<td>0.0075</td>
<td>13.65921</td>
<td>13.65901</td>
<td>0.00146</td>
<td>13.67806</td>
<td>13.67781</td>
<td>0.00183</td>
<td>13.65921</td>
<td>13.65901</td>
<td>0.00146</td>
</tr>
<tr>
<td>0.0090</td>
<td>19.79589</td>
<td>19.79587</td>
<td>0.00010</td>
<td>19.81609</td>
<td>19.81619</td>
<td>-0.00050</td>
<td>19.79589</td>
<td>19.79587</td>
<td>0.00010</td>
</tr>
<tr>
<td>0.0105</td>
<td>27.07146</td>
<td>27.07133</td>
<td>0.00048</td>
<td>27.09119</td>
<td>27.09122</td>
<td>-0.00011</td>
<td>27.07146</td>
<td>27.07133</td>
<td>0.00048</td>
</tr>
<tr>
<td>0.0120</td>
<td>35.47588</td>
<td>35.47573</td>
<td>0.00042</td>
<td>35.49501</td>
<td>35.49476</td>
<td>0.00070</td>
<td>35.47588</td>
<td>35.47573</td>
<td>0.00042</td>
</tr>
</tbody>
</table>
Table VIII. The Axial Force in Elements of B Substructure

<table>
<thead>
<tr>
<th>Times</th>
<th>Element No.</th>
<th>111</th>
<th>112</th>
<th>113</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.003</td>
<td>235.1038</td>
<td>282.6908</td>
<td>235.1038</td>
<td></td>
</tr>
<tr>
<td>0.006</td>
<td>252.9327</td>
<td>304.9388</td>
<td>252.9327</td>
<td></td>
</tr>
<tr>
<td>0.009</td>
<td>179.1082</td>
<td>254.5373</td>
<td>179.1082</td>
<td></td>
</tr>
<tr>
<td>0.012</td>
<td>137.4126</td>
<td>223.7419</td>
<td>137.4126</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Times</th>
<th>Element No.</th>
<th>141</th>
<th>142</th>
<th>143</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>0.003</td>
<td>185.0618</td>
<td>951.0315</td>
<td>185.0618</td>
<td></td>
</tr>
<tr>
<td>0.006</td>
<td>199.0282</td>
<td>1021.000</td>
<td>199.0282</td>
<td></td>
</tr>
<tr>
<td>0.009</td>
<td>177.9509</td>
<td>1021.209</td>
<td>177.9509</td>
<td></td>
</tr>
<tr>
<td>0.012</td>
<td>159.4311</td>
<td>959.688</td>
<td>159.4311</td>
<td></td>
</tr>
</tbody>
</table>
Table IX. Percent Frequency Error Using 62 Degrees of Freedom

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Full Beam (Hz)</th>
<th>Case 1 (Hz)</th>
<th>(%)</th>
<th>Case 2 (Hz)</th>
<th>(%)</th>
<th>Case 3 (Hz)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15.13289</td>
<td>15.13290</td>
<td>0.0000665</td>
<td>15.13291</td>
<td>0.000132</td>
<td>15.13293</td>
<td>0.000264</td>
</tr>
<tr>
<td>2</td>
<td>41.69619</td>
<td>41.69637</td>
<td>0.000432</td>
<td>41.69685</td>
<td>0.001583</td>
<td>41.69673</td>
<td>0.001295</td>
</tr>
<tr>
<td>3</td>
<td>81.70638</td>
<td>81.70777</td>
<td>0.001701</td>
<td>81.71215</td>
<td>0.007062</td>
<td>81.71170</td>
<td>0.006511</td>
</tr>
<tr>
<td>4</td>
<td>135.0071</td>
<td>135.0132</td>
<td>0.004518</td>
<td>135.0395</td>
<td>0.023999</td>
<td>135.0395</td>
<td>0.023999</td>
</tr>
<tr>
<td>5</td>
<td>140.3144</td>
<td>140.3154</td>
<td>0.000713</td>
<td>140.3343</td>
<td>0.014182</td>
<td>140.3182</td>
<td>0.002708</td>
</tr>
<tr>
<td>6</td>
<td>201.5912</td>
<td>201.6091</td>
<td>0.008879</td>
<td>201.7213</td>
<td>0.064537</td>
<td>201.6405</td>
<td>0.015576</td>
</tr>
<tr>
<td>7</td>
<td>280.5578</td>
<td>280.5662</td>
<td>0.002994</td>
<td>280.6451</td>
<td>0.031116</td>
<td>280.7314</td>
<td>0.061877</td>
</tr>
<tr>
<td>8</td>
<td>281.4407</td>
<td>281.4865</td>
<td>0.016273</td>
<td>281.6908</td>
<td>0.088864</td>
<td>281.8770</td>
<td>0.015502</td>
</tr>
<tr>
<td>9</td>
<td>374.5384</td>
<td>374.5812</td>
<td>0.011427</td>
<td>374.6278</td>
<td>0.023869</td>
<td>374.8512</td>
<td>0.083516</td>
</tr>
<tr>
<td>10</td>
<td>420.6751</td>
<td>420.6842</td>
<td>0.002163</td>
<td>421.1304</td>
<td>0.108231</td>
<td>421.0158</td>
<td>0.080989</td>
</tr>
<tr>
<td>11</td>
<td>480.8666</td>
<td>480.9641</td>
<td>0.020276</td>
<td>482.2726</td>
<td>0.292389</td>
<td>482.8321</td>
<td>0.408741</td>
</tr>
<tr>
<td>12</td>
<td>560.5507</td>
<td>560.6017</td>
<td>0.009098</td>
<td>561.7351</td>
<td>0.211292</td>
<td>561.4299</td>
<td>0.156846</td>
</tr>
<tr>
<td>13</td>
<td>600.4075</td>
<td>600.6184</td>
<td>0.035126</td>
<td>605.3069</td>
<td>0.816012</td>
<td>604.0111</td>
<td>0.600192</td>
</tr>
<tr>
<td>14</td>
<td>700.1585</td>
<td>700.2570</td>
<td>0.014068</td>
<td>701.7052</td>
<td>0.220907</td>
<td>703.3938</td>
<td>0.462081</td>
</tr>
<tr>
<td>15</td>
<td>733.1426</td>
<td>733.6937</td>
<td>0.075169</td>
<td>745.0415</td>
<td>1.622999</td>
<td>740.1181</td>
<td>0.951452</td>
</tr>
<tr>
<td>16</td>
<td>839.4147</td>
<td>839.5912</td>
<td>0.021027</td>
<td>845.1065</td>
<td>0.678068</td>
<td>840.3091</td>
<td>0.106550</td>
</tr>
<tr>
<td>17</td>
<td>879.0530</td>
<td>880.5704</td>
<td>0.172618</td>
<td>929.3795</td>
<td>5.725081</td>
<td>912.3958</td>
<td>3.793036</td>
</tr>
</tbody>
</table>
Table IX. Percent Frequency Error Using 62 Degrees of Freedom (concluded)

<table>
<thead>
<tr>
<th>Mode No.</th>
<th>Full Beam (Hz)</th>
<th>Case 1 (Hz)</th>
<th>(%)</th>
<th>Case 2 (Hz)</th>
<th>(%)</th>
<th>Case 3 (Hz)</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>978.2478</td>
<td>978.7669</td>
<td>0.053064</td>
<td>1000.558</td>
<td>2.280629</td>
<td>993.7466</td>
<td>1.584343</td>
</tr>
<tr>
<td>19</td>
<td>1038.119</td>
<td>1042.146</td>
<td>0.387913</td>
<td></td>
<td></td>
<td>1119.255</td>
<td>7.815674</td>
</tr>
<tr>
<td>20</td>
<td>1116.602</td>
<td>1117.016</td>
<td>0.037076</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>1210.321</td>
<td>1222.255</td>
<td>0.986019</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>1254.366</td>
<td>1254.961</td>
<td>0.047434</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>1391.513</td>
<td>1392.356</td>
<td>0.060582</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>1395.636</td>
<td>1400.455</td>
<td>0.345291</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>1527.959</td>
<td>1529.241</td>
<td>0.083903</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>1594.042</td>
<td>1617.311</td>
<td>1.459748</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>1663.636</td>
<td>1665.641</td>
<td>0.120519</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>1798.475</td>
<td>1801.4451</td>
<td>0.165140</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>1805.515</td>
<td>1849.961</td>
<td>2.461680</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>1932.408</td>
<td>1941.881</td>
<td>0.490217</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>2030.027</td>
<td>2070.290</td>
<td>1.983373</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>34</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. Substructure Formulation Tree and Solution Sequence
(a) Total beam model.

(b) Representative finite element model of any component.

(c) Case 1 - All components combined simultaneously.

(d) Case 2 - Components combined sequentially.

(e) Case 3 - Components combined in pairs. Pairs then combined sequentially.

Figure 3. Total Beam Model and Various Subdivided Representations.
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 9. Comparison of Methods with Frequency Error of 1.0%.
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 PHASE1
PASSWORD = MOLSYN
SOF(1) = FTLY,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
CROD 1 1 1 2
CROD 11 1 11 12
CROD 12 1 12 13
CROD 21 1 21 22
CROD 22 1 22 23
CROD 31 1 31 32
CROD 32 1 32 33
CROD 41 1 41 42
CROD 42 1 42 43
CROD 51 1 51 52
CROD 52 1 52 53
CROD 111 1 11 12
CROD 112 1 12 13
CROD 113 1 13 14
CROD 122 1 12 13
CROD 123 1 13 14
CROD 131 1 21 22
CROD 132 1 22 23
CROD 133 1 23 24
CROD 141 1 31 41
CROD 142 1 32 42
CROD 143 1 33 43
CROD 151 1 41 51
CROD 152 1 42 52
CROD 153 1 43 53
CROD 212 1 22 23
CROD 211 1 21 22
CROD 222 1 22 23
CROD 231 1 23 24
CROD 242 1 24 25
CROD 242 1 25 26
CROD 251 1 25 26
CROD 252 1 25 26
GROSET
GRID 1 . 0 -30.0 . 0
GRID 2 . 0 30.0 . 0
GRID 3 . 0 30.0 . 0
GRID 11 40.0 -30.0 . 0
GRID 12 40.0 30.0 . 0
GRID 13 40.0 30.0 . 0
GRID 21 80.0 -30.0 . 0
GRID 22 80.0 30.0 0.0
GRID 23 80.0 30.0 0.0
GRID 31 120.0 -30.0 0.0
GRID 32 120.0 30.0 0.0
GRID 33 160.0 -30.0 0.0
GRID 41 160.0 30.0 0.0
GRID 42 160.0 30.0 0.0
GRID 43 200.0 -30.0 0.0
GRID 51 200.0 30.0 0.0
GRID 52 200.0 30.0 0.0
GRID 53 200.0 30.0 0.0
MAT 1 10.0E+6 0.3 2.5E-4
PROD 1
ENDDATA

NASTRAN FILES = UMF $ CDC AND IBM
ID = 0EM2032+NASTRAN
APP DISP = SUBS
SOL 2,0
TIME 3
END
SUBSTRUCTURE PHASE1
PASSWORD = MOLSYN
SOF(1) = FT19,500 $ CDC AND IBM
NAME = BBASIC
SOFPRINT TOC
ENDSUBS
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
GRID 1 1 1 2
GRID 2 1 1 3
GRID 3 1 2 4
GRID 4 2 1 4
GRID 5 1 3 4
GRID 6 1 4 4
GRID 7 2 1 4
GRID 8 2 2 4
GRID 9 2 3 4
GRID 10 2 4 4
GRID 11 3 1 4
GRID 12 3 2 4
GRID 13 3 3 4
GRID 14 3 4 4
GRID 15 4 1 4
GRID 16 4 2 4
GRID 17 4 3 4
GRID 18 4 4 4
GRID 19 5 1 4
GRID 20 5 2 4
GRID 21 5 3 4
GRID 22 5 4 4
GRID 23 6 1 4
GRID 24 6 2 4
GRID 25 6 3 4
GRID 26 6 4 4
GROSET 1
GRID 2 30.0 0.0 0.0
GRID 3 -30.0 0.0 0.0
GRID 4 30.0 40.0 0.0
GRID 5 0.0 40.0 0.0
3456
GRID 13  -30.0  40.0  0
GRID 21  30.0  80.0  0
GRID 22   0  80.0  0
GRID 23  -30.0  80.0  0
GRID 32  30.0  120.0  0
GRID 33  -30.0  120.0  0
GRID 41  30.0  160.0  0
GRID 42   0  160.0  0
GRID 43  -30.0  160.0  0
MAT1 1 10.0+6 1   3   2.5-4
PROD 1
ENDDATA

& NASTRAN FILES = UMF & CDC AND IBM
ID DEM2033,NASTRAN
APP Disp, SUBS
SOL 3,0
TIME 5
END
SUBSTRUCTURE PHASE2
PASSWORD = MDLSYN
SOF(1) = FT19+500 & CDC AND IBM
OPTIONS K,M,P
SOFPRINT TOC
MREDUCE ABASIC
NAME MA
BOUNDARY 5
FIXED 5
METHOD 19
OUTPUT 1,5,6,9,10
SOFPRINT TOC
MREDUCE CBASIC
NAME MB
BOUNDARY 4
FIXED 4
METHOD 29
OUTPUT 1,5,6,9,10
SOFPRINT TOC
MREDUCE CBASIC
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
TRANSFORM 20
COMPONENT MC
TRANSFORM 40
SOFPRINT TOC
MREDUCE MCOMB
NAME RTRUSS
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
BDYC  42  BBASIC  42
BDYC  4  BBASIC  3
BDYC  3  ABASIC  1
BDYC  7  CBASIC  2
BDYS  1  12  31  32  33
BDYS  3  12  1  2  3
BDYS  2  12  1  2  3
BDYS  42  1  2
EIGR  19  GIV  0  10000.0
+E1
MAX
EIGR  39  GIV  0  10000.0
+E4
MAX
EIGR  29  GIV  0  10000.0
+E3
MAX
EIGR  90  GIV  0  10000.0
+E2
MAX
TRANS  20  240.0  30.0
T2  200.0  30.0
T1  40  240.0  -100.0
ENDDATA

NASTRAN FILES = UMF $ CDC AND IBM
ID  D2035$NASTRAN
APP DMAP.SUBS
BEGIN  DISP 09 - DIRECT TRANSIENT RESPONSE ANALYSIS - APR. 1982 $
PRECHK  ALL $
FILE  UDVT=APPEND/TOL=APPEND $
PARAM  */MPY*/CARDNO/0/0 $
GP1  GEOM1,GEOM2,/*GPL,*EQEXT,GPDT,CASTM,BGPD,T,SIL/S,N,USET/ S,N,
NOGDP/ALWAYS=-1 $
PLTTRAN  BGPD,T,SIL/NOGDP,SIP/USET/S,N,USEP $
PURGE  USET/GM,G0,KAA,BAA,MAA,K4AA,PST,KFS,OP,EST,FCT,PLTSETX,PLTPAR,
GPSET,ELSET,NOGDP $
COND  LBL5,NOGDP $
GP2  GEOM2,/*EQEXT,FCT $
PARAM  PCDB/*PRES/*JUMPPLOT $
PURGE  PLTSETX,PLTPAR,GPSET,ELSET,JUMPPLOT $
COND  P1,JUMPPLOT $
PLTSET  PCDB,/*EQEXT,FCT,PLTSETX,PLTPAR,GPSET,ELSET,S,N,USET/S,N,
JUMPPLOT=-1 $
PRTMSG  PLTSETX/ $
PARAM  /*MPY*/PLTFLG/1/1 $
PARAM  /*MPY*/PFILE/0/0 $
COND  P1,JUMPPLOT $
PLOT  PLTTPAR,GPSET,ELSET,CASECC,BGPD,T,EQEXT,SIL,S,ECT,/*PLOTX1/
USET/S,N,JUMPPLOT/S,N,PLTFLG/S,N,PFIL $
PRTMSG  PLOTX1/ $
LABEL  P1 $
GP3  GEOM3,/*EQEXT,GEOM2/SLT,GPDT/NOGRAV $
TAL  ECT,EPT,BGPD,T,SIL,GPDT,CASTM/EST,GEI,GPECT,/*USET/S,N,NOSIMP=
-1/1/S,N,NOGENL=-1/S,N,GENEL $
PURGE  K4GG,GPST,OPST,MMG,BGG,K4NN,K4FF,K4AA,MNN,MFF,MAA,BNN,BFF,BAA,
KGGA,NOSIMP/OPST/GENEL $
COND  LBL1,NOSIMP $
JUMP FINIS $ 
LABEL ERROR1 $ 
PRTPARM /*-1*/DIRTRD* $ 
LABEL ERROR3 $ 
PRTPARM /*-3*/DIRTRD* $ 
LABEL FINIS $ 
PURGE DUMMY/ALWAYS $ 
END $ 
TIME 3 
DIAG 14 
END 
SUBSTRUCTURE PHASE3 
PASSW0RD = M0LSYN 
SOF(1) = FT19+500 $ CDC AND IBM 
ENDSUBS 
TITLE = TRUSS DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS 
DLOAD = 101 
TSTEP = 40 
OLOAD = ALL 
DISP = ALL 
FORCE = ALL 
BEGIN BULK 
CROD 1 1 1 2 
CROD 2 1 2 3 
CROD 11 1 11 12 
CROD 12 1 12 13 
CROD 21 1 21 22 
CROD 22 1 22 23 
CROD 31 1 31 32 
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 
CROD 232 1 22 33 
CROD 241 1 32 41 
CROD 242 1 32 43 

36
APPENDIX A. (concluded)

GRIDSET

GRID 1  30.0  0.0  0.0  3456
GRID 2  0.0  0.0  0.0
GRID 3  30.0  0.0  0.0
GRID 11 30.0  40.0  0.0
GRID 12  0.0  40.0  0.0
GRID 13  30.0  40.0  0.0
GRID 21 30.0  80.0  0.0
GRID 22  0.0  80.0  0.0
GRID 23  30.0  80.0  0.0
GRID 31 30.0  120.0  0.0
GRID 32  0.0  120.0  0.0
GRID 33  30.0  120.0  0.0
GRID 41 30.0  160.0  0.0
GRID 42  0.0  160.0  0.0
GRID 43  30.0  160.0  0.0
MAT1  1  10.0  6.3  2.3-4
PROD  1  1  3
QAREA 980  42  1  1.0 3
TLOAD 42  980  1.0  0.0  0.12
ETP 42  42  3.0  3  0  0  0.12
ENDDATA

/EOF

11.30.27, UCLP, ODL00948, 0.423 KINS
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 = MDLSYN
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, RC 2
BEGIN BULK
BAROR 1   1   1   2
CBAR 2   1   2   3
CBAR 3   1   3   4
CBAR 4   1   4   5
CBAR 5   1   5   6
CBAR 6   1   6   7
CBAR 7   1   7   8
CBAR 8   1   8   9
CBAR 9   1   9  10
CBAR 10  1  10  11
GRIDSET
GRID 1  0.  0.  0.
GRID 2  10.  0.  0.
GRID 3  20.  0.  0.
GRID 4  30.  0.  0.
GRID 5  40.  0.  0.
GRID 6  50.  0.  0.
GRID 7  60.  0.  0.
GRID 8  70.  0.  0.
GRID 9  80.  0.  0.
GRID 10 90.  0.  0.
GRID 11 100.  0.  0.
PBAR 1  1  2.591-4
M84R 1   1   5   6
MAT1 10.0  10.0  0.0  1
ENDDATA

NASTRAN FILES = UMF $ CDC AND IBM
ID DEM2032,NASTRAN
APP DISP,SUBS
SOL 3,0
TIME 5
CEND
SUBSTRUCTURE PHASE2
PASSWORD = MDLSYN
SOF(1) = FT17,900 $ 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
M REDUCE GBASIC
NAME MB
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 MB, MC, MD, ME, MF, MG
NAME ABCDEFG
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
M REDUCE ABCDEFG
NAME BEAM
BOUNDARY 20
METHOD 22
OUTPUT 1, 5, 6, 9, 10
SOFPRINT TOC
ENDSUB

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 50
BDYC 40
BDYC 30
BDYS 126 11
BDYS 126 1
TRANS 2 100. 0. 0. 100. 0. 1. +T2
TRANS 3 200. 0. 0. 200. 0. 1. +T3
TRANS 4 300. 0. 0. 300. 0. 1. +T4
TRANS 5 400. 0. 0. 400. 0. 1. +T5
TRANS 6 500. 0. 0. 500. 0. 1. +T6
TRANS 7 600. 0. 0. 600. 0. 1. +T7
EIGR 1 INV 0 3000.00 10 10 +E1
EIGR 2 INV 0 3000.00 10 10 +E2
EIGR 3 INV 0 3000.00 10 10 +E3
EIGR 22 INV 0 2000.00 40 40 +E22
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
CEND
SUBSTRUCTURE PHASE1
PASSWORD = MDLSYN
SOF(I) = 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, R6 2
BEGIN BULK
BAROR
CBAR 1 1 1 2
CBAR 2 1 1 3
CBAR 3 1 1 4
CBAR 4 1 1 5
CBAR 5 1 1 6
CBAR 6 1 1 7
CBAR 7 1 1 8
CBAR 8 1 1 9
CBAR 9 1 1 10
CBAR 10 1 1 11
GRIDSET
GRID 1 1 0 0 0
GRID 2 2 10 0 0
GRID 3 3 20 0 0
GRID 4 4 30 0 0
GRID 5 5 40 0 0
GRID 6 6 50 0 0
GRID 7 7 60 0 0
GRID 8 8 70 0 0
GRID 9 9 80 0 0
GRID 10 10 90 0 0
GRID 11 11 100 0 0
PBAR 1 1 10 0 6
MAT1 1 1 0 0 .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 = MDLSYN
SOF(I) = FT17;500 & CDC AND IBM
EQUIV ABASIC, DBASIC
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 BBASIC
NAME MB
BOUNDARY 2
FIXED 2
METHOD 2
MREDUCE CBASIC
NAME MC
BOUNDARY 7
FIXED 7
METHOD 2
MREDUCE DBASIC
NAME MD
BOUNDARY 8
FIXED 8
METHOD 2
MREDUCE EBASIC
NAME ME
BOUNDARY 9
FIXED 9
METHOD 2
MREDUCE GBASIC
NAME MG
BOUNDARY 3
FIXED 3
METHOD 3
COMBINE MB, MB
NAME AB
TOLERANCE 0.01
OUTPUT 2, 7, 12
COMPONENT MB
TRANSFORM 2
MREDUCE AB
NAME MAB
BOUNDARY 10
FIXED 10
METHOD 22
COMBINE MAB, MC
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, MD
NAME ABCD
TOLERANCE 0.01
OUTPUT 2, 7, 12
COMPONENT MD
TRANSFORM 4
MREDUCE ABCD
NAME MABCD
BOUNDARY 22
FIXED 22
METHOD 22
**CONSOLIDATE**

**NAME** ABCDE
**TOLERANCE** 0.01
**OUTPUT** 2,7,12

**TRANSFORM** 5
**MREDUCE** ABCDE
**NAME** MABCDE
**BOUNDARY** 23
**FIXED** 23

**METHOD** 22
**COMBINE** MABCDE, MF
**NAME** ABCDE
**TOLERANCE** 0.01
**OUTPUT** 2,7,12

**TRANSFORM** 6
**MREDUCE** ABCDEF
**NAME** MABCDEF
**BOUNDARY** 24
**FIXED** 24

**METHOD** 22
**COMBINE** MABCDEF, MG
**NAME** ABCDEFG
**TOLERANCE** 0.01
**OUTPUT** 2,7,12

**TRANSFORM** 7
**MREDUCE** ABCDEFG
**NAME** BEAM
**BOUNDARY** 20
**METHOD** 22
**OUTPUT** 1,5,6,9,10
**SOPPRINT** T0C
**ENDSUBS**

**TITLE** BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
**SUBTITLE** NASTRAN DEMONSTRATION PROBLEM NO. 2-3-2
**LABEL** MODAL REDUCE, COMBINE, MODAL, RECOVSY, RUN2, P8 S52

**BEGIN** BULK

<table>
<thead>
<tr>
<th>BDYC</th>
<th>7</th>
<th>CBASIC</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>BDYC</td>
<td>9</td>
<td>EBSIC</td>
<td>50</td>
</tr>
<tr>
<td>BDYC</td>
<td>21</td>
<td>CBASIC</td>
<td>50</td>
</tr>
<tr>
<td>BDYC</td>
<td>22</td>
<td>DBASIC</td>
<td>50</td>
</tr>
<tr>
<td>BDYC</td>
<td>23</td>
<td>DBASIC</td>
<td>50</td>
</tr>
<tr>
<td>BDYC</td>
<td>24</td>
<td>FBASIC</td>
<td>50</td>
</tr>
<tr>
<td>BDYC</td>
<td>11</td>
<td>FBASIC</td>
<td>50</td>
</tr>
<tr>
<td>BDYC</td>
<td>18</td>
<td>DBASIC</td>
<td>50</td>
</tr>
<tr>
<td>BDYC</td>
<td>10</td>
<td>BBASIC</td>
<td>50</td>
</tr>
<tr>
<td>BDYC</td>
<td>15</td>
<td>CBASIC</td>
<td>40</td>
</tr>
<tr>
<td>BDYC</td>
<td>22</td>
<td>BBASIC</td>
<td>50</td>
</tr>
<tr>
<td>BDYC</td>
<td>30</td>
<td>GBASIC</td>
<td>30</td>
</tr>
<tr>
<td>BDYS1</td>
<td>30</td>
<td>126</td>
<td>11</td>
</tr>
<tr>
<td>BDYS1</td>
<td>40</td>
<td>126</td>
<td>11</td>
</tr>
<tr>
<td>BDYS1</td>
<td>50</td>
<td>126</td>
<td>11</td>
</tr>
</tbody>
</table>

**TRAN** 4
**T4** 350.0 0.0 300.0 0.0 0.0 300.0 0.0 1.0 1.0 +T4
**T6** 350.0 0.0 300.0 0.0 0.0 300.0 0.0 1.0 1.0 +T6
**T2** 150.0 0.0 100.0 0.0 0.0 100.0 0.0 1.0 1.0 +T2
**T3** 250.0 0.0 200.0 0.0 0.0 200.0 0.0 1.0 1.0 +T3
**T5** 450.0 0.0 400.0 0.0 0.0 400.0 0.0 1.0 1.0 +T5

**DBASIC** 30

---

42
APPENDIX C. (concluded)

<table>
<thead>
<tr>
<th>ITEM</th>
<th>650.</th>
<th>600.</th>
<th>0.</th>
<th>0.</th>
<th>600.</th>
<th>0.</th>
<th>1.</th>
</tr>
</thead>
<tbody>
<tr>
<td>T7</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGR 1</td>
<td>INV</td>
<td>.0</td>
<td>3000.00</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGR 2</td>
<td>INV</td>
<td>.0</td>
<td>3000.00</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGR 3</td>
<td>INV</td>
<td>.0</td>
<td>3000.00</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IGR 22</td>
<td>INV</td>
<td>.0</td>
<td>1000.0</td>
<td>40</td>
<td>40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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 = MDLSYN
SOF(1) = FT17,500$NEW $ CDC AND IBM
NAME = ABASIC
SOPRINT TO C
ENDSUBS
TITLE = BEAM DYNAMIC ANALYSIS USING AUTOMATED MODAL SYNTHESIS
LABEL = SUBSTRUCTURE 1, RUN 1, PHASE 1, R6 2
BEGIN BULK
BAROR 1 1 1 2
BARC 1 2 3 4
BARC 4 1 5 6
BARC 6 1 7 8
BARC 8 1 9 10
BARC 10 1 10 11
GRIDSET 345
GRID 1 0 0 0
GRID 2 10 0 0
GRID 3 20 0 0
GRID 4 30 0 0
GRID 5 40 0 0
GRID 6 50 0 0
GRID 7 60 0 0
GRID 8 70 0 0
GRID 9 80 0 0
GRID 10 90 0 0
GRID 11 100 0 0
PBAR 1 1 6.3 2.59-4
MAT1 1 10.0 0.0 0.0
ENDDATA

NASTRAN FILES = UMF $ CDC AND IBM
ID DEM2032$NASTRAN
APP DISP$SUBS
SOL 3,0
TIME 10
CEND
SUBSTRUCTURE PHASE2
PASSWORD = MDLSYN
SOF(1) = FT17,500 $ 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 BBASIC
NAME MB
BOUNDARY 2
FIXED 2
METHOD 2
MREDUCE CBASIC
NAME MC
BOUNDARY 7
FIXED 7
METHOD 2
MREDUCE CBASIC
NAME MD
BOUNDARY 8
FIXED 8
METHOD 2
MREDUCE CBASIC
NAME ME
BOUNDARY 9
FIXED 9
METHOD 2
MREDUCE CBASIC
NAME MF
BOUNDARY 11
FIXED 11
METHOD 2
MREDUCE CBASIC
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 MAB
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 MAB*MCD
NAME ABCD
TOLERANCE 0.01
OUTPUT 2.7.12
COMPONENT MCD
TRANSFORM 3
MREDUCE ABCD
NAME MABCD
BOUNDARY 30
FIXED 30
METHOD 25
COMBINE MEF*MG
NAME EFG
TOLERANCE 0.01
OUTPUT 2.7.12
COMPONENT MG
TRANSFORM 3
MREDUCE EFG
NAME MEFG
BOUNDARY 35
FIXED 35
METHOD 25
COMBINE MABCD*MEFG
NAME ABCDEFG
TOLERANCE 0.01
OUTPUT 2.7.12
COMPONENT MEFG
TRANSFORM 5
MREDUCE ABCDEFG
NAME BEAM
BOUNDARY 20
METHOD 25
OUTPUT 1.5.6.9.10
SOFORMAT 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

BDYC 30  DBASIC 30
BDYC 35  DBASIC 40
BDYC 40  CBASIC 50
BDYC 49  EBASIC 50
BDYC 11  FBASIC 50
BDYC 25  EBASIC 40
BDYC 8  DBASIC 50
BDYC 10  BBASIC 30
BDYC 5  CBASIC 40
BDYC 2  BBASIC 50
BDYC 3  GBASIC 40
BDYC 20  ABASIC 30
BDYS1 30  126  11
BDYS1 40  126  11
BDYS1 50  126  11

TRANS 2  100.  0.  0.  100.  0.  1.  +T2
TRANS 3  200.  0.  0.  200.  0.  1.  +T3
TRANS 5  400.  0.  0.  400.  0.  1.  +T5
TRANS 7  600.  0.  0.  600.  0.  1.  +T7

EIGR 1  INV  .0  3000.00  10  10  +E1
EIGR 2  INV  .0  3000.00  10  10  +E2

46
APPENDIX D. (concluded)

<table>
<thead>
<tr>
<th>EIGR</th>
<th>MAX</th>
<th>INV</th>
<th>3000.00</th>
<th>10</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIGR</td>
<td>3</td>
<td>INV</td>
<td>1000.00</td>
<td>40</td>
<td>40</td>
</tr>
<tr>
<td>EIGR</td>
<td>25</td>
<td>INV</td>
<td>2000.00</td>
<td>40</td>
<td>40</td>
</tr>
</tbody>
</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.

15. Supplementary Notes
Langley Technical Monitor: Joseph E. Walz