THE COST EFFECTIVENESS OF MINICOMPUTERS VERSUS MAIN FRAMES FOR --ETC(U)
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**Title:** The Cost Effectiveness of Minicomputers vs. Main Frames for Structural Analysis Problems.

**Authors:** Raphael T. Haftka, Anneliese K. von Mayrhauser

**Summary:**
A study of the cost effectiveness of minicomputers vs. main frames for structural analysis programs is described. It compares the performance of several finite element programs including SAP IV and SPAR. Most of the runs were performed with the Illinois Institute of Technology PRIME 400 minicomputer and the United Computing System UNIVAC 1100/81 main frame. Other computers were used selectively. The matrix of structural problems included beam, plate and shell problems and static, dynamic and nonlinear analysis.
THE COST EFFECTIVENESS OF MINICOMPUTERS VS. MAIN FRAMES FOR STRUCTURAL ANALYSIS PROBLEMS

Raphael T. Haftka
Anneliese K. Von Mayrhauser
Illinois Institute of Technology
Chicago, Illinois 60616

ABSTRACT

A study of the cost effectiveness of minicomputers vs. main frames for structural analysis programs is described. The study compares the performance of several finite element programs including SAP IV and SPAR. Most of the runs were performed with the Illinois Institute of Technology PRIME 400 minicomputer and the United Computing System UNIVAC 1100/81 main frame. Other computers were used selectively. The matrix of structural problems included beam, plate and shell problems and static, dynamic and nonlinear analysis.

MINICOMPUTERS PROMISE CHEAPER, more widely available computing facilities, but they pose many problems, particularly to those with large calculations in mind. The smaller main memory means that users must make more use of disk I/O. Many minicomputers have a smaller word size (8 or 16 bits per word) with a devastating effect on accuracy. (Storaasli and Foster [1] report 4 digit accuracy on a PRIME 400 for a medium-sized problem as compared to 8-13 digit accuracy on a CDC CYBER 173.) Longer elapsed times leave more room for machine hardware failures during a run. At Berkeley, Pearson reports some theoretical calculations required twenty-four hours or more, but the mean time between failures (MTBF) was also approximately twenty-four hours. Lack of adequate software libraries, debugging facilities, documentation and operations staff often hampers users of minicomputers.

Several past studies of the performance of minicomputers and main frames have concentrated on the machine cost aspect. Chemists have taken the lead in doing large scale calculations on small machines, perhaps because of their familiarity with the use of minicomputers for laboratory process control. Peter Lykos of the Illinois Institute of Technology organized an American Chemical Society Symposium on Minicomputers and Large Scale Computations in June, 1977 [2]. Four of the papers from this meeting are particularly relevant to the present study since they involve large minicomputers with a cost in $100,000 - $200,000 range: Pearson et. al. [3]; Norbeck and Certain [4]; Wagner et. al. [5]; and Freuler and Petrie [6]. These papers have shown that based on machine cost alone minicomputers may be two to four times more cost effective than main frames. However, the National Resource for Computation in Chemistry Committee has concluded that "Minicomputers alone cannot meet the needs of the chemistry community" ([7], p. 1).

The structural analysis community is also experiencing a shift from main frames to minicomputers (e.g., Swanson [8]). For example, most of the major finite element packages are now available on the PRIME 400.

The users of structural analysis software on minicomputers have conducted several studies that point to the economic advantages of using such machines (e.g., Storaasli and Foster [1]; Conaway [9]). These are based on data gathered by running structural analysis programs for various problems. The scope of the comparison was limited by the relatively small amount of data that was generated.

The purpose of the present study is to extend the previous studies in several directions. First, to use a wider mix of programs and problems for the comparison. Second, to include in the study several machines so that the results do not reflect only the charging algorithm at a particular installation. Last, the present study also attempts to further assess the human factors involved in such a comparison.

CHOICE OF STRUCTURAL ANALYSIS PROGRAMS AND PROBLEMS

Since the overwhelming majority of structural analysts use finite element methods, the present study is limited to such programs.

It is impossible to get a very accurate comparison of the performance of the mini and main frame systems without an exhaustive battery of test problems. However, we believe that by judicious choice of the type of problems and the type of structural analyses employed, one can obtain a reasonably reliable comparison of performance.

*Numbers in parentheses designate References at end of paper

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The following are the elements in such a comparison.

**TYPE OF ANALYSIS** - The type of structural analysis to be included in the tests must include those which are most commonly in use. This study includes the following:

1. Linear static solution for displacement and stresses
2. Linear eigenvalue analysis - calculation of buckling loads and vibration modes
3. Nonlinear response due to large deformations and material nonlinearities

**TYPE OF PROBLEM** - Three structural problems are used:

1. A simple cantilever beam
2. A plate with a hole
3. A stiffened cylinder

These problems are solved for the different analysis types. Several models are used for each problem ranging from a very crude model to a refined one. The number of degrees of freedom ranging from a few dozen for a crude model to more than a thousand for the refined one.

**COMPUTER PROGRAMS** - Three computer programs are used; these programs are:

1. **SAP IV** - A general purpose finite element program developed at the University of California at Berkeley probably the most widely used "free" (it costs $200.00) finite element code.
2. **SPAR** - A general purpose finite element program developed by W. D. Whetstone which serves as a prototype of a commercially developed code.
3. **TWOODEL** - A special purpose finite element program developed by D. Malkus at IIT for large deformation analysis of 2 dimensional elasticity problems. It is a representative of in house codes.

**THE COMPUTER PROGRAMS**

**SAP IV** - SAP IV (12) is also a general purpose finite element program that has static, vibration and dynamic analysis capabilities. It has been developed by Wilson and his students at Berkeley and is available at nominal cost ($200) to the public. It is probably the most widely used "free" finite element program. There are more advanced versions of SAP denoted as SAP V, SAP VI, etc. which are available at considerable cost ($9,000.00) from the University of Southern California. In the present study SAP IV is used.

The program was originally written for a CDC system. However, it has been converted to other systems. On the UCS UNIVAC 1100/81, there are three versions of SAP IV. However only one of these is working. The program can be compiled using UNIVAC's FORTRAN V compiler. An attempt to use the more efficient ASCII FORTRAN compiler was unsuccessful. A substantial change in the program and I/O format statements may be required to make SAP IV suitable for this compiler. There also is an absolute version of SAP IV which is supported by UCS and is available for problem solution.

The **PRIME** version of SAP IV was generated by Feeser of RPI. The first version of SAP IV which we received from the PRIME users' library was highly mutilated. Another tape was then obtained from RPI, Troy, after several months' wait. This tape had about 60 lines of code missing towards the end of the STRETR SUBROUTINE. Two following subroutines were also destroyed. Luckily this particular piece of code was correct on the earlier tape, and we were able to patch the code to make it work. Both times we received 800 BPI tapes. The PRIME installation at IIT has only a 1600 tape drive. However, the conversion was another non-trivial task.

**SPAR** - SPAR (10) is a general purpose finite element program developed by W. D. Whetstone for NASA, first at Lockheed and then at his own EISI company. The program has linear static analysis, eigensolutions for vibration and buckling and model response capabilities. It does not have nonlinear analysis or direct integration capabilities. The program has a public version which is distributed by the government through COSMIC. It also has a proprietary version called EAL (for Engineering Analysis Language).

The public version of SPAR was installed on the UNIVAC without any problem. Installation on the PRIME was much more troublesome. Difficulties were due to some bugs in the PRIME version that had to be corrected and due to the virtual memory system of the PRIME that did not seem to work well for very large arrays. Additionally, the PRIME company issues new releases of the operating system quite often. Many times the older version of SPAR did not work with the newer operating system and the programs had to be recompiled and reloaded (a non-trivial effort because SPAR is composed of so many individual programs).

**TWOODEL** - TWOODEL (13) is a special purpose finite element program for two dimensional finite elasticity developed by Malkus at IIT. It is a relatively small program and was developed simultaneously for the UNIVAC and PRIME systems. The problem description is built into the program so that refining the mesh necessitates changes to program patches.

**COMPUTERS AND CHARGING ALGORITHMS**

A study on the cost effectiveness of a minicomputer and a main frame can be based on a detailed economic study of the costs of owning and operating each machine. Such a study is
feasible for a particular type of machine and a particular owner. It is, however, difficult to generalize to the broad category of minicomputers and main frames. The approach taken in the present work is to use the charging algorithms in several installations as the measure of the cost of running any of the selected problems. In most cases the charging algorithms are devised to recover the total cost of owning and operating the system, and in some cases to show profit.

Most of the runs were performed at the computer center at the Illinois Institute of Technology. The school operates its own PRIME 400 minicomputer and buys computing services in a UNIVAC 1100/81 from the United Computing System Corporation (UCS). A few runs were made also on the CDC CYBER 176 owned by a large manufacturing company (LMC) and on the UCS CDC CYBER 176. The performance of the programs on the first three computers was used to predict performance on one new additional systems. The following is a brief description of the computer systems that were used in this study, their charging algorithms and the method used to predict performance on them.

**IIIT** - The PRIME 400 is a medium size minicomputer which is used at IIIT to support interactive computing. The present configuration has 1.25 Megabytes of memory and two disk drives. The system is very busy from about 9 AM Monday through Saturday with about 20 to 30 users. However, most of the users are not CPU intensive. As a result the CPU intensive structural analysis programs often show very good response times even during the day. In running on the PRIME 400 it was found that the response time and I/O times are quite sensitive to the number of users while the CPU time is not. To account for the variability runs were performed for several user environments on the PRIME and the performance averaged.

The charging algorithms for the system is given in Table 1 (considerable discounts are available at non-business hours). While most of the users do not pay the charges, some do. The charging algorithm is intended to cover the total cost of owning and operating the system and providing user support. Total billings are about $16,000.00 a month.

**NASA - LANGLEY RESEARCH CENTER PRIME 400** - The NASA Langley Computer Center operates several minicomputers including a PRIME 400 computer. The charging algorithm (see Table 1) was devised to recover the capital and operating costs. The NASA PRIME 400 supports a small number of users; however, the users run more CPU intensive jobs than the IIIT users.

Based on these considerations it was assumed that program performance is similar on the IIIT and NASA systems. The cost of running a job on the NASA PRIME was calculated based on this assumption.

**NASA - LANGLEY RESEARCH CENTER CYBER 173** - The NASA Langley Research Center operates several CDC main frames including two CYBER 173 computers which are used to support interactive computation. The charging algorithm is devised to recover capital and operating expenses.

One of us (Haftka) has an extensive experience using the SPAR program on both the IIIT and NASA systems. Based on this experience the following assumptions were used to predict cost on the NASA CYBER 173.

1. The CPU time on the CYBER 173 is 1.5 times that of the CPU time on the UNIVAC 1100/81.
2. The I/O charges are calculated based on the number of reads and writes from the SPAR data base available in the SPAR output. It was assumed that these numbers are similar for both systems, and that the charge per disk access is 1.7 times the minimum charge per access. This is based on the feature of the charging algorithm which is relatively insensitive to the number of words in each read or write operation.
3. The amount of core required is assumed to vary from 70K octal for the smallest number of nodes to 120K for the largest number of nodes.
4. Based on the above considerations the cost of running SPAR on the NASA CYBER 173 is

\[
\text{Cost} = (1 + 0.048A)(0.0136T) + 0.003n_{IO}
\]

where

- \(T\) = UNIVAC 1100/81 CPU time (sec)
- \(n_{IO}\) = combined number of disk reads and writes reported by SPAR
- \(A\) = core storage (in units of 10K octal words)

**LARGE MANUFACTURING COMPANY CDC CYBER 176 -** A few runs of SPAR were made on a CYBER 176 which is owned by a large manufacturing company. The charging algorithm is given in Table 1. It appears to be fairly high on CPU and low on I/O and core storage charges. In predicting costs on this machine it was assumed that CPU times can be predicted from the UNIVAC 1100/81 results based on published data (14) rating the UNIVAC 1100/81 at 1800 KOPS and the CYBER 176 at 9300 KOPS. It was assumed that the ratio of I/O time to CPU time is the same on both machines. Because the I/O cost on the CYBER 176 is low, even a large error in this assumption is not expected to change the cost much. For SAP IV the data for the UCS CYBER were used for the LMC CYBER estimates.

**CONCORDIA COLLEGE COMPUTER NETWORK (CCCN)** - CCCN provides administrative, instructional and research computing services to a large number of educational institutions. The service includes a large software development staff and the charges are computed to recover costs of operating the center. Interactive and batch services are provided by a UNIVAC 90/80 main frame installed in December, 1980. The UNIVAC 90/80 is roughly equivalent to an IBM 370/158 in raw processing power. The prediction of costs of running on the CCCN UNIVAC 90/80 were based on the charging algorithm given in Table 1 with the following assumptions.

1. CPU times are 2.25 longer than on the UNIVAC 1100/81. This is based on published data (14) rating the UNIVAC 1100/81 at 1800 KOPS and

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the UNIVAC 90/80 at 900 KOPS.

2. Core requirements were estimated at
200 K bytes for the small problems and at 300 K
bytes for the large problems.

IIT RESEARCH INSTITUTE VAX 11/780 - The
IIT Research Institute (IITRI) operates a DEC VAX
11/780 with 3 megabytes of core memory and 650
megabyte disk space. The IITRI computer is not
intended for uses involving much "number
 crunching" so that it does not have a floating
point processor. It is not heavily loaded so
that time is available to outside users. The
charging algorithm is given in Table 1.

RESULTS

BEAM PROBLEM - A cantilever beam was mod-
eled by plane beam elements (E24 elements in
SPAR) and three vibration modes and frequencies
were calculated using the SPAR program. The
number of nodes was varied from 5 to 600 and with
three degrees of freedom per node; the maximum
number of degrees of freedom is 1800. However,
even for 600 nodes the problem is not costly to
run because of the very small band width associ-
ated with a one dimensional problem.

For small problem sizes (up to 25) the prob-
lem can be run in single precision. For larger
number of nodes the limited double precision op-
tion in SPAR (double precision used only for
assembling the stiffness matrix) must be employed.

This simple problem exposed a bug in the
PRIME version of SPAR. The program could not
calculate more than two vibration modes and fre-
frequencies. The problem occurred in the subspace
iteration method and seemed to indicate that the
initial vectors generated by a random number rou-
tine were not linearly independent. On the
UNIVAC there was no problem to get the required
three lowest frequencies.

The CPU, I/O, response times and cost for
the beam problem are given for the UNIVAC 1100/81
in Table 2 and for the IIT PRIME 400 in Table 3.
The cost of running the problems is calculated
based on the prime time rate. The total cost
proved to be very close to a linear function of
the number of nodes for both computers. It was
therefore possible to predict accurately the cost of
600 node run by extrapolating the cost of the
5-280 node runs. It is therefore assumed that
the 5-600 node results can be used safely to
extrapolate cost up to 1200 nodes. The actual
and predicted cost results for both computers are
also shown in Figure 1. From Tables 2 and 3 and
Figure 1 it is clear that the beam runs are about
twice as expensive to run on the UCS UNIVAC
1100/81 as on the IIT PRIME 400. The response
time or turnaround time is favorable on the PRIME
for the small problems but the UNIVAC is quite
faster for the larger problems.

The performance of other computers for the
beam problem was actually measured or estimated
and the results are summarized in Table 4. It
can be seen from Table 4 that the costs of run-
ning the problem on the NASA PRIME 400 are com-
parable to those at IIT. However, comparison
with the other main frames reveal costs which are
significantly lower than those of the UNIVAC
1100/81. Part of the difference may be due to
the fact that the CDC CYBER machines are not
operated for profit and do not have marketing
expenses. The low cost of the PRIME version of
SPAR reflects low I/O charges on that machine compared to the
NASA CYBER 173. On the CYBER 176 about $1.40 of
the $2.24 cost is CPU related and the rest is
I/O related cost. On the NASA CYBER 173 only
$0.57 of the $8.60 cost is CPU related and the
rest is I/O related. In assessing the total cost
data in Table 4 the main difference is not
between minicomputer and mainframes. Rather it
is between the service bureau computers (the two
UNIVAC machines) and the user owned machines
which have lower charges.

PLATE PROBLEM - A rectangular plate with
a hole was modeled with quadrilateral plane
stress finite elements. Because of symmetry only
one quarter of the plate is modeled, see Fig-
ure 2. The plate is subjected to uniform loads
and the stresses in it are calculated for the
cases where the number of nodes varies between
35 and 594. The problem was run with the SPAR
and SAP programs. CPU and I/O times response
times and cost on the UNIVAC 1100/81 are given.
As can be seen from Figure 5 which compares
the cost of running SPAR for various problem
sizes, the problem is much cheaper to run on the
PRIME than on the UNIVAC 1100/81. Further-
more, the 289 node problem was the largest that

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could be run on the UNIVAC 1100/81 because of core limitations. The PRIME 400 with its virtual memory could handle larger problems. The excellent performance of the program on the PRIME 400 was attributed to two factors.

First, the large core requirements on the UNIVAC 1100/81 are very expensive (fifty percent of the cost of the 289 run was core cost). Second, the program was written by the developer on both machines. As a result it does not suffer from the deterioration in performance that afflicts programs that have been converted to different machines by users who are not as knowledgeable about the program as its developer.

This applies to the SPAR and SAP programs. Alem is rather expensive, it was not run for all UNIVAC 1100/81 are very expensive (fifty per- possible that these could be resolved too, but problems remained for the larger problems. It is possible that these could be resolved too, but problem could not be run on the main frame computers with virtual memory. On the UNIVAC the program automatically switches to use magnetic tapes in such a situation. This results in very large I/O times and high charges. The results are given in Table 14. This problem illustrates how the problem size influences resource consumption and charges. That is, for the smallest problem overhead charges dominate which are lowest on the minicomputers and make them cheaper. For the medium sized problem CPU consumption is dominant and the main frame is cheaper, whereas for the large problem the additional core requirements were accommodated more cheaply by the computers with virtual memory.

STIFFENED CYLINDER PROBLEM - A stiffened cylindrical shell, see Figure 6, modeled by plate and beam elements, because of symmetry only one half of a 90° segment of the shell was modeled. The lowest four vibration frequencies and the buckling load of the cylinder were calculated using the SPAR program. Three models were used with 5x5, 10x10 and 15x15 grids of elements. This corresponds to 36, 121 and 256 nodes, respectively. The largest model has about 1500 degrees of freedom.

The cylinder problem revealed two bugs in the SPAR program. The stress analysis which is a preliminary to the buckling calculation was not correct when combined membrane-bending elements (type E43 in SPAR) were employed. As a result it was necessary to use twice as many elements; pure membrane elements (type E44) was no problem (type E43). Unfortunately, the mass matrix was not calculated properly with this replacement. As a result we had to perform the calculations in two separate runs, one using double elements for the performance analysis and one using combined elements for the vibration analysis. This did not increase the cost of the run substantially but was an inconvenience for the analyst.

The result of CPU and I/O times, response time and cost are given in Table 11 for the UCS UNIVAC 1100/81 and in Table 12 for the IIT PRIME 400. Comparison with other computers is given in Table 13 for the largest problem of 256 nodes. It can be seen that for this problem the performance of the PRIME 400 is dismal and that of the CDC very good.

The experience with the same problem with the SAP IV program was quite different. The PRIME 400 version ran with no difficulties while the UNIVAC 1100/81 and the UCS CDC CYBER 7600 encountered convergence difficulties. These difficulties were bypassed by change of parameters for the 36 node problem but difficulties remained for the larger problems. It is possible that these could be resolved too, but it required a degree of familiarity with the SAP IV program that the authors do not have.

The cylinder problem was next analyzed for transient response by direct integration on the SAP IV program. The response to an oscillating normal load was calculated for forty time steps (each of 0.0125 sec). Since the cylinder problem is rather expensive, it was not run for all problem sizes on all computers. For the 256 node problem the amount of scratch disk space required by the program was of the order of five megabyte on the PRIME 400 and was impossible to run in periods when the disk utilization was high. On the UNIVAC the program automatically switches to use magnetic tapes in such a situation. This results in very large I/O times and high charges. The results are given in Table 14. This problem illustrates how the problem size influences resource consumption and charges. That is, for the smallest problem overhead charges dominate which are lowest on the minicomputers and make them cheaper. For the medium sized problem CPU consumption is dominant and the main frame is cheaper, whereas for the large problem the additional core requirements were accommodated more cheaply by the computers with virtual memory.

CONCLUDING REMARKS

A study of the performance of structural analysis programs on main frame and minicomputers has not demonstrated a clear cut advantage of either type of computer. Difficulties were encountered on both types of computers for different problems. For the minicomputers some of these difficulties arose from portability problems when structural analysis packages that were developed on main frame computers were converted imperfectly to minicomputers. Another factor is that software is easier to get for a main frame. As the problem sizes increased, the minicomputers showed reduced efficiency for those programs which were not developed for them; but on the other hand, some of the main frames were unable to run those problems adequately, too. The minicomputer clearly outperformed the main frame for the one program which has been developed on the minicomputer.

When costs are compared there was also not much difference between the main frames and the minicomputers except in the case of the user owned CDC CYBER machines. This probably reflects a highly competitive marketplace where the decrease in the cost of raw computation has stimulated an increase in programming and computer services offered. Main frames no longer hold a monopoly on structural analysis software (or most other software for that matter) and have to price their services adequately to compete with the minicomputers.

If one is merely interested in the cost,
the user owned machines which just charge to
cover their costs naturally fare better than
machines owned by organizations which need to
make a profit and may have marketing and other
related expenses. This reduces the problem to
one of microeconomics and price theory (15).

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### Table 1
Charging Algorithms (dollars)

1. **IIT PRIME 400**
   - $0.02 (T_1 + T_2) + T_3$
   - $T_1 = $CPU time (sec)$
   - $T_2 = $I/O time (sec)$
   - $T_3 = $wall time (hours)$

2. **NASA Langley Research Center - PRIME 400**
   - $30T_1 + 15T_2$
   - $T_1 = $CPU time (hours)$
   - $T_2 = $wall time (hours)$

3. **UCS UNIVAC 1100/81**
   - $0.18T_1 + 0.0011A(T_1 + T_2)$
   - $T_1 = $CPU time (sec)$
   - $T_2 = $I/O time (sec)$
   - $A = $core (512) words$

4. **Concordia College UNIVAC 90/80**
   - $(0.156 + 0.0000248A)T$
   - $T = $CPU time (sec)$
   - $A = $core (kilobytes)$

5. **Large Manufacturing Company CDC CYBER 176**
   - $0.2T_1 + 0.0003A (T_1 + T_2) + 0.03 * T_2$
   - $T_1 = $CPU time (sec)$
   - $T_2 = $I/O time (sec)$
   - $A = $core (kilowords)$

6. **NASA Langley Research Center - CDC CYBER 173**

7. **UCS CDC CYBER 176**
   - Confidential

8. **IIT Research Institute VAX 11/780**
   - $0.05T_1 + 5T_2$
   - $T_1 = $CPU time (sec)$
   - $T_2 = $connect time (hours)$

---

### Table 2
Beam Results on the UCS UNIVAC 1100/81 Using SPAR

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>CPU Time (sec)</th>
<th>I/O Time (sec)</th>
<th>Turnaround Time (min)</th>
<th>Cost (dollars)</th>
</tr>
</thead>
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<tr>
<td>5</td>
<td>5.06</td>
<td>15.77</td>
<td>3:21</td>
<td>1.83</td>
</tr>
<tr>
<td>25</td>
<td>5.74</td>
<td>16.12</td>
<td>2:50</td>
<td>2.07</td>
</tr>
<tr>
<td>60</td>
<td>7.07</td>
<td>18.17</td>
<td>6:04</td>
<td>2.66</td>
</tr>
<tr>
<td>90</td>
<td>8.30</td>
<td>19.79</td>
<td>2:41</td>
<td>3.16</td>
</tr>
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<td>125</td>
<td>10.29</td>
<td>22.81</td>
<td>4:26</td>
<td>4.07</td>
</tr>
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<td>250</td>
<td>16.70</td>
<td>32.59</td>
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<td>6.90</td>
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<tr>
<td>450</td>
<td>22.52</td>
<td>41.73</td>
<td>3:16</td>
<td>9.53</td>
</tr>
<tr>
<td>600</td>
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<td>59.68</td>
<td>7:45</td>
<td>13.80</td>
</tr>
<tr>
<td>1200 *</td>
<td>60.76</td>
<td>72.10</td>
<td>8:55</td>
<td>30.89</td>
</tr>
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</table>

* predicted
### Table 3

Beam Results on the IIT PRIME 400 (Averages)

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>CPU Time (sec)</th>
<th>I/O Time (sec)</th>
<th>Response Time</th>
<th>Cost (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>14.70</td>
<td>17.68</td>
<td>1:03</td>
<td>0.67</td>
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<tr>
<td>25</td>
<td>19.33</td>
<td>17.43</td>
<td>2:37</td>
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<td>1:57</td>
<td>1.80</td>
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<td>22.84</td>
<td>6:02</td>
<td>3.25</td>
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<td>125</td>
<td>47.82</td>
<td>37.25</td>
<td>11:04</td>
<td>5.16</td>
</tr>
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<td>280</td>
<td>94.24</td>
<td>63.11</td>
<td>13:47</td>
<td>6.68</td>
</tr>
<tr>
<td>450</td>
<td>141.07</td>
<td>132.87</td>
<td>26:36</td>
<td>14.14</td>
</tr>
<tr>
<td>600</td>
<td>197.38</td>
<td>125.76</td>
<td>26:36</td>
<td></td>
</tr>
<tr>
<td>1200*</td>
<td>422.92</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* predicted

### Table 4

Comparison of the 600 and 1200 Node Beam Problems on Various Computers
(1200 Node Results Are Given in Parentheses)

<table>
<thead>
<tr>
<th>Computer</th>
<th>CPU (sec)</th>
<th>I/O (sec)</th>
<th>Turnaround Time (min)</th>
<th>Total Cost (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IIT PRIME 400*</td>
<td>*197.38</td>
<td>125.76</td>
<td>13:47</td>
<td>6.88 (14.14)</td>
</tr>
<tr>
<td>NASA LRC</td>
<td>(422.92)</td>
<td>(262.02)</td>
<td>(26:36)</td>
<td></td>
</tr>
<tr>
<td>PRIME 400*</td>
<td>197.38</td>
<td>125.76</td>
<td>13:47</td>
<td>5.08 (10.17)</td>
</tr>
<tr>
<td>UCS UNIVAC</td>
<td>*30.73</td>
<td>59.68</td>
<td>7:45</td>
<td>13.80 (30.89)</td>
</tr>
<tr>
<td>1100/81*</td>
<td>(60.76)</td>
<td>(72.10)</td>
<td>(8:55)</td>
<td></td>
</tr>
<tr>
<td>NASA LRC</td>
<td>46.1</td>
<td></td>
<td></td>
<td>8.60 (20.78)</td>
</tr>
<tr>
<td>CYBER 173*</td>
<td>(91.14)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMC CYBER 176</td>
<td>*6.05</td>
<td>24.5</td>
<td>--</td>
<td>2.24 (3.98)</td>
</tr>
<tr>
<td>UNIVAC 90/80*</td>
<td>(136.71)</td>
<td></td>
<td>--</td>
<td>11.13 (22.34)</td>
</tr>
</tbody>
</table>

* estimated
+ average

Haftka and Von Mayrhofer
### Table 5

Plate Linear Analysis with SPAR on Various Computers

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>CPU (sec)</th>
<th>I/O (sec)</th>
<th>Turnaround (min:sec)</th>
<th>Cost (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIVAC 1100/81</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>4.80</td>
<td>14.25</td>
<td>1:27</td>
<td>1.69</td>
</tr>
<tr>
<td>72</td>
<td>6.98</td>
<td>15.55</td>
<td>1:44</td>
<td>2.46</td>
</tr>
<tr>
<td>143</td>
<td>11.89</td>
<td>18.36</td>
<td>2:08</td>
<td>4.22</td>
</tr>
<tr>
<td>285</td>
<td>24.46</td>
<td>25.27</td>
<td>2:48</td>
<td>8.69</td>
</tr>
<tr>
<td>594</td>
<td>60.58</td>
<td>44.78</td>
<td>4:36</td>
<td>21.94</td>
</tr>
<tr>
<td>1200</td>
<td>170.27</td>
<td>102.31</td>
<td>9:23</td>
<td>62.89</td>
</tr>
<tr>
<td>IIT PRIME 400</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>35</td>
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<td>19.18</td>
<td>1:23</td>
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<td>29.91</td>
<td>2:58</td>
<td>7.81</td>
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<td>44.96</td>
<td>4:30</td>
<td>4.18</td>
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<td>285</td>
<td>285.14</td>
<td>123.65</td>
<td>8:56</td>
<td>8.39</td>
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<tr>
<td>594</td>
<td>805.06</td>
<td>679.25</td>
<td>41:24</td>
<td>28.71</td>
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<tr>
<td>1200</td>
<td>2500.40</td>
<td>1370.10</td>
<td>144:15</td>
<td>126.21</td>
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</table>

### Table 6 - Plate Linear Analysis with SAP IV on Various Computers

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<th>Number of Nodes</th>
<th>CPU (sec)</th>
<th>I/O (sec)</th>
<th>Turnaround (min:sec)</th>
<th>Cost (dollars)</th>
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<tbody>
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<tr>
<td>35</td>
<td>4.52</td>
<td>1.11</td>
<td>1:13</td>
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<td>1.93</td>
<td>1:51</td>
<td>1.56</td>
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<tr>
<td>143</td>
<td>11.55</td>
<td>3.54</td>
<td>2:12</td>
<td>2.97</td>
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<tr>
<td>285</td>
<td>25.38</td>
<td>8.19</td>
<td>3:08</td>
<td>7.15</td>
</tr>
<tr>
<td>594</td>
<td>78.59</td>
<td>26.94</td>
<td>10:08</td>
<td>23.61</td>
</tr>
<tr>
<td>1200*</td>
<td>316.58</td>
<td>122.14</td>
<td>18:54</td>
<td>98.67</td>
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<td>IIT PRIME 400+</td>
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<td></td>
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<td>30.82</td>
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<td>1.26</td>
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<td>41.15</td>
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<td>82.61</td>
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<td>216.10</td>
<td>54:08</td>
<td>28.95</td>
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<td>3791.00</td>
<td>685.74</td>
<td>112:12</td>
<td>108.60</td>
</tr>
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<td></td>
<td></td>
<td></td>
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<td>--</td>
<td>0.96</td>
</tr>
<tr>
<td>72</td>
<td>1.00</td>
<td>3.08</td>
<td>--</td>
<td>1.92</td>
</tr>
<tr>
<td>143</td>
<td>1.69</td>
<td>4.48</td>
<td>--</td>
<td>3.36</td>
</tr>
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<td>4.10</td>
<td>10.82</td>
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<td>7.20</td>
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<td>11.96</td>
<td>30.21</td>
<td>--</td>
<td>21.60</td>
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<td>99.18</td>
<td>--</td>
<td>76.81</td>
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<td></td>
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<td>0:25</td>
<td>0.52</td>
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<tr>
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<td>--</td>
<td>0:30</td>
<td>1.05</td>
</tr>
<tr>
<td>143</td>
<td>59.62</td>
<td>--</td>
<td>3:30</td>
<td>2.98</td>
</tr>
<tr>
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<td>9.12</td>
</tr>
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<td>594</td>
<td>568.33</td>
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<td>12:41</td>
<td>28.42</td>
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</table>

* estimates
+ averages
** jobs were run in batch mode, no connect time charges
### Table 7
Comparison of the Cost of Linear Analysis of the 594 (1200) Node Plate Model on Various Computers (in Dollars)

<table>
<thead>
<tr>
<th>Computer System</th>
<th>SAP IV 594</th>
<th>SAP IV 1200</th>
<th>SPAR 594</th>
<th>SPAR 1200</th>
</tr>
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<tbody>
<tr>
<td>IIT PRIME 400*</td>
<td>28.95</td>
<td>108.60</td>
<td>28.71</td>
<td>126.21</td>
</tr>
<tr>
<td>NASA LRC PRIME 400*</td>
<td>23.38</td>
<td>59.64</td>
<td>17.06</td>
<td>56.90</td>
</tr>
<tr>
<td>UCS UNIVAC 1100/81*</td>
<td>23.61</td>
<td>98.67</td>
<td>21.94</td>
<td>62.89</td>
</tr>
<tr>
<td>NASA LRC CYBER 173</td>
<td>6.84</td>
<td>18.90</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>LMC CYBER 175*</td>
<td>4.23</td>
<td>11.39</td>
<td>2.85</td>
<td>7.82</td>
</tr>
<tr>
<td>Concordia College UNIVAC 90/80</td>
<td>28.98</td>
<td>116.42</td>
<td>22.28</td>
<td>69.57</td>
</tr>
<tr>
<td>UCS CYBER 176</td>
<td>21.60</td>
<td>70.81</td>
<td>--</td>
<td>--</td>
</tr>
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<td>IIT Research Institute VAX 11/780</td>
<td>28.42</td>
<td>**</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

* average of several runs
* predicted results
** data insufficient for prediction

### Table 8
Plate Nonlinear Analysis on the UCS UNIVAC 1100/81

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>CPU Time (sec)</th>
<th>I/O Time (sec)</th>
<th>Core Storage Kwords</th>
<th>Turnaround Time (min)</th>
<th>Cost (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>19.97</td>
<td>0.35</td>
<td>22.9</td>
<td>32:47</td>
<td>4.61</td>
</tr>
<tr>
<td>72</td>
<td>54.15</td>
<td>0.66</td>
<td>28.4</td>
<td>38:01</td>
<td>13.13</td>
</tr>
<tr>
<td>143</td>
<td>156.91</td>
<td>1.29</td>
<td>42.5</td>
<td>55:10</td>
<td>42.68</td>
</tr>
<tr>
<td>289</td>
<td>549.69</td>
<td>1.78</td>
<td>76.0</td>
<td>137:21</td>
<td>189.33</td>
</tr>
<tr>
<td>600*</td>
<td>2030.59</td>
<td>3.59</td>
<td>175.7</td>
<td>650:43</td>
<td>1151.80</td>
</tr>
</tbody>
</table>

* estimates

### Table 9
Plate Nonlinear Analysis on the IIT PRIME 400

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>CPU Time (sec)</th>
<th>I/O Time (sec)</th>
<th>Response Time (min)</th>
<th>Cost (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>156.01</td>
<td>2.74</td>
<td>7:08</td>
<td>3.29</td>
</tr>
<tr>
<td>72</td>
<td>379.95</td>
<td>3.81</td>
<td>10:09</td>
<td>7.84</td>
</tr>
<tr>
<td>143</td>
<td>978.05</td>
<td>19.47</td>
<td>29:59</td>
<td>20.45</td>
</tr>
<tr>
<td>289</td>
<td>2693.59</td>
<td>69.70</td>
<td>70:50</td>
<td>56.44</td>
</tr>
<tr>
<td>600*</td>
<td>8693.00</td>
<td>267.91</td>
<td>204:14</td>
<td>193.06</td>
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</table>

* estimates

### Table 10
Comparison of the Cost (in Dollars) of Nonlinear Analysis of the 289 and 600 Node Plate Models on Various Computers Using the TWODEL Program

<table>
<thead>
<tr>
<th>Computer System</th>
<th>CPU Time (sec)</th>
<th>Core+ Time (sec)</th>
<th>Cost (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IIT PRIME 400</td>
<td>2694.</td>
<td>8693.</td>
<td>56.44</td>
</tr>
<tr>
<td>NASA LRC PRIME 400*</td>
<td>2694.</td>
<td>8693.</td>
<td>40.13</td>
</tr>
<tr>
<td>UCS UNIVAC 1100/81*</td>
<td>550.</td>
<td>2030.6</td>
<td>189.33</td>
</tr>
<tr>
<td>LMC CDC CYBER 176*</td>
<td>58.8</td>
<td>217.1</td>
<td>12.52</td>
</tr>
<tr>
<td>Concordia College UNIVAC*</td>
<td>1238.</td>
<td>4570.7</td>
<td>203.03</td>
</tr>
</tbody>
</table>

* estimates; + UCS UNIVAC 1100/81 and LMC CDC CYBER 176 core requirements are given in K words. Concordia College UNIVAC core requirements are given in K bytes.

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Table 11
Cylinder Buckling and Vibration Analysis on the UCS UNIVAC 1100/81

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>CPU Time (sec)</th>
<th>I/O Time (sec)</th>
<th>Turnaround Time (min)</th>
<th>Cost (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>27.28</td>
<td>19.34</td>
<td>7.09</td>
<td>7.36</td>
</tr>
<tr>
<td>121</td>
<td>110.65</td>
<td>28.16</td>
<td>10.11</td>
<td>29.21</td>
</tr>
<tr>
<td>256</td>
<td>302.59</td>
<td>48.45</td>
<td>19.52</td>
<td>79.97</td>
</tr>
</tbody>
</table>

Table 12
Cylinder Buckling and Vibration Analysis on the IIT PRIME 400

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>CPU Time (sec)</th>
<th>I/O Time (sec)</th>
<th>Turnaround Time (min)</th>
<th>Cost (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>579.93</td>
<td>343.28</td>
<td>64</td>
<td>19.53</td>
</tr>
<tr>
<td>121</td>
<td>3197.10</td>
<td>1164.54</td>
<td>156</td>
<td>90.23</td>
</tr>
<tr>
<td>256</td>
<td>10784.0</td>
<td>6589.98</td>
<td>774</td>
<td>360.38</td>
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</tbody>
</table>

Table 13
Comparison of the 256 Cylinder Problem on Various Computers

<table>
<thead>
<tr>
<th>Computer</th>
<th>CPU Time (sec)</th>
<th>I/O Time (sec)</th>
<th>Total Cost (dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IIT PRIME 400*</td>
<td>10784</td>
<td>6590</td>
<td>360.38</td>
</tr>
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<td>10784</td>
<td>6590</td>
<td>283.37</td>
</tr>
<tr>
<td>UCS UNIVAC 1100/81</td>
<td>302.59</td>
<td>48.45</td>
<td>79.97</td>
</tr>
<tr>
<td>Concordia College</td>
<td>680.8</td>
<td>--</td>
<td>110.96</td>
</tr>
<tr>
<td>UNIVAC 90/80*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LMC CDC CYBER 176*</td>
<td>58.2</td>
<td>24.2</td>
<td>12.64</td>
</tr>
<tr>
<td>NASA LRC CYBER 173*</td>
<td>453.9</td>
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<td>29.55</td>
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Table 14
Direct Integration Transient Response of Stiffened Cylinder

<table>
<thead>
<tr>
<th>Number of Nodes</th>
<th>CPU Time (sec)</th>
<th>I/O Time (sec)</th>
<th>Turnaround Time (min)</th>
<th>Cost (dollars)</th>
</tr>
</thead>
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<tr>
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<td>3.59</td>
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<tr>
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<td>12.3</td>
<td>10.7</td>
<td>4</td>
<td>6.12</td>
</tr>
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<td>CYBER 176</td>
<td>7.8</td>
<td>26.6</td>
<td></td>
<td>14.40</td>
</tr>
<tr>
<td>VAX 11/780</td>
<td>65.12</td>
<td>--</td>
<td>3.1</td>
<td>3.26</td>
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<tr>
<td>121 - PRIME 400</td>
<td>2795</td>
<td>528.8</td>
<td>147</td>
<td>68.93</td>
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<td>133.7</td>
<td>66.1</td>
<td>14.9</td>
<td>42.50</td>
</tr>
<tr>
<td>VAX 11/780</td>
<td>1049.38</td>
<td>--</td>
<td>28.7</td>
<td>52.47</td>
</tr>
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<td>10411</td>
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<td>470</td>
<td>249.20</td>
</tr>
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<td>UNIVAC 1100/81</td>
<td>493.8</td>
<td>2423.2</td>
<td>120</td>
<td>556.70</td>
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Fig. 1 - Comparison of total cost for beam problem using the SPAR program
Fig. 2 - A typical model for plate with hole problem
Fig. 3 - Comparison of total cost for plate problem using the SPAR program

Fig. 4 - Comparison of total cost for plate problem using the SAP IV program

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Fig. 5 - Comparison of total cost for plate problem using the TWODEL program
Fig. 6 - A typical cylinder model