AN EVALUATION OF SUPERMINICOMPUTERS
FOR THERMAL ANALYSIS

By

Olaf O. Storaasli[*], James B. Vidal[**], Gary K. Jones[***]

INTRODUCTION

The computer hardware on which thermal analysis is run now and will be run in the future is undergoing significant changes as shown in figure 1. The past and projected market share for mainframes, minicomputers, and microcomputers is shown on the left of figure 1 (refs. 1 and 2). The figure shows a dramatic decrease in market share for mainframe computers as the minicomputers and microcomputers become capable of solving problems formerly solved on mainframes only. Figure 1 shows on the right the most dramatic increase in revenues is projected to be for 32-bit minicomputers to reach 4.3 billion dollars by 1985. In a parallel effort, 32-bit microcomputers (CPU on a chip) with virtual memory and Winchester disk drives are being introduced (micromainframes) which promise to provide mainframe capability in smaller packages at significantly reduced cost (i.e., "VAX on a chip"). The cost vs. capability or "cost-effectiveness" is the driving factor in the choice of future computing capability. The economy of scale criteria used to justify large centralized computer complexes is being challenged by wide-scale use of inexpensive minicomputers which are proliferating in much the same way as hand-held calculators.

Minicomputers of the past were not considered for complex thermal analysis because of insufficient memory, speed, accuracy, and secondary storage. However, two factors have changed the situation: (1) the introduction of virtual memory operating systems, and (2) 32-bit word architecture on minicomputers to produce so-called "superminicomputers." Virtual memory operating systems allow all software and problems (regardless of size) currently running on mainframe computers to run on minicomputers (albeit slower) by using disk memory as an extension of real memory. The 32-bit architecture (with 64-bit double precision) provides the necessary accuracy and compatibility with large computers to simplify software conversion.

The object of this paper is to evaluate the use of superminicomputers for thermal analysis by solving a series of increasingly complex thermal analysis problems on both superminicomputers and large mainframe computers. The approach involved (1) installation and verification of the SPAR thermal analyzer software on superminicomputers at Langley Research Center and Goddard Space Flight Center, (2) solution of six increasingly complex thermal problems on this equipment, and (3) comparison of solution (accuracy, CPU time, turnaround time, and cost) with solutions on large mainframe computers.

---

*   NASA-Langley Research Center, Hampton, VA 23665.
** Digital Equipment Corporation, Richmond, VA 23229.
***NASA-Goddard Space Flight Center, Greenbelt, MD 20771.

COMPUTER TERMS

Although minicomputer-related technology is rapidly changing, the
following definitions should help to clarify terminology used in the paper.

Microcomputer:

4 to 6 bit computer with the CPU on a single chip.
Cost: $100 to $15,000

Micromainframe:

32-bit computer with the CPU on from 1 to 3 chips.
Cost: $4,000 to $40,000

Minicomputer:

16 to 32 bit computer with the CPU consisting of
components on a CPU board.
Cost: $15,000 to $100,000

Superminicomputer:

32-bit minicomputer with virtual memory
operating system.
Cost: $50,000 to $500,000

Mainframe Computer:

32 to 64 bit computer with a conventional CPU
on many boards.
Cost: Millions of dollars

Supercomputer:

64-bit computer with high-speed CPU.
Cost: Tens of millions of dollars

Virtual Memory:

Storage technique in which disk memory is used
to augment real memory.

CAD/CAM:

Computer-aided design/computer-aided manufacturing.

Turnaround:

Wall clock time elapsed from initiation to
completion of computations (function of other
activity on the computer).

Byte:

Unit of computer storage equivalent to one
character of 8 bits (i.e., 200 MB = 200 million
characters).

DECNET:

Digital Equipment Corporation NETwork facility
to communicate with other DEC computers.

UT200:

Control Data Corporation protocol for remote.

PRIMENET:

PRIME Computer NETwork facility.

SUPERMINICOMPUTER HARDWARE AND SOFTWARE

The configuration of the Langley superminicomputer used in this study is shown in figure 2. It consists of a Digital Equipment Corporation (DEC) 32-bit VAX 11/780 CPU with 1 million bytes (characters) of memory, 0.2 billion bytes of disk memory, a tape drive, remote communications (DECNET, UT200), and 16 terminal ports. The 32-bit architecture provides the engineer with approximately seven or more decimal digits of accuracy. In addition, a second superminicomputer at Langley was used to cross-reference and plot results. It consists of a 32-bit PRIME 750 CPU with 2 million bytes of memory, 0.3 billion bytes of disk memory, a tape drive, printer, remote communications (PRIMENET, UT200), and 16 terminal ports. Both the VAX and PRIME 750 have virtual memory operating systems permitting users to address in excess of 4 billion bytes. This large address space simplifies conversion of thermal analysis software from large mainframe computers.

The configuration of the Goddard superminicomputer (one of fifteen) used in this study is shown in figure 3. It consists of a VAX CPU with four million bytes of memory, 0.1 billion bytes of disk storage, three tape drives, two line printers, card reader, 64-bit array processor, remote communications (DECNET), and 32 terminal ports.

The thermal analysis capability contained in the SPAR finite element structural analysis software (ref. 3) was recently installed and tested using six test problems on both the Control Data Corporation (CDC) CYBER 175 and 203 computers at Langley (ref. 4). Since the basic SPAR software had already been converted to both VAX and PRIME superminicomputers (refs. 5 to 9), the new thermal analysis processor software and six sample problems were transferred from the CDC CYBER to the VAX and PRIME superminicomputers via the UT200 communications link. Several software modifications were made to COMMON block dimensions of the thermal processors to take advantage of virtual memory. Also, slight changes were made to the six input files to reflect the character differences contained in the following table. These are special characters used for SPAR free field input.

Function	CDC 175 203	VAX	UNIVAC	PRIME
Text/File	" '	'	'	#
Record Term	; ;	; or :	:	:
Continuation	% >	>	>	%

The disk input/output subroutines are critical for optimum performance and much could be done to improve the performance of both VAX and PRIME by rewriting these routines as was done on the mainframe. However, for this study, the code was not optimized and the code used was 100 percent FORTRAN. The CYBER 203 results also reflected a minimal use of vectorization.

The following table shows the equivalent CPU charges and accuracy for the computers used in the study based on Langley charging algorithms which have considerable variation on the CYBER due to I/O charges.

Computer	Bits/word	Cost/CPU hour	Significant digits
CDC CYBER 203	64	1492 to 4963[a]	14
CDC CYBER 175	60	735 to 3717[a]	13
PRIME 750 LaRC	32	56	7
DEC VAX 11/780 LaRC	32	33	7

[a]varies according to CPU I/O mix

THERMAL ANALYSIS TEST PROBLEMS

A detailed description of the six thermal analysis test problems is contained in reference 4. Additional descriptions of four of the problems and the algorithms used in transient thermal analysis are contained in reference 10. Figure 4 shows an insulated Space Shuttle orbiter test frame tested under transient heating as described in reference 11. The figure shows an aluminum frame with 190 grid points and 158 elements surrounded by insulation with applied surface temperatures causing conduction in the aluminum structure and insulation, and radiation across the air gap. The material properties are updated every 50 seconds to allow for changes in properties of aluminum and insulation which are functions of temperature and temperature and pressure, respectively. A temperature history at 10 second intervals for 1000 seconds is required.

A model of a 30-meter deployable antenna with 55 grid points and 183 conduction and radiation elements is shown in figure 5. It is subjected to solar radiation heating with interelement time-dependent shadowing considered. A temperature history every 0.01 hour for 24 hours is required.

A model of a single bay of the Shuttle orbiter wing with 123 grid points and 151 elements subject to time-dependent surface heating is shown in figure 6. The model is subject to interelement and space radiation for which a temperature history is required every second for 2500 seconds.

A model of the Space Shuttle orbiter wing with 1542 grid points and 2125 rod triangle and quadrilateral elements subjected to aerodynamic surface heating is shown in figure 7. The external insulation on each surface is modeled by five layers of solid prismatic elements. The material properties were updated in time steps of 100 seconds and the temperature history for 3000 seconds was required.

A half-model of an insulated cylinder with 800 grid points and 650 elements subjected to time-dependent surface heating along the shaded region is shown in figure 8. The material properties were updated every 200 seconds and a temperature history is required every 10 seconds for 2000 seconds.

A model of a multiwall thermal protection system with 333 grid points and 1096 elements located on nine titanium sheets subject to transient temperature imposed at the outer surface of the panel is shown in figure 9. It is assumed that the heat load does not vary in directions parallel to the plane of the panel. A temperature history of 2000 seconds with 1 second intervals is required.

TEST PROCEDURE

The results for the test cases were first obtained on the Langley VAX and then compared with the CYBER 175 and 203 (ref. 4) shown in figure 10. The six test problems were run on the VAX in both heavy use and dedicated environments to evaluate performance. The updated SPAR software with new thermal processors, together with the six sample problems, were transferred to and run on a NASA-Goddard VAX for performance evaluation. Three of the sample problems were also run on the Langley PRIME to evaluate the performance of a superminicomputer from a different manufacturer.

For many cases, the thermal analysis software evaluation was only one of many applications running concurrently on the superminicomputers. Other competing applications included the modification, recompilation, and use of computer-aided design/computer-aided manufacturing (AD-2000, refs. 12 and 13), date base management and finite element modeling, and analysis software.

RESULTS

Figure 10 shows the implicit Frank-Nicholson algorithm solution times (CPU and elapsed) and cost for all six test cases (across the top) for four computers in decreasing size (down the left). The figure shows three entries for each sample problem for each computer. For example, the entries for the Space Shuttle frame on the VAX means the solution took 128 CPU seconds, 278 elapsed seconds, and cost $1.17.

Figure 10 shows that, in general, the Langley VAX was representative of other superminis in that it was somewhat faster than the Goddard VAX and somewhat slower than the PRIME 750. It is expected that the VAX elapsed (and possibly CPU time) results would be significantly faster if fast disk utility calls were used instead of the 100 percent FORTRAN I/O used. The elapsed times are primarily an indication of competing CAD/CAM and analysis applications running concurrently and subject to change as the demand on the CPU changes. Recently announced superminicomputers (i.e., PRIME 850, ref. 14) drastically reduce such elapsed times through the use of dual processors. The results shown in figure 10 are further broken down in figures 11, 12, and 13 for CPU time, elapsed (wall) time, and cost, respectively.

The percent of the VAX CPU time (log scale) of the PRIME 750 and CYBER 175 and 203 computers is shown in figure 11 for each of the six sample problems (represented by bars). The numbers (and corresponding shading) above the bars in figure 11 indicate the actual CPU time taken by the VAX in seconds. The figure shows that the CYBER 175 takes slightly more than 5 percent of the Langley VAX CPU time, the CYBER 203 slightly less than 5 percent, and the PRIME 750 slightly less than the VAX.

The elapsed (wall) time with the maximum value indicated at the top of each bar is shown in figure 12. The figure shows that for the typical loadings (applications) on the computers, the elapsed (wall) time on the superminis was about the same as on mainframe computers. A low showing on this chart may indicate low utilization of a machine.

The cost comparison for the various computers as a function of the maximum cost in dollars is shown at the top of each bar in figure 13. For all problems, the lowest cost was for the VAX with the Langley PRIME 750 about 10 percent higher. The minimum cost to obtain solutions on superminicomputers ranged from 11 to 59 percent of the maximum cost which was accrued on the main-frames. Figure 13 shows the CYBER 203 solutions to be the most costly for the largest and smallest problems, while the CYBER 175 produced the maximum cost for the other four problems.

The general conclusions to be drawn from the results shown in figures 10 to 13 are that superminis under similar loadings with mainframe computers will produce results (elapsed wall time) in approximately the same elapsed time with the superminis taking about 20 times as much CPU time, but costing only 11 to 59 percent of the cost of mainframe solutions. The accuracy of the supermini-computer results from all machines agreed with the CDC mainframe results for all problems to within five significant digits (except for one case where several numbers out of several thousand of one-time history degraded to three significant digits). If increased accuracy is necessary, double precision (64-bit accuracy) is available on both the VAX and PRIME 750 superminicomputers at the expense of additional CPU time. However, it was felt that the five-place accuracy obtained for the superminicomputer results was suitable for this study.

CONCLUDING REMARKS

This paper demonstrates the feasibility and cost-effectiveness of solving thermal analysis problems (both large and small) on interactive superminicomputers. The installation of the SPAR thermal analyzer software on superminicomputers was relatively straightforward since the SPAR data base management was already converted to both PRIME 750 and VAX minicomputers. The interactive features, high speed terminal communications, "user friendly" features of the operating systems, and communications software between the superminicomputers and mainframe computers made the software conversion, evaluation, and testing of the test cases possible in a fraction of the time normally required. The five-place accuracy of the results on the supermini-computers for single precision was better than expected so that the double precision options on the superminicomputers were not required. The time results showing superminicomputers taking about 20 times as much CPU time is about as expected based on the relative CPU speed of the superminicomputer and mainframe processors. The fact that both superminicomputers and mainframes take approximately the same elapsed time for the solutions was surprising. It may be advantageous from an elapsed time standpoint to solve problems on supermini-computers during off-hours since results are likely not to be available on a typically loaded mainframe any faster. The elapsed time on all single processor machines is a function of the number of concurrent computations, and the good performance shown by the CYBER 203 and bad performance of the CYBER 175 are possibly due to low and high utilization, respectively.

The solution cost for superminicomputers ranged from 11 to 59 percent of the mainframe solution costs. One of the important factors leading to the cost-effectiveness shown in the results is the low purchase cost (resulting from high production rates) of superminicomputers. It is felt that the cost-effectiveness and capability demonstrated by the superminicomputers in this paper adds impetus to the trend to produce superminicomputer capability (32-bit architecture with virtual memory) in smaller, less expensive packages.

REFERENCES

1. Micro Mart Growth Seen Threat to IBM. Computerworld, vol. XV, no. 25, June 22, 1981, p. 65.

2. Low-End 32-Bit Minis Join High-End Supermicros in Siege on Traditional 16-Bit Mart. Computerworld, vol. XV, no. 40, Oct. 5, 1981, pp. 67, 71.

3. Marlowe, M. B.; Moore, R. A.; and Whetstone, W. D.: SPAR Thermal Analysis Processors Reference Manual, System Level 16. Volume 1: Program Execution. NASA CR-159162, 1979.

4. Robinson, James C.; Riley, M.; and Haftka, R. T.: Evaluation of the SPAR Thermal Analyzer on the CYBER-203 Computer. Computational Aspects of Heat Transfer in Structures, NASA CP-2216, 1982, pp. 395-414.

5. Storaasli, Olaf O.; and Murphy, Ronald C.: Finite Element Analysis in a Mini-computer/Mainframe Environment. Research in Computerized Structural Analysis and Synthesis, NASA CP-2059, 1978, pp. 77-88.

6. Foster, Edwin P.; and Storaasli, Olaf O.: Using SPAR Structural Analysis on a Minicomputer. Seventh Conference on Electronic Computation, American Soc. Civ. Eng., c.1979, pp. 363-373.

7. Foster, Edwin P.; and Storaasli, Olaf O.: Structural Analysis on a Minicomputer. Engineering Software, R. A. Adey, ed., Pentech Press (London: Plymouth), c.1979, pp. 43-54.

8. Storaasli, Olaf O.; and Foster, Edwin P.: Cost-Effective Use of Minicomputers to Solve Structural Problems. J. Aircr., vol. 16, no. 11, Nov. 1979, pp. 775-779.

9. Storaasli, Olaf O.: On the Role of Minicomputers in Structural Design. Comput. & Struct., vol. 7, no. 1, Feb. 1977, pp. 117-123.

10. Adelman, Howard M.; and Haftka, Raphael T.: On the Performance of Explicit and Implicit Algorithms for Transient Thermal Analysis of Structures. NASA TM-81880, 1980.

11. Gallegos, J. J.: Thermal Math Model Analysis of FRSI Test Article Subjected to Cold Soak and Entry Environments. A Collection of Technical Papers - AIAA/IES/ASTM 10th Space Simulation Conference, Oct. 1978, pp. 131-136. (Available as AIAA Paper 78-1627.)

12. Storaasli, Olaf O.: Integrated Computer-Aided Design Using Minicomputers. Preprint 80-671, American Soc. Civil Eng., Oct. 1980.

13. Blackburn, C. L.; Dovi, A. R.; Kurtze, W. L.; and Storaasli, O. O.: IPAD Applications to the Design, Analysis, and/or Machining of Aerospace Structures. A Collection of Technical Papers, Part 1 - AIAA/ASME/ASCE/AHS 22nd Structures, Structural Dynamics & Materials Conference, Apr. 1981, pp. 96-104. (Available as AIAA-81-0512.)

14. Scannell, Tim: Prime Supermini Most Powerful Yet. Computerworld, vol. XV, no. 16, Apr. 20, 1981, pp. 1, 8.

Equipment	1956	1966	1976	1986
Mainframes ($100,000 and Up)	100%	70%	16%	1%
Minicomputers ($15,000 to $100,000)	—	30%	75%	31%
Microcomputers (Less than $15,000)	—	—	9%	68%

Source: The Gartner Group

UNIT SHIPMENTS
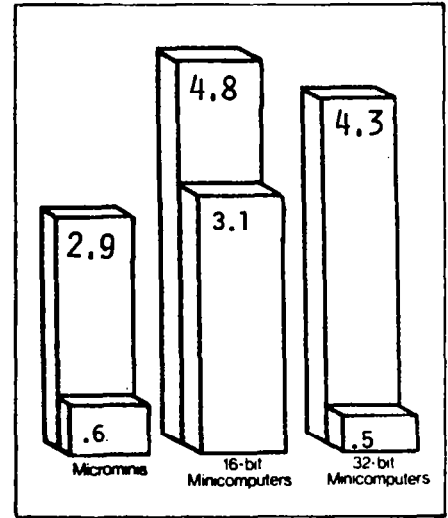
REVENUE IN BILLIONS
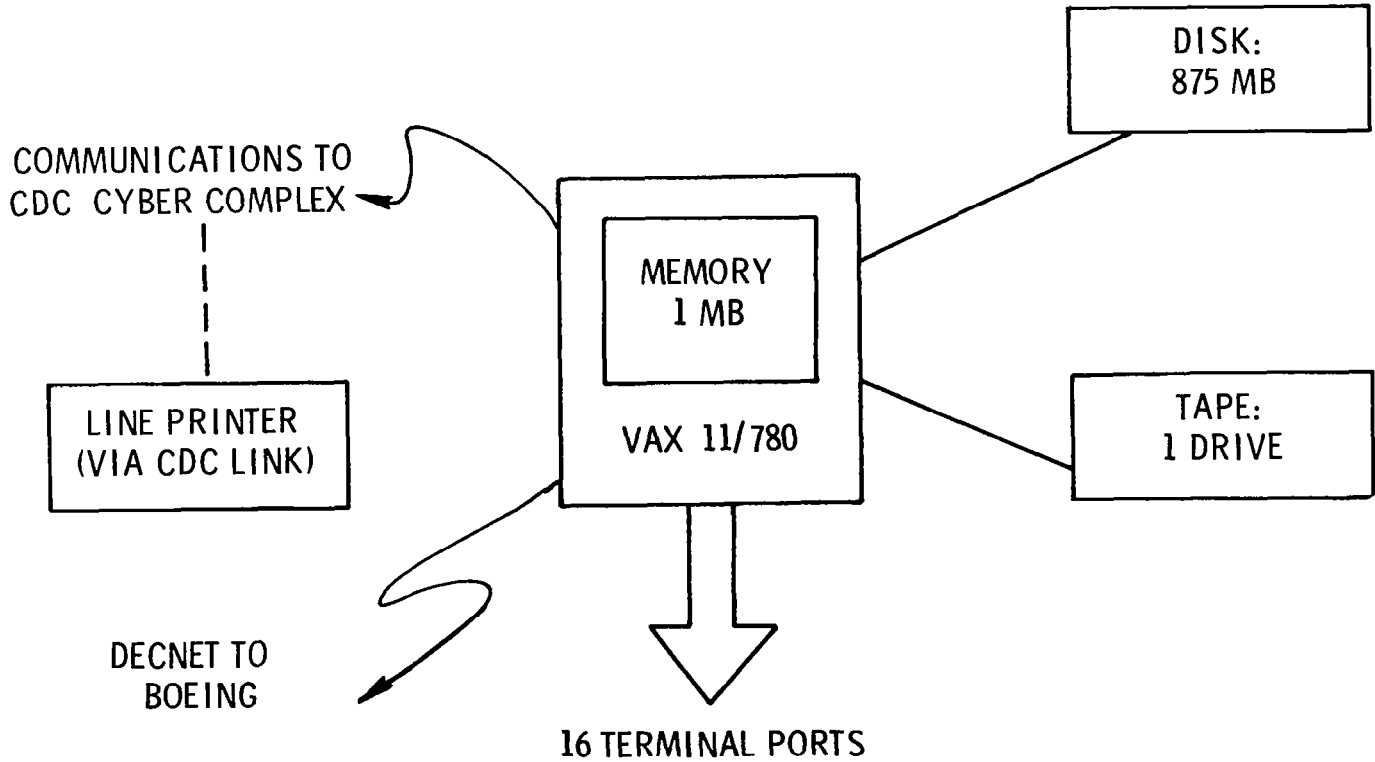(1980-1985)

Figure 1.- Past and future computer environment.
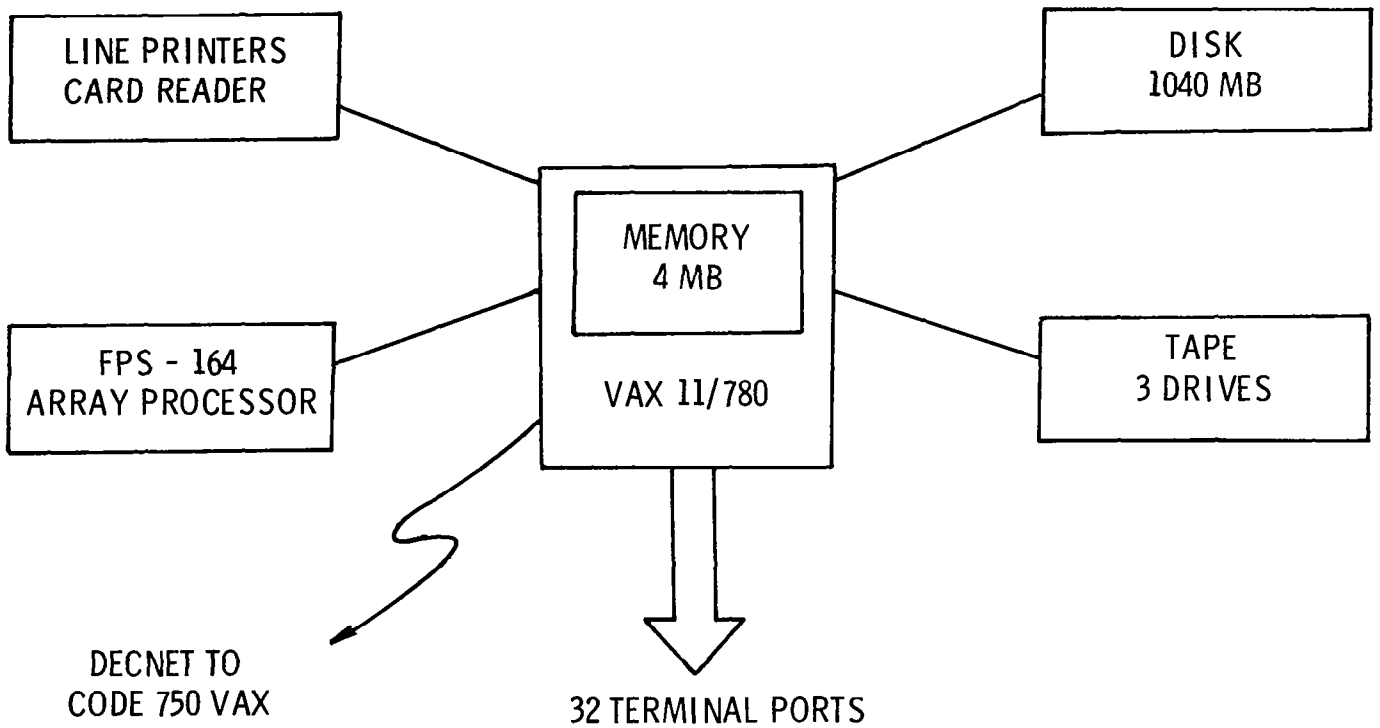
Figure 2.- Langley VAX superminicomputer system.
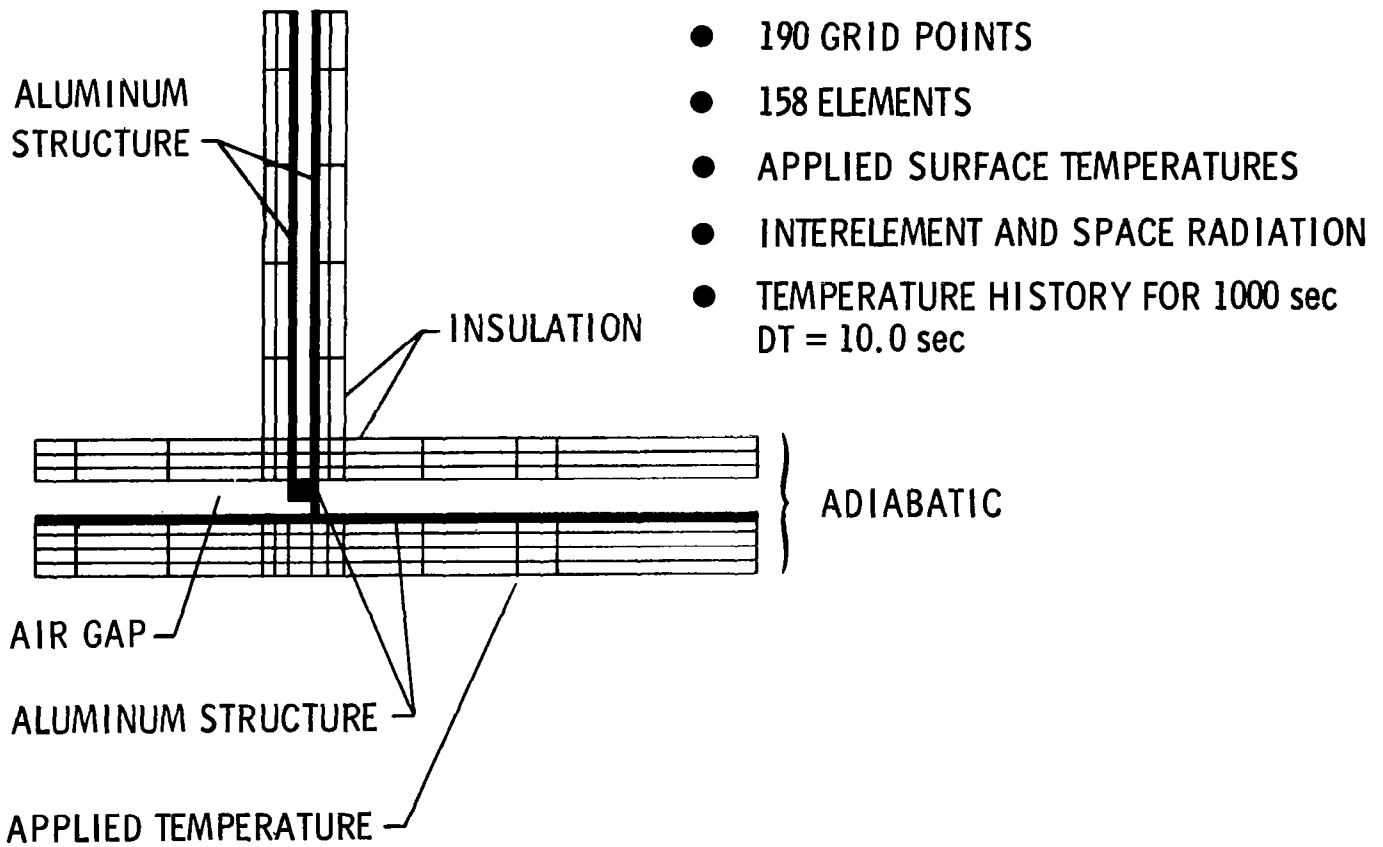
Figure 3.- Goddard Code 730 superminicomputer system.

- 190 GRID POINTS
- 158 ELEMENTS
- APPLIED SURFACE TEMPERATURES
- INTERELEMENT AND SPACE RADIATION
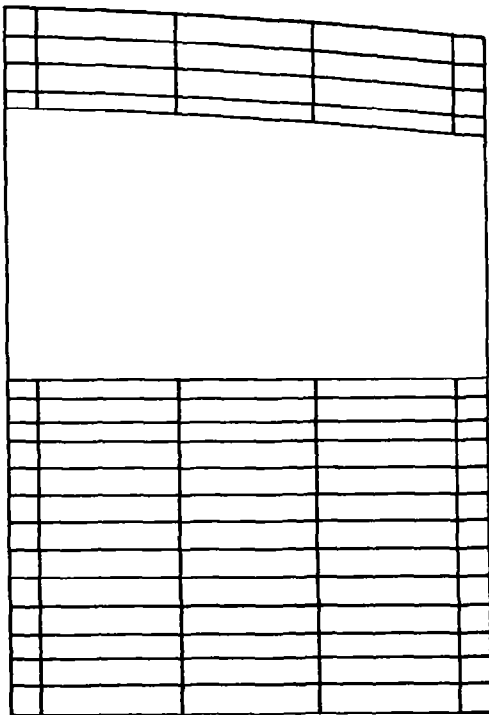- TEMPERATURE HISTORY FOR 1000 sec DT = 10.0 sec

Figure 4.- Insulated Space Shuttle test frame model.
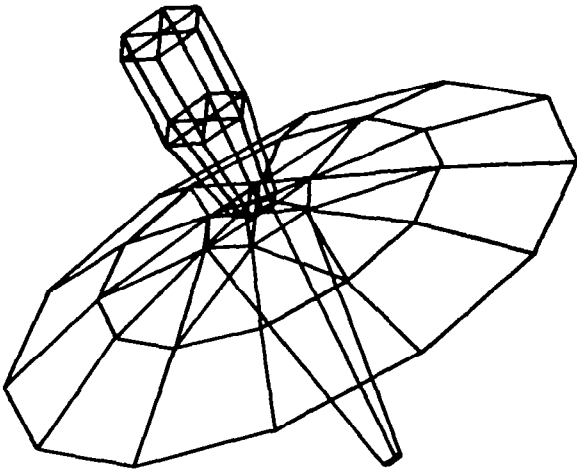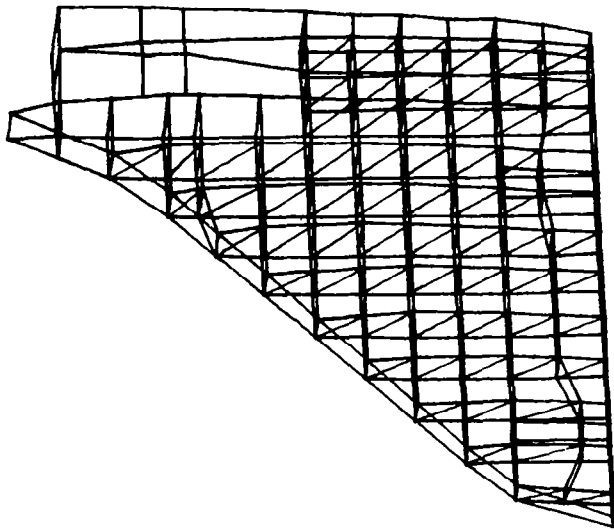
- 55 GRID POINTS
- 183 ELEMENTS
- INTERELEMENT RADIATION
- TIME-DEPENDENT SHADOWING
- TEMPERATURE HISTORY FOR 24 HOURS
  DT = .01 hr

Figure 5.- 30-meter deployable antenna model.

- 123 GRID POINTS
- 151 ELEMENTS
- TIME DEPENDENT SURFACE HEATING
- INTERELEMENT AND SPACE RADIATION
- TEMPERATURE HISTORY FOR 2500 sec
  DT = 1.0 sec

Figure 6.- Space Shuttle orbiter wing-bay model.

- 1542 GRID POINTS
- 2125 ELEMENTS
- APPLIED SURFACE TEMPERATURES (AERO HEATING)
- 1-D ELEMENTS USED FOR RSI
- TEMPERATURE HISTORY FOR 3000 sec DT = 100.0 sec

Figure 7.- Space Shuttle orbiter wing model.

REGION OF APPLIED HEATING
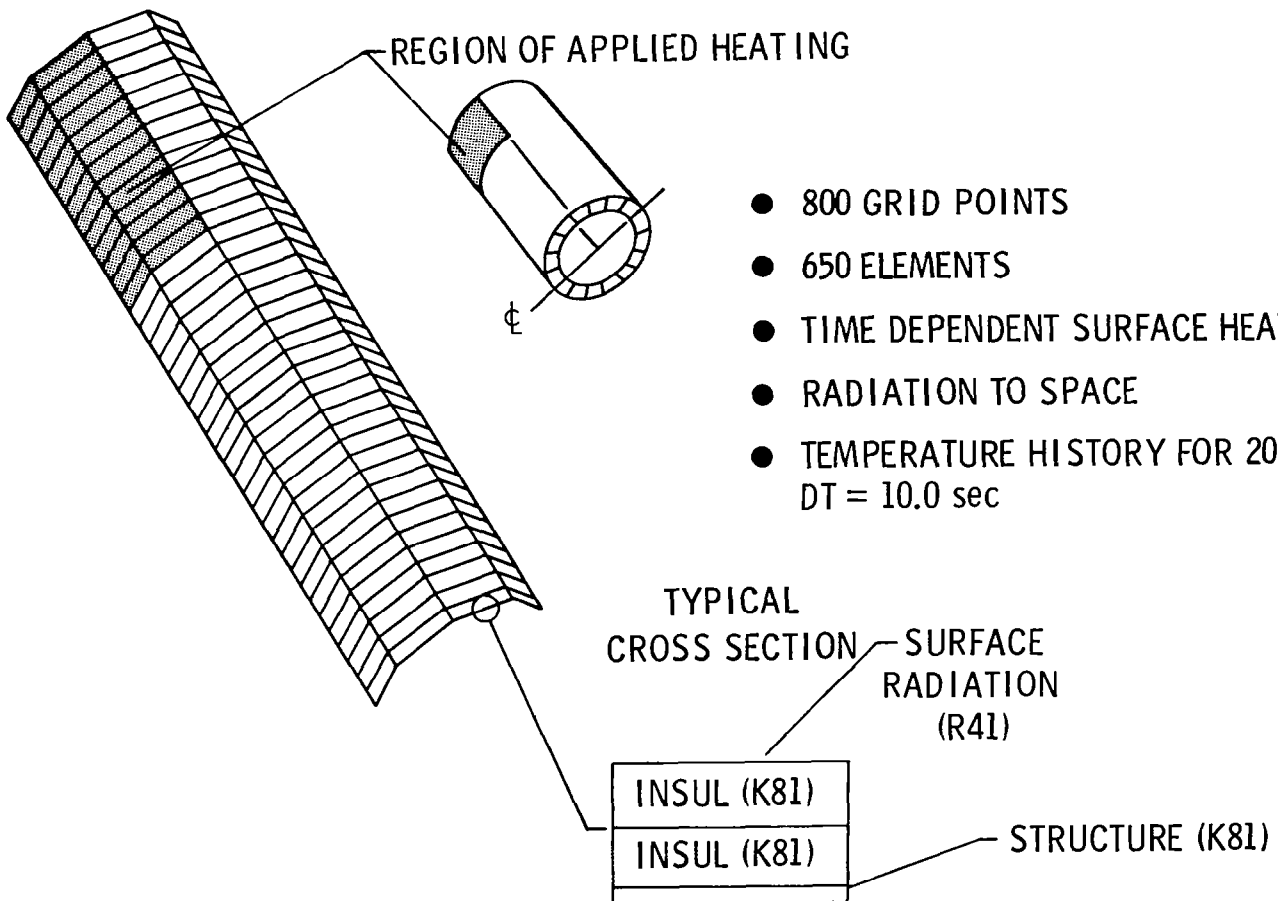
- 800 GRID POINTS
- 650 ELEMENTS
- TIME DEPENDENT SURFACE HEATING
- RADIATION TO SPACE
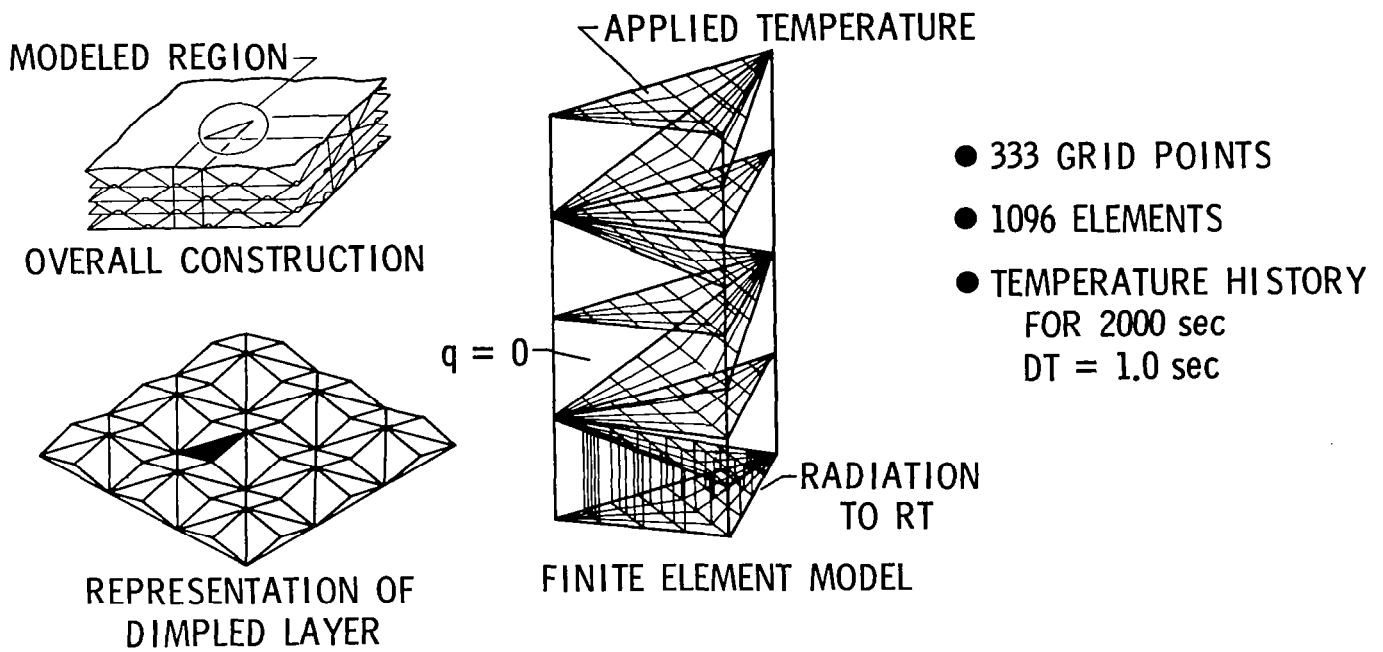- TEMPERATURE HISTORY FOR 2000 sec DT = 10.0 sec

TYPICAL CROSS SECTION — SURFACE RADIATION (R41)

INSUL (K81)

INSUL (K81)

STRUCTURE (K81)

Figure 8.- Insulated cylinder model.

MODELED REGION⌐

OVERALL CONSTRUCTION

REPRESENTATION OF
DIMPLED LAYER

⌐APPLIED TEMPERATURE

q = 0

RADIATION
TO RT

FINITE ELEMENT MODEL

● 333 GRID POINTS

● 1096 ELEMENTS

● TEMPERATURE HISTORY
FOR 2000 sec
DT = 1.0 sec

Figure 9.- Multiwall thermal protection system model.

COMPUTER	TEST CASES,	CPU (SEC)/ELAPSED (SEC) COST $				
	SHUTTLE FRAME	ANTENNA	SHUTTLE PANEL	SHUTTLE WING	CYLINDER	MULTIWALL
CDC 203	8/13 11.03	32/429 20.80	58/64 34.00	86/120 39.00	68/78 31.85	149/720 61.75
CDC 175	8/91 3.92	46/1306 41.16	88/2199 61.21	145/24000 149.30	164/5708 45.26	223/28949 44.92
PRIME 750	121/170 1.89	672/4025 10.45	1084/2512 16.86	-	-	-
VAX 11/780 (LRC)	128/278 1.17	936/3275 8.58	1264/2494 11.59	1840/9199 16.86	2013/3366 18.45	3060/4357 28.05

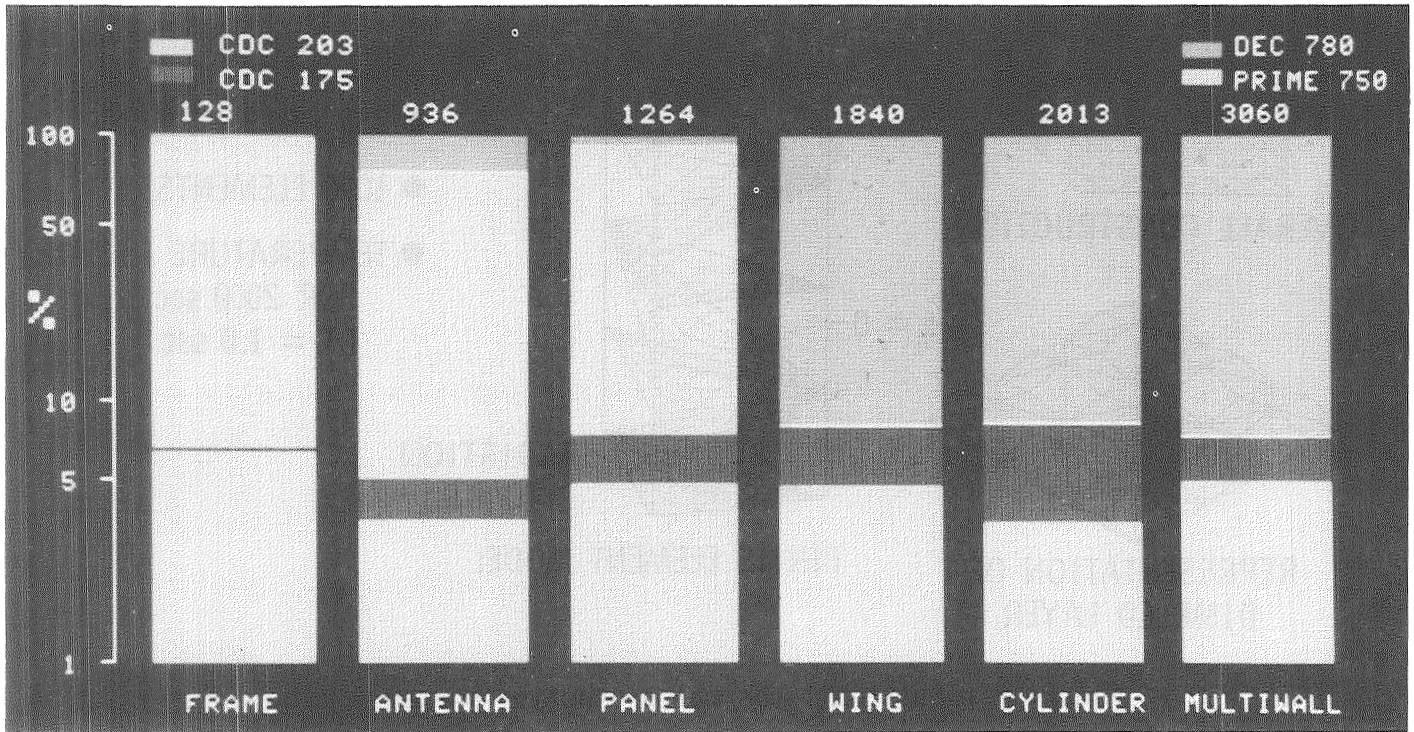Figure 10.- Computer time and cost comparison.

Figure 11.- Computer CPU time comparison. Numbers above bars indicate actual CPU time taken by VAX in seconds.
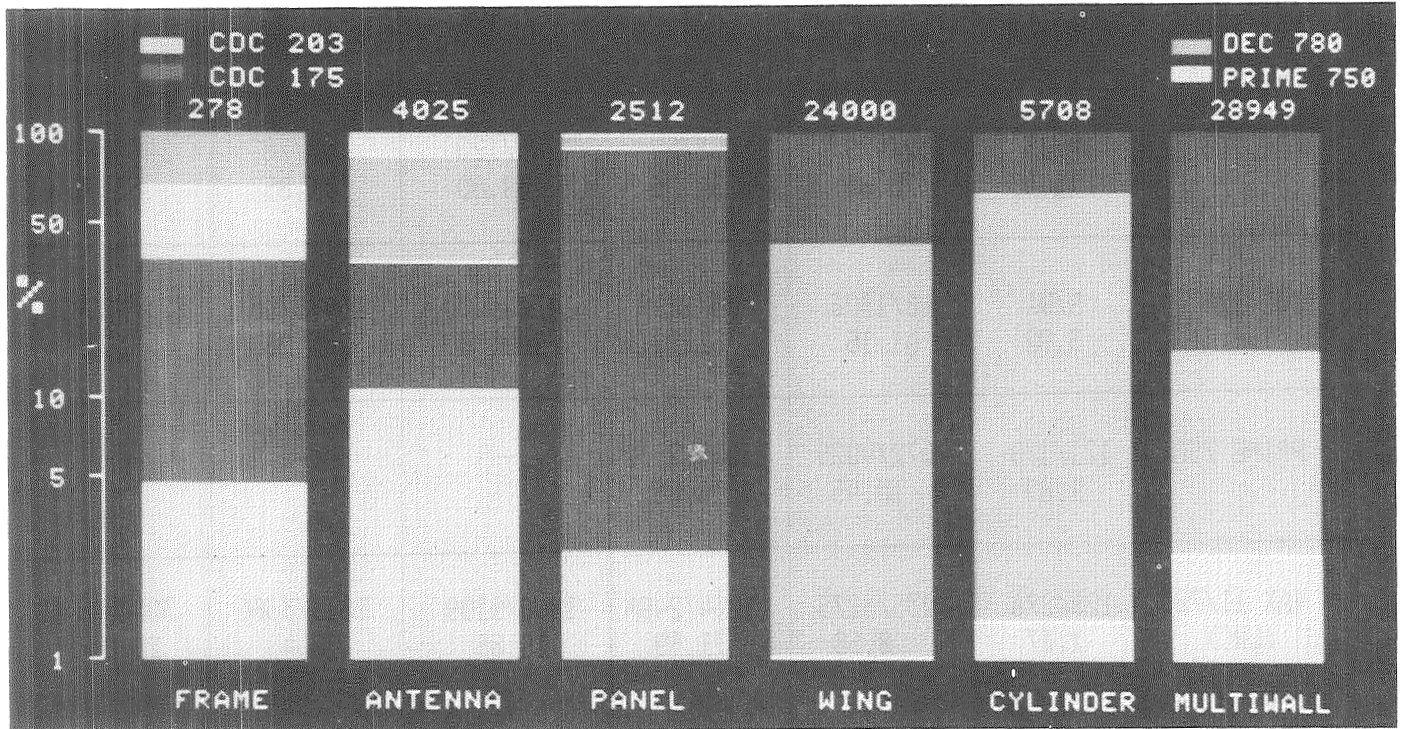

Figure 12.- Computer solution (elapsed) time comparison. Numbers above bars indicate maximum value of elapsed (wall) time.
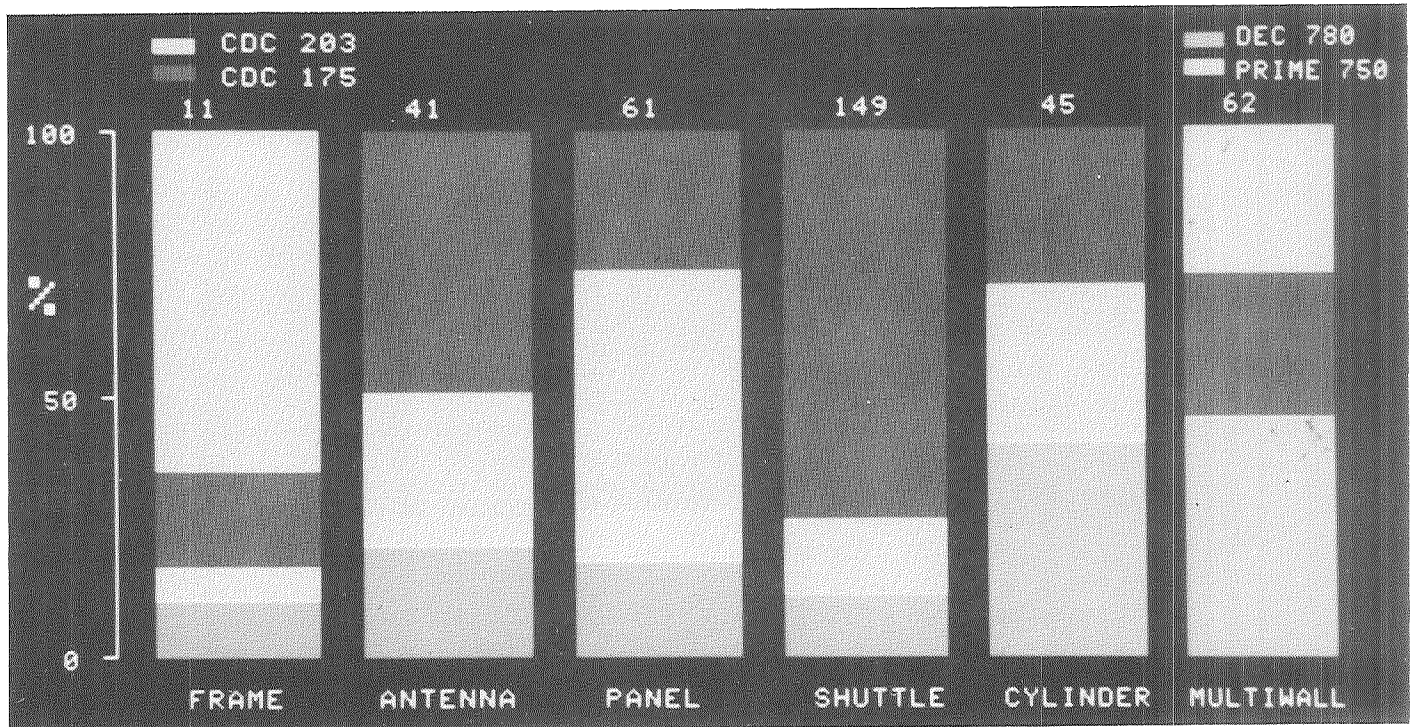
Figure 13.- Computer cost comparison. Numbers above bars indicate maximum cost in dollars.