Pentium® Pro Processor Workstation Performance Brief

September 1996

Order Number: 242999-001

Intel Corporation
P.O. Box 7641
Mt. Prospect, IL 60056-7641

or call 1-800-879-4683

CONTENTS

FIGURES

TABLES

INTRODUCTION

[1]This performance brief compares the performance of Pentium® Pro processor systems to other non-Intel processor-based workstations, such as those based on the SPARC*, MIPS*, PowerPC*, PA-RISC*, and Alpha* architectures. Traditionally, Intel Architecture processors have been used in personal computers running operating systems like DOS* and Windows* for business and personal productivity applications such as word processing, spreadsheets, and presentations. Workstations have been used for scientific and technical applications such as mechanical computer-aided design and analysis (MCAD), electronic computer-aided design (ECAD), scientific modeling and analysis, high performance graphics and imaging, and other computationally intensive tasks. Workstations often include two-dimensional and three-dimensional graphics accelerators.

The distinction between a personal computer and a workstation has been based on processor performance, operating system features, graphics capabilities, and applications. Today, that distinction is being blurred by the availability of high performance Pentium Pro processors that are being used in workstation and server products from a variety of vendors. The widespread adoption of PCI as a high speed peripheral interconnect has allowed workstation-class graphics accelerators to be attached to Pentium and Pentium Pro processor-based systems. The availability of UNIX*, Microsoft Windows NT*, SCSI disks and high-speed network connectivity on the Intel architecture provides robust multitasking capabilities. The high performance of Intel processors has caused many traditional workstation applications to migrate to the Intel platform. The Pentium and Pentium Pro processors provide workstation capabilities at competitive performance levels and superior price/performance.

This performance summary documents the performance of the new Pentium Pro processors on a variety of workstation benchmarks. Competitive results are included for other non-Intel processor-based workstations for which performance data is available. This performance summary does not attempt to provide benchmark results for all workstations throughout the price range of the workstations available. Instead it focuses on those in the price range of an Intel architecture-based workstation. Hence the justification for including a particular workstation in this report is based on the list price of the workstation platform. Intel Pentium Pro processor-based workstations are targeted for the introductory and the volume workstation markets. This performance brief examines those platforms from other non-Intel processor-based workstations that are considered to be in these markets. In some performance comparisons throughout this brief, platforms or architectures may appear that exceed this qualification. These are included for reference only since the configuration or the architecture is not considered a workstation platform. In these cases, an Intel processor-based workstation may have been configured to match certain characteristics of the other platforms.

Intel Pentium Pro processor-based systems are denoted in the graphs with a "↓" above the system's bar when non-Intel processor-based platforms are included. In the graphics portion of the paper, this symbol is used to represent a PCI graphics accelerator card tested in a Pentium Pro processor-based platform.

THE INTEL PENTIUM® PRO PROCESSOR

The Pentium Pro processor family is the next generation of Intel's processor technology. The Pentium Pro processor family currently consists of the following processors:

Endnotes

1 System configurations, including software and hardware design, may affect actual performance.

- Pentium Pro processor at 200 MHz (512K L2 cache)
- Pentium Pro processor at 200 MHz (256K L2 cache)
- Pentium Pro processor at 180 MHz (256K L2 cache)
- Pentium Pro processor at 166 MHz (512K L2 cache)

While fully compatible with all existing Intel architecture-compatible software, the Pentium Pro processor is specifically optimized to run 32-bit software. This includes demanding software like CAD/CAM, numerical analysis, 3D and multimedia authoring applications running on workstations. The Pentium Pro processor delivers superior performance over the wide-range of applications that exist today and new applications that are coming in the future. It achieves this superior performance through an innovative architectural technique called "Dynamic Execution". Dynamic Execution removes software bottlenecks via incorporated features such as out-of-order execution and register-renaming. The Pentium Pro processor design also includes glueless logic to support up to four processors in a multiprocessor design. Other high-performance features include the tightly coupled L2 cache and an advanced processor bus.

Manufactured using Intel's high-volume and well-proven 0.35 µm technology, the 200 MHz Pentium Pro processor delivers outstanding integer and floating-point performance. (See Figures 1-4.) The following numbers are for the peak rating of the SPEC benchmarks and represent the results for a Fujitsu ICL superserver J650I* containing a single Pentium Pro processor running at 200 MHz with 512K of L2 cache.

- SPECint95* rating is 8.71
- SPECfp95* rating is 6.68

The Pentium Pro processor has been designed with balanced integer and floating-point performance. This balanced integer and floating-point performance design gives it an edge in workstation applications. For example, MSC/NASTRAN*, a state-of-the-art mechanical engineering tool that is very floating point intensive, runs particularly well on the Pentium Pro processor due to the processor's balanced design. Results for MSC/NASTRAN on Intel processor-based workstations are reported and contrasted with other workstations later in this document.

PRODUCT FEATURE HIGHLIGHTS

- Fully compatible with the entire library of software based on operating systems such as Windows NT*, UNIX* SVR4*, SCO UNIX*, NEXTSTEP*, Solaris*, OS/2*, as well as Windows 95*, Windows for Workgroups 3.11*, Windows 3.1*, and DOS.
- The onboard, high-speed secondary cache and an advanced processor bus provide the bandwidth needed for computer-intensive applications.
- Glueless 4-way MP delivers superior performance and provides cost-effective upgrade path.
- Support for enhanced data integrity and reliability features for mission-critical applications: ECC (Error Checking and Correction), Fault Analysis & Recovery, and Functional Redundancy Checking.
- Dynamic Execution:
  - Multiple Branch prediction allows many branches to be outstanding
  - Dataflow analysis enables out-of-order execution over tens of instructions
  - Speculative Execution enables many instructions to be executed beyond the program counter
- Headroom for performance growth through process improvement. The 200 MHz Pentium Pro processor is manufactured using the well-proven 0.35 µm process.

Dynamic Execution involves optimally adjusting instruction execution by predicting program flow, analyzing the program's dataflow graph to choose the best order to execute the instructions, then speculatively executing instructions in the preferred order.

Branch prediction is a concept found in many mainframe and high-speed microprocessor architectures. It allows the processor to decode instructions beyond branches to keep the instruction pipeline full. In the Pentium Pro processor, the instruction fetch/decode unit uses a highly optimized branch prediction algorithm to predict the direction of the instruction stream through multiple levels of branches, procedure calls, and returns.

Pipe-lined machines must fetch the next instruction before they have completely executed the previous instruction. If the previous instruction was a branch, then the next-instruction fetch could have been to the wrong place. Branch prediction is a technique that attempts to infer the correct next instruction address, knowing only the current one. Typically it uses a Branch Target Buffer (BTB), a small separate memory that watches the instruction cache index and attempts to predict which index should be accessed next, based on branch history.

Dynamic data flow analysis involves real-time analysis of the flow of data through the processor to determine data and register dependencies and to detect opportunities for out-of-order instruction execution. The Pentium Pro processor dispatch/execute unit can simultaneously monitor many instructions and execute these instructions in the order that optimizes the use of the processor's multiple execution units, while maintaining the integrity of the data being operated on. This out-of-order execution keeps the execution units busy even when cache misses and data dependencies among instructions occur.

Speculative execution refers to the processor's ability to execute instructions ahead of the program counter but ultimately to commit the results in the order of the original instruction stream. To make speculative execution possible, the Pentium Pro processor microarchitecture decouples the dispatching and executing of instructions from the commitment of results. The processor's dispatch/execute unit uses data-flow analysis to execute all available instructions in the instruction pool and store the results in temporary registers. The retirement unit then linearly searches the instruction pool for completed instructions that no longer have data dependencies found, the retirement unit commits the results of these instructions to memory and/or the Intel Architecture registers (the processor's eight general-purpose registers and eight floating-point registers) in the order they were originally issued and retires the instructions from the instruction pool.

Through deep branch prediction, dynamic data-flow analysis, and speculative execution, Dynamic Execution removes the constraint of linear instruction sequencing between the traditional fetch and execute phases of instruction execution. It allows instructions to be decoded deep into multi-level branches to keep the instruction pipeline full. It promotes out-of-order instruction execution to keep the processor's six instruction execution units running at full capacity. Finally, it commits the results of executed instructions in original program order to maintain data integrity and program coherency.

In summary, Dynamic Execution technology optimally adjusts instruction execution by predicting program flow by analyzing the program's dataflow graph to choose the best order to execute the instructions, then having the ability to speculatively execute instructions in the preferred order. The Pentium Pro processor dynamically adjusts its work, as defined by the incoming instruction stream, to minimize overall execution time.

SPEC

SPEC95* is a software benchmark product produced by the Standard Performance Evaluation Corp. (SPEC), a non-profit group of computer vendors, system integrators, universities, research organizations, publishers and consultants throughout the world. It provides measures of performance for comparing compute-intensive workloads on different computer systems. SPEC95 consists of two suites of benchmarks: CINT95* for measuring and comparing compute-intensive integer performance, and CFP95* for measuring and comparing compute-intensive floating-point performance. The two suites provide component-level benchmarks that measure the performance of the computer's processor, memory architecture and compiler. SPEC benchmarks are selected from existing application and benchmark source code running across multiple platforms. Each benchmark is tested on different platforms to obtain fair performance results across competing hardware and software systems.

SPEC95 is the third major version of the SPEC benchmark suites, which in 1989 became the first widely accepted standard for comparing compute-intensive performance across various architectures. The new release replaces SPEC92*, which has been phased out. SPEC no longer publishes SPEC92 results and has discontinued selling the benchmark suite. Performance results from SPEC95 cannot be compared to those from SPEC92, since new benchmarks have been added and existing ones changed.

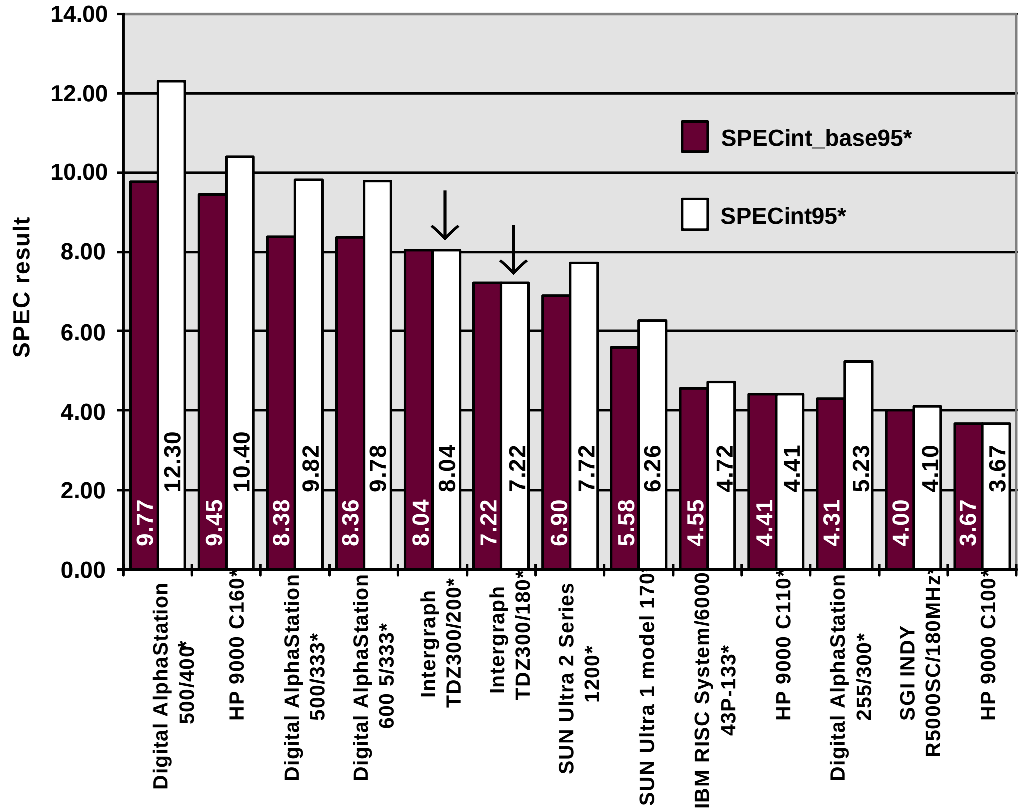
The CINT95 suite, written in C language, contains eight CPU-intensive integer benchmarks. It measures and calculates the following metrics:

- SPECint95 — The geometric mean of eight normalized ratios (one for each integer benchmark) when compiled with aggressive optimization for each benchmark.
- SPECint_base95* — The geometric mean of eight normalized ratios when compiled with the conservative optimization for each benchmark.

The CFP95 suite, written in FORTRAN* language, contains ten CPU-intensive floating-point benchmarks. It measures and calculates the following metrics:

- SPECfp95 — The geometric mean of 10 normalized ratios (one for each floating-point benchmark) when compiled with aggressive optimization for each benchmark.
- SPECfp_base95* — The geometric mean of 10 normalized ratios when compiled with conservative optimization for each benchmark.

In the following figures, the Intel Pentium Pro processor performance is compared with other non-Intel processors. Figures 1-4 show the SPECint95 and SPECfp95 performance of the Pentium Pro processors. As the following figures show, the 200 MHz Pentium Pro processor-based system from Intergraph Computer Systems delivers comparable performance with today's highest rated non-Intel processor-based systems.



Results for Intel processors have been submitted to SPEC for publication; all others obtained from the SPEC website, August 1996.

Figure 1. SPECint_base95* and SPECint95* Benchmarks

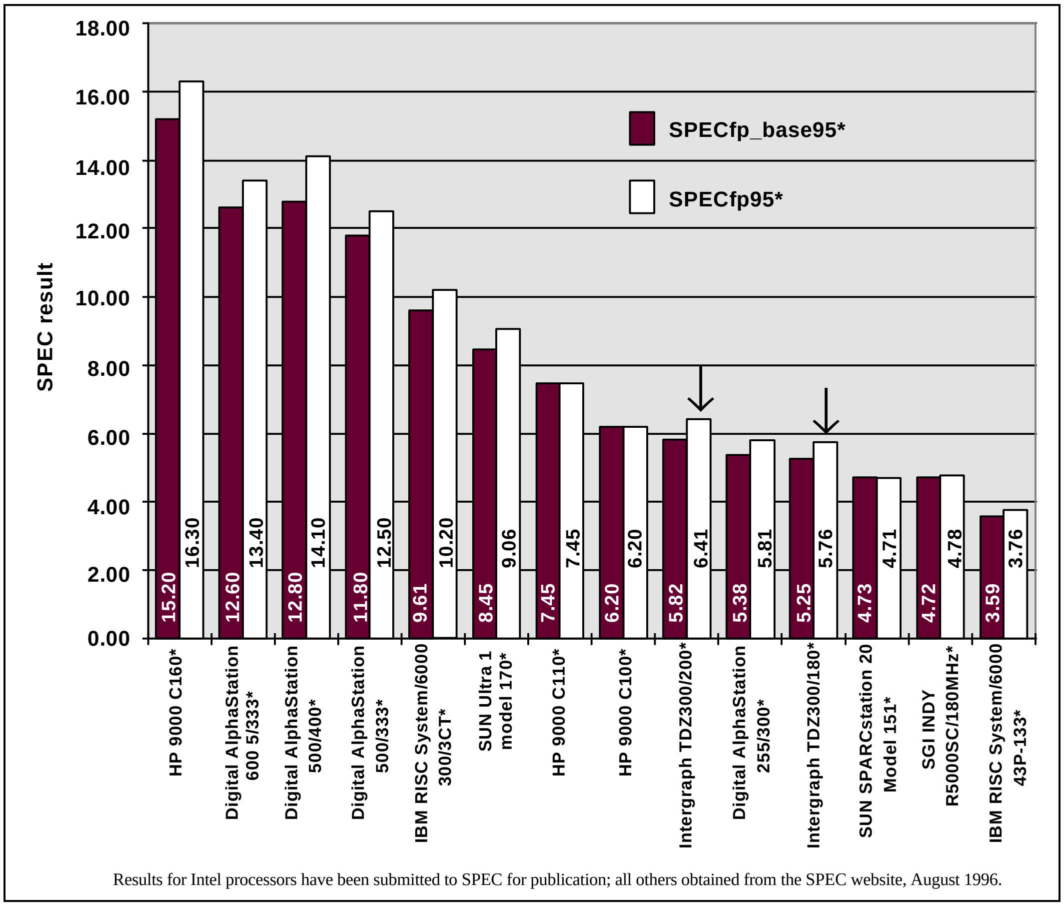
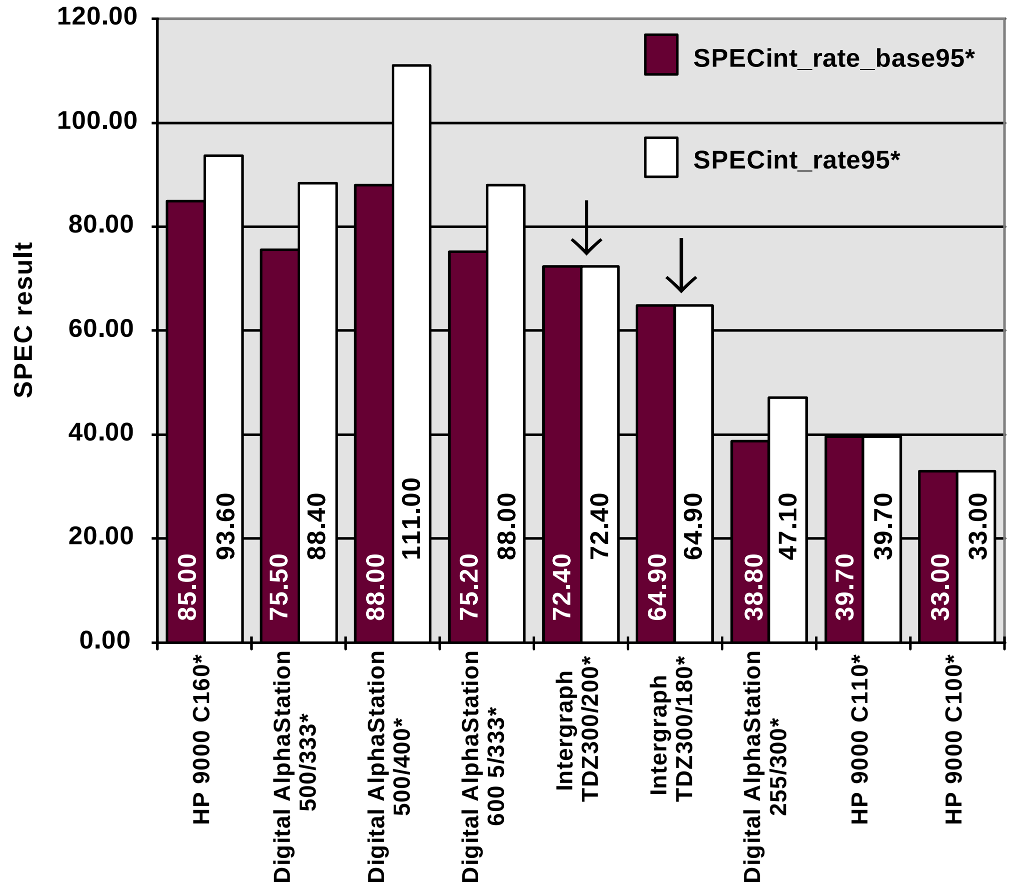


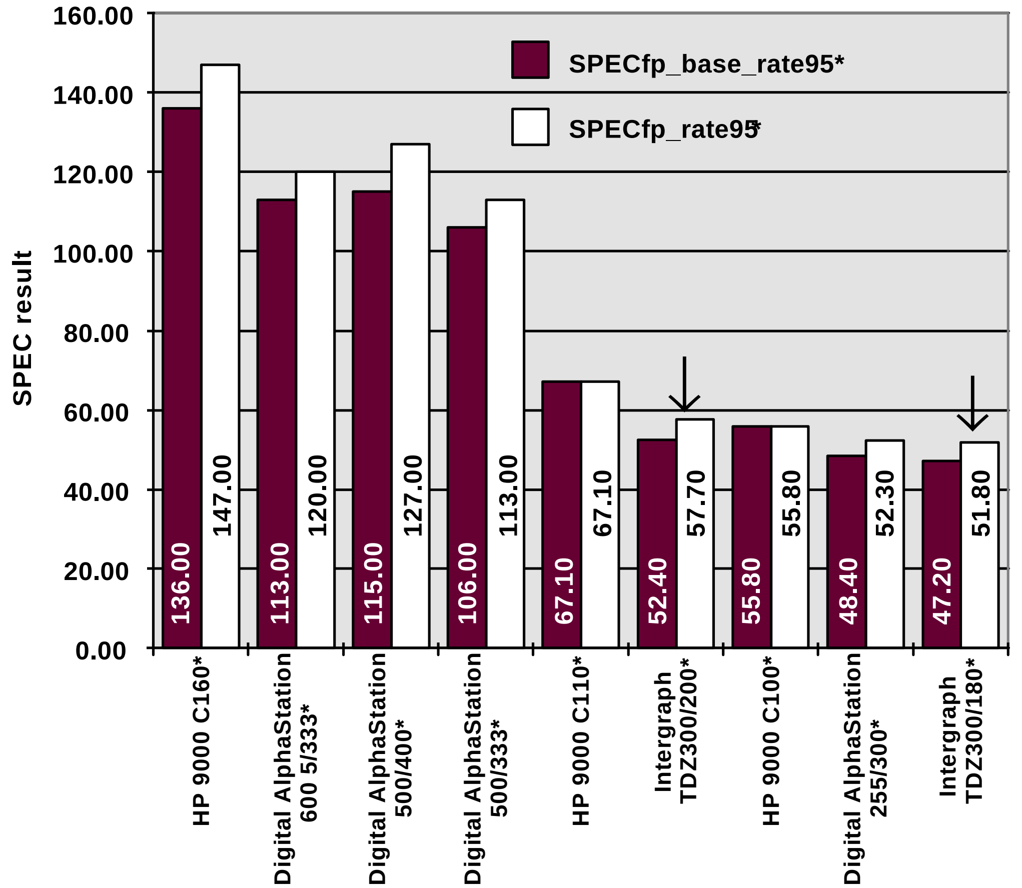
Figure 2. SPECfp_base95* and SPECfp95* Benchmarks

The SPEC organization also publishes results for throughput (rate) measurement. The benchmark numbers that represent throughput are known as SPECint_rate95*, SPECfp_rate95*, SPECint_rate_base95* and SPECfp_rate_base95*. With this method, called the "homogeneous capacity method," several copies of a given benchmark are executed. This method is particularly suitable for multiprocessor systems. The results express how many jobs of a particular type (characterized by a particular benchmark) can be executed in a given time. The SPEC rates therefore characterize the capacity of a system for compute-intensive jobs of similar characteristics. Because of the different units, the values SPECint95/SPECfp95 and SPECrate_int95/SPECrate_fp95 cannot be compared directly. The SPEC_rate results are shown for an Intel Pentium Pro processor-based system and several of today's leading non-Intel processor-based workstations.



Results for Intel processors have been submitted to SPEC for publication; all others obtained from the SPEC website, August 1996.

Figure 3. SPECint_rate_base95* and SPECint_rate95* Benchmarks



Results for Intel processors have been submitted to SPEC for publication; all others obtained from the SPEC website, August 1996.

Figure 4. SPECfp_base_rate95* and SPECfp_rate95* Benchmarks

APPLICATION PERFORMANCE BENCHMARKS

In this section, we present the Pentium Pro processor performance on Windows NT* application-based benchmarks such as MicroStation* 95, Pro/E* and MSC/NASTRAN*.

SYSmark* for Windows NT*

SYSmark* for Windows NT* is a suite of application software and associated benchmark scripts that have been developed by Business Applications Performance Corporation (BAPCo) in order to provide a tool for accurate and realistic measurement of system performance of personal computers running popular business-oriented applications in the Windows NT operating environment. The scripts are developed to reflect usage patterns of PC users in a business-oriented environment.

Workloads for SYSmark for Windows NT were developed based on BAPCo's standardized practice of surveying users to determine how they exercise popular applications in day-to-day work. The applications selected for testing had to be able to run across all three popular architectures (Intel, MIPS and Alpha). SYSmark for Windows NT can generate performance metrics as a composite of all the different applications or for a specific application, such as word processing or spreadsheets.

- WORD PROCESSING
  - Microsoft Word* 6.0
  - (native 32-bit on all architectures)
- SPREADSHEET
  - Microsoft Excel* 5.0
  - (native 32-bit on all architectures)
- PROJECT MANAGEMENT
  - Welcom Software Technology Texim Project* 2.0e
  - (native 32-bit on all architectures)
- COMPUTER-AIDED DESIGN
  - Orcad MaxEDA* 6.0 (PCB design tool)
  - (native 32-bit on all architectures)
- PRESENTATION GRAPHICS
  - Microsoft PowerPoint* 4.0
  - (16-bit Windows emulation)

Figure 5 illustrates the SYSmark for Windows NT Performance on the Intel Pentium Pro processor.

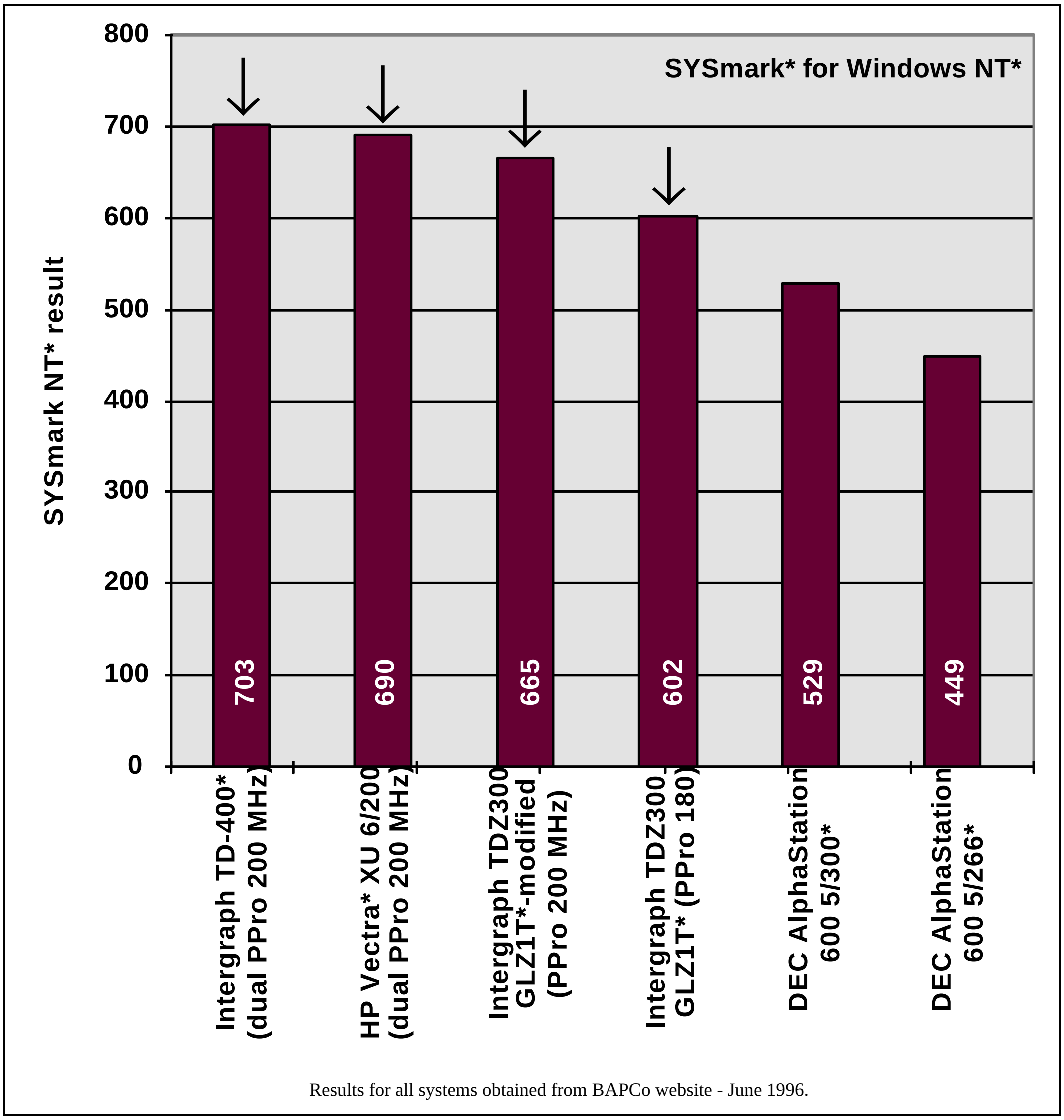


Figure 5. SYSmark* for Windows NT* Benchmark

LINPACK* 100x100 Benchmark

LINPACK* is a linear equation solver written in FORTRAN. The LINPACK program consists of floating-point addition and multiplication of matrices.

100x100 LINPACK solves a 100x100 matrix of simultaneous linear equations. Source code changes are not allowed so that the results may be used to evaluate the compiler's ability to optimize for the target system.

The LINPACK benchmark measures the execution rate in MFLOPS (millions of floating-point operations per second). When running, the benchmark depends on memory-bandwidth and gives little weight to I/O. Therefore, when LINPACK data fits into system cache, performance may be higher. Figure 6 shows the LINPACK performance of two Pentium Pro processor-based systems and other non-Intel processor-based systems.

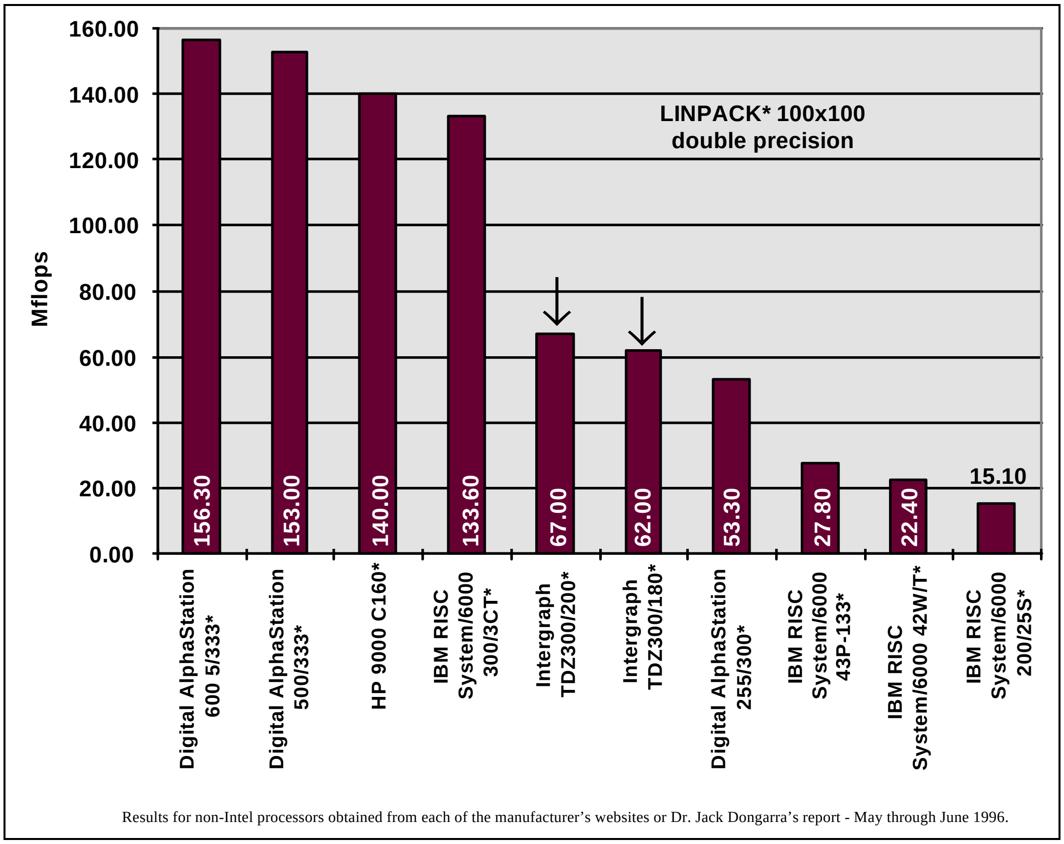


Figure 6. LINPACK* MFLOPS Performance

MicroStation* 95 Performance Benchmark

This benchmark replaces CADbench* which was a fully-automated benchmark that ran with MicroStation*. The new benchmark contains 10 tests, which use nine files. The basic operation consists of copying each design file to a temporary directory before doing the manipulations, recording the times for each test, and then deleting all but one newly-created design file. The copying of files is not included in the times that are reported.

The 10 tests are grouped into three sets of tests to better test certain aspects of the system. Within Group 1, three tests form the 2D heavy video test. Results yield very good representations of the power of the processor and video subsystem. Within Group 2 are two tests that add the disk I/O subsystem to the test results. Group 3 switches to 3D, and the processor must be good at floating-point calculations.

For this test MicroStation 95 Performance Benchmark was run seven times for each different configuration with a warm boot in between each run. The warm boot was used to reset all operating system "states" to the same value prior to each run. Results were then averaged and the standard deviation calculated. When possible, the exact same combination of drives loaded, memory and its use, MicroStation setup and resolution of monitors was used.

The benchmark was run on Pentium Pro processor-based systems and DEC* Alpha-based systems. The chart shown in this report contains only those systems containing the Intel 200 MHz Pentium Pro processor using 64 MB of memory compared with systems using the DEC Alpha processor running at both 300 MHz and 333 MHz, also with 64 MB of memory. The actual benchmark data in the article references other systems as well, but these were chosen to represent the highest available performance available for the Pentium Pro processor and the consistent 64 MB of memory across the platforms. One DEC Alpha system used 128 MB of memory. This particular system was not chosen since the amount of memory can affect the time of the result. The Symbion Pro* and the Xi Pro* used the Intel Pentium Pro processor.

Figure 7 shows the results of the MicroStation 95 benchmark from MicroStation Manager magazine comparing Pentium Pro processor-based systems with non-Intel processor-based systems.

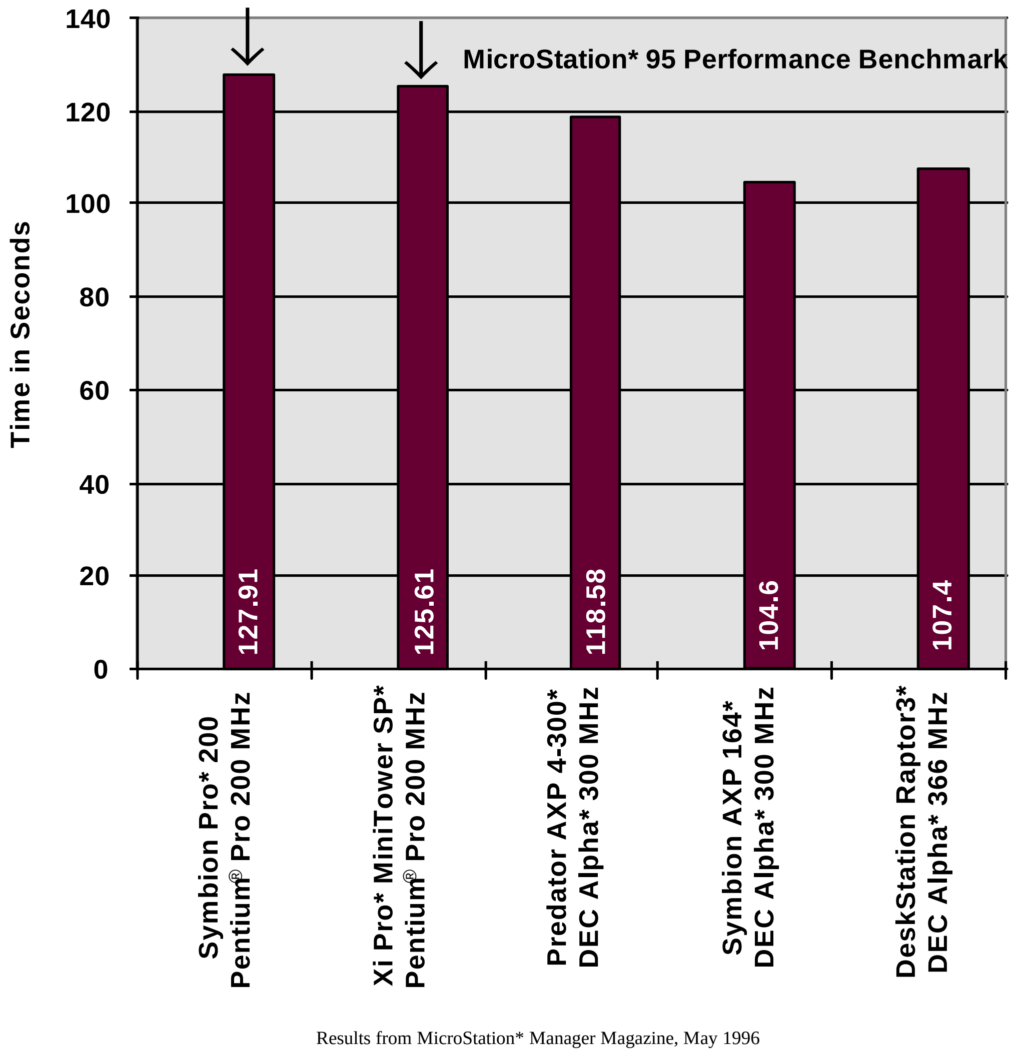


Figure 7. MicroStation* 95 Performance Benchmark.

MSC/NASTRAN*

MSC/NASTRAN*, the principal product of the MacNeal Schwendler Corporation, is the industry's leading Finite Element Analysis (FEA) program.

MSC/NASTRAN offers a wide variety of analysis types, including linear statics, normal modes, buckling, heat transfer, frequency response, transient response, random response, response spectrum analysis, and aeroelasticity. Virtually any material type can be modeled, including composites and hyper elastic materials.

Sparse matrix numerical methods, incorporated in every analysis type, greatly increase the solution speed and reduce the amount of disk space, making the numerical processing fast and efficient.

The following benchmarks from the MSC/NASTRAN suite demonstrate that the NT version of the code, running on the Intel Pentium Pro processor, provides the type of performance that users have come to expect from technical workstations.

MSC/NASTRAN Version 68.2 has been ported to the Windows NT environment running on Intel platforms. This is a released product and the results presented show that the Intel platforms, running Windows NT, represent a good choice for MSC/NASTRAN.

POWER TRAIN VIBRATIONAL MODEL

A vibration analysis of a power train model with approximately 60,000 degrees of freedom has been run on a variety of platforms as a comparative reference. In order to find the natural frequencies in the range 0 to 100 Hz, MSC/NASTRAN performed two decompositions and 18 solves, and extracted 18 modes. Figure 8 shows the MSC/NASTRAN performance of the Pentium Pro processor-based systems on what might be considered a typical workstation configuration with 128 MB of memory or less. Figure 9 shows the MSC/NASTRAN performance on larger memory configurations. These include a Cray supercomputer and workstations configured with at least 256 MB of memory. This chart is included for reference only to represent configurations that are of definitely higher cost than those focused on in this performance brief.

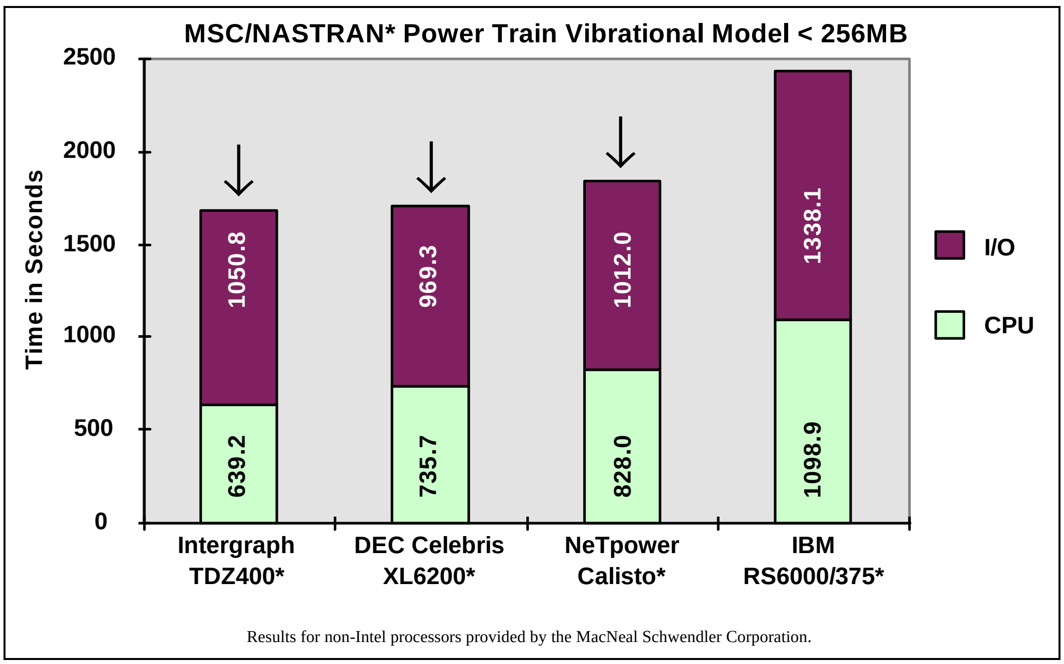


Figure 8. MSC/NASTRAN* Power Train Vibrational Model Performance

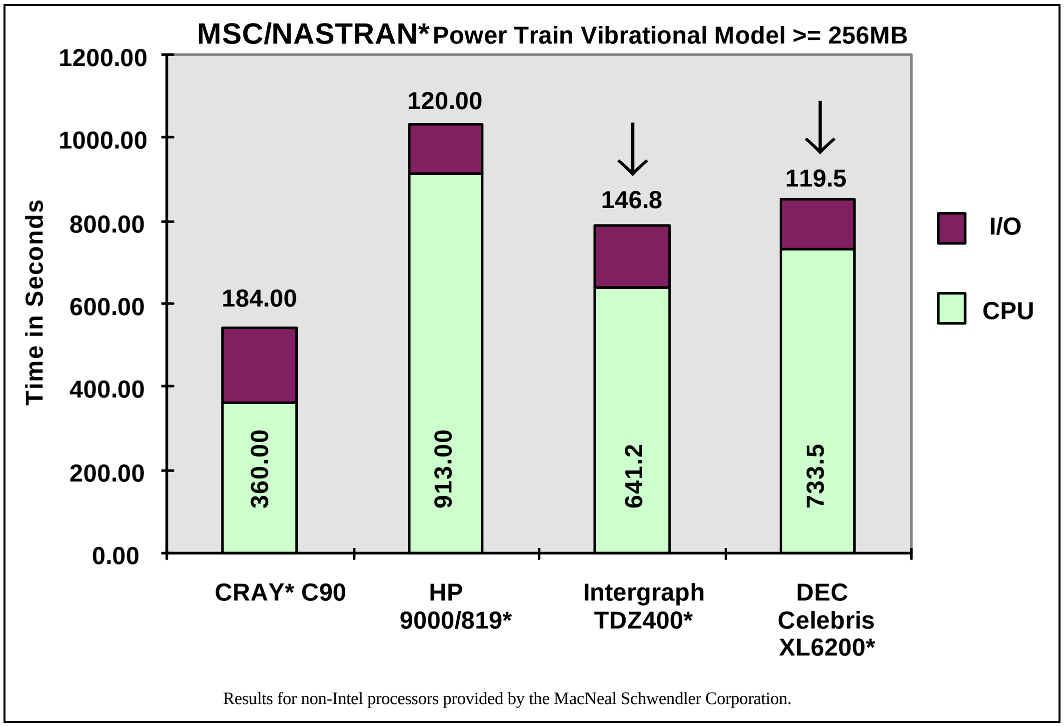


Figure 9. MSC/NASTRAN* Power Train Vibrational Model Performance

BCELL*

The BCELL* benchmark has been used for many past versions of MSC/NASTRAN. This benchmark represents the overall CPU time in seconds for the calculations involved. The model in the BCELL benchmark is a cube of solids with a plate on each surface of each solid. The tests run represent ~10000 and ~22000 degrees of freedom. These models were chosen to be an upper bound of resource requirements. All runs were done by MSC at their facility except the result for the DEC Celebris XL6200* system. This run was done in the Workstation Technology Lab at Intel. Figures 10 and 11 show the performance of Intel Pentium Pro processor-based systems compared with non-Intel processor-based systems on the BCELL benchmark using ~10000 and ~22000 degrees of freedom.

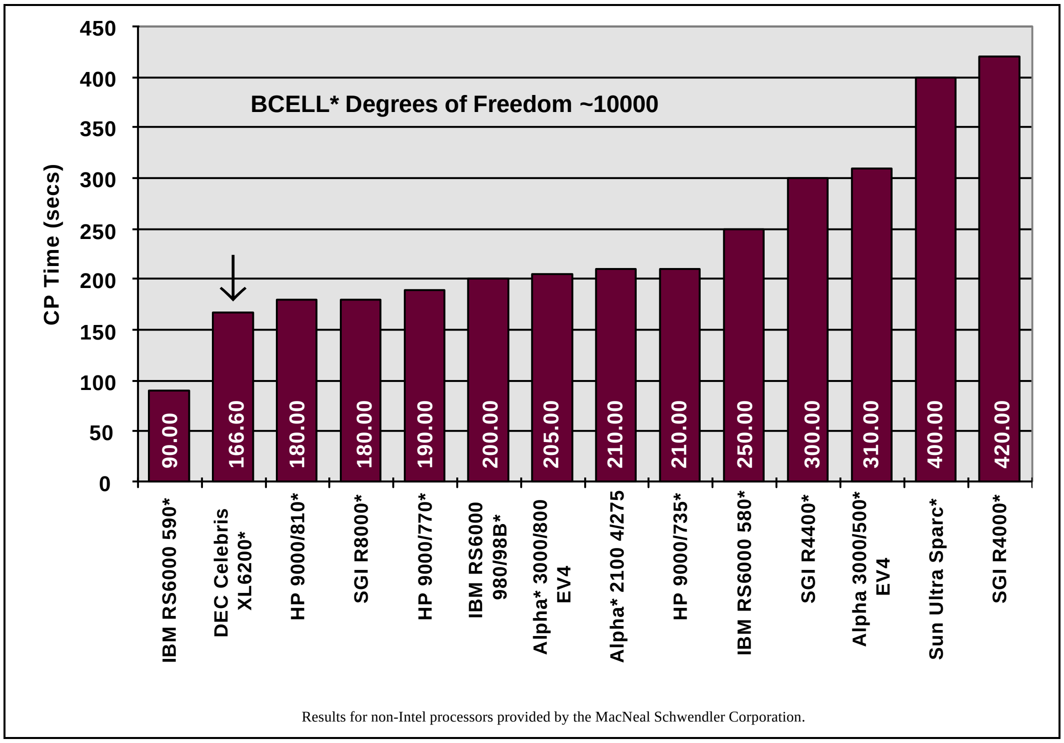


Figure 10. MSC/NASTRAN* BCELL* Model Performance ~10000 Degrees of Freedom

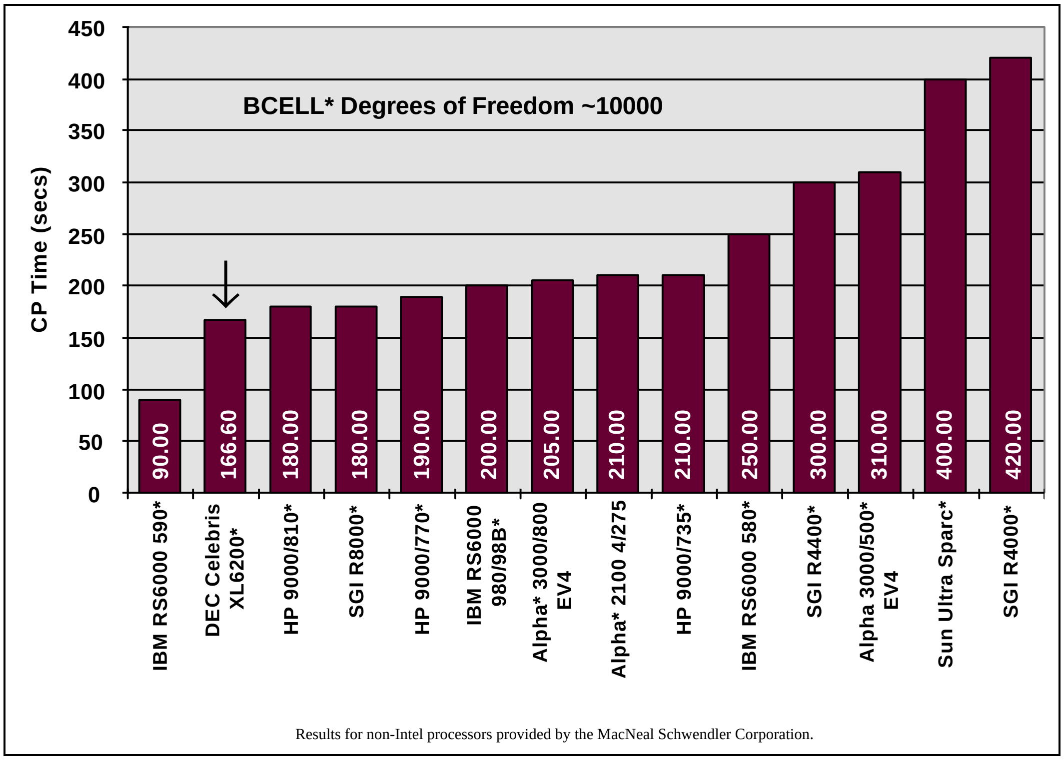


Figure 11. MSC/NASTRAN* BCELL* Model Performance ~22000 Degrees of Freedom

ANSYS*

ANSYS* is one of the most widely used Finite Element Analysis packages in the world today. From nonlinear and linear, structural, thermal, piezoelectrics and acoustics analysis to optional modules for electromagnetic field and computational fluid dynamics studies, the ANSYS program provides the tools to meet almost any engineering need.

ANSYS has designed a set of benchmark programs, known as the LS benchmarks, which have data that demonstrates how well large ANSYS problems perform on computer systems. The data contains five static analysis examples using the ANSYS frontal solver. These examples were deliberately set with a large wavefront to stress the computer systems. The analysis examples represent a cantilevered plate with one element through the thickness. The mesh size is varied for the different cases. A force loading applied to the plate at the free end. The ANSYS 3D solid isoparametric element, SOLID45, is used in these static examples.

Name	No. of Elements	No. of Nodes	Active Degrees of Freedom	Maximum Wavefront	RMS Wavefront	Disk Requirements (MB)
LS1	1,000	2,222	6,060	618	573.3	100
LS2	2,000	4,422	12,060	1,218	1,131.9	200
LS3	3,000	6,622	18,060	1,818	1,690.5	400
LS4	4,000	8,822	24,060	2,418	2,249.0	600
LS5	6,000	12,642	36,120	1,818	1,754.1	700

Following are the results obtained on four commercially available Pentium Pro processor workstations. These machines come with a variety of memory architectures, disk drives and number of processors. All reported Intel results are from ANSYS Version 5.3, released on July 10, 1996.

CP Time	LS1	LS2	LS3	LS4	LS5
Calisto*	40.749	257.941	865.795	2035.537	1767.101
Celebris*	38.075	235.208	900.945	1975.661	1570.158
TDZ-400*	34.141	207.609	709.391	1512.125	1403.813
Vectra*	38.906	247.625	861.25	1866.125	1659.672

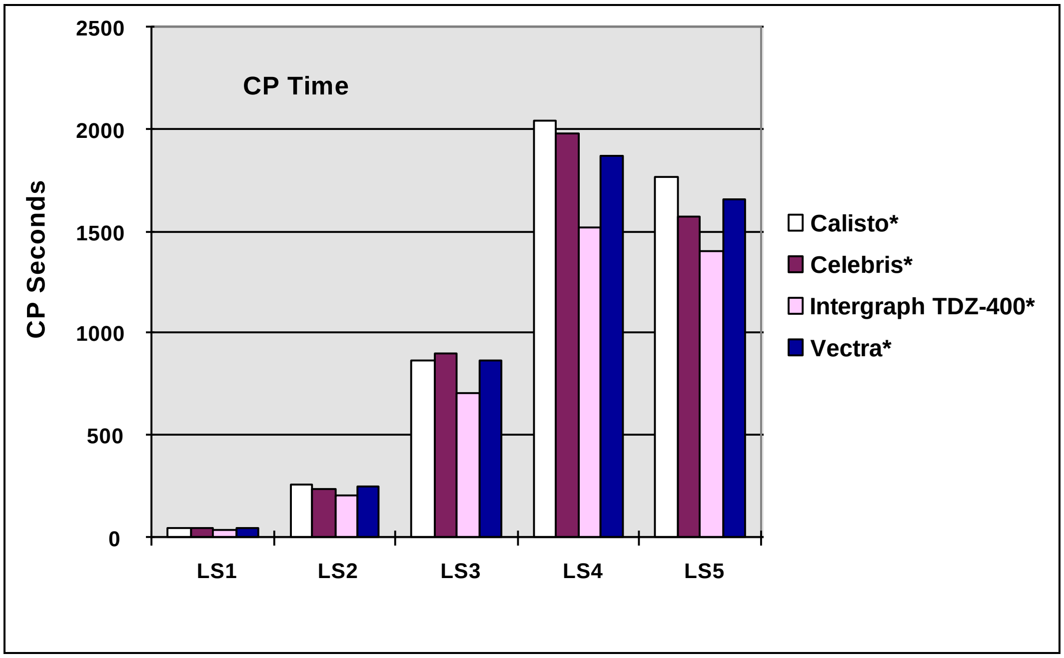


Figure 12. ANSYS* LS Performance

Comparative results of elapsed time are less reliable. The current routine for reporting elapsed time in ANSYS reports in even seconds. Further, elapsed time numbers, because of the reliance of ANSYS on reading and writing scratch files, depend upon the structure and fullness of the file system plus other system and network activity. In fact, consecutive runs on the same machine can show deviations in the elapsed time of several percent.

Run Time	LS1	LS2	LS3	LS4	LS5
Calisto*	50	303	987	2267	2119
Celebris*	46	284	1022	2205	1877
TDZ-400*	41	219	832	1814	1790
Vectra*	46	301	988	2113	1983

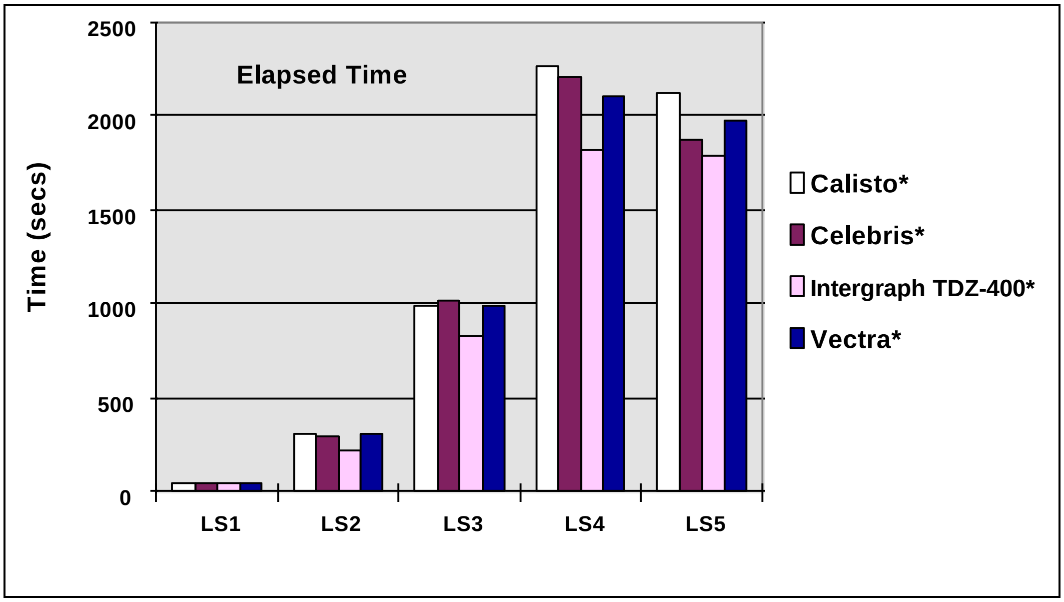


Figure 13. ANSYS* Performance

Following is a chart of ANSYS performance compared with several other available workstations. The Intel processor-based machine was an Intergraph TDZ400* 200 MHz Pentium Pro processor-based system with 256 MB of memory. The results are shown in the chart compared to results for other non-Intel processor-based systems running Release 5.2. ANSYS has not published numbers for Release 5.3 on the large scale benchmark. These numbers are for reference only.

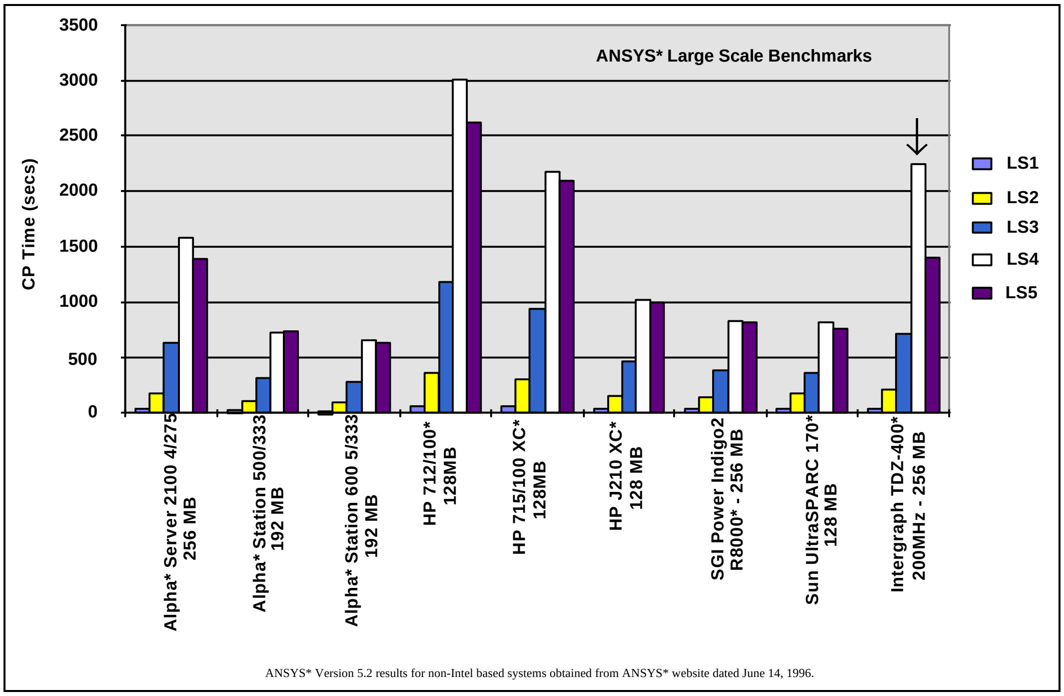


Figure 14. ANSYS* 5.3/Intergraph & ANSYS* 5.2/non-Intel systems

Parametric Technology Corporation – Pro/ENGINEER*

Parametric Technology Corporation's Pro/ENGINEER* is a suite of integrated software products that automate the mechanical design-through-manufacturing process. This unique, fully-associative suite of mechanical design automation software includes application-specific products that address the complete spectrum of product-development activities.

Within the Pro/ENGINEER family, more than 50 modules address every aspect of product development: design, drafting, manufacturing. In addition, specialized tools meet your requirements for advanced surfacing, assembly management, design optimization, cable and pipe routing, die design, data management, and more. Since all applications are fully associative, engineering teams work in parallel to develop product designs and their manufacturing processes concurrently.

The Systems Group at Texas Instruments has developed a benchmark for Parametric Technology Corporation's Pro/ENGINEER. This benchmark has been made publicly available via *Pro/E: The Magazine*. The results of their benchmarking has been published in three issues to date, most recently in the March/April 1996 edition.

The results published were obtained using Release 15 of Pro/ENGINEER. One machine was tested with a beta version of Release 16.

The Texas Instruments group developed the Pro/ENGINEER benchmark to test overall system performance on complex assembly models and assembly drawings. Texas Instruments engineers modeled real parts and assemblies to create an accurate manufacturing design work environment. The models represented a wide range of sizes and complexities, while the benchmark tested many of the advanced capabilities of Pro/ENGINEER such as holes, chamfers, rounds, and attachment hardware. The goal was not to stress a single task, but to test a cross section of tasks and operations that make up a true work environment. As a result, the benchmark measured 59 tasks including those only performed occasionally such as plotting

PostScript* files and creating exploded views, as well as more frequently executed tasks such as model spinning, panning or zooming, and rotation. The benchmark's developers determined the mix of operations as well as the relative weighting of those operations by observing the engineers' usage patterns over a period of several weeks. Evaluation of output files known as "trail files" led to the determination of the weighting factors. These trail files contain the actual commands chosen during the time a design engineer is using Pro/ENGINEER.

The test exercises the graphics capabilities as well as the computational capabilities of the platform being tested. It also contains some occasionally performed tasks, such as generating shaded color PostScript files and measuring mass properties. Weighting factors were determined to represent how often a user might use these commands in a single eight-hour day. Adequate memory was used in each machine to ensure there was enough RAM to avoid excessive paging out to disk. The RAM requirement for this benchmark is 192 MB.

The results presented here are for Release 16 of Pro/ENGINEER. The SGI result is for a beta release of Release 16 while the NeTpower result is for a production release of Pro/ENGINEER Release 16. Release 17 of Pro/ENGINEER is scheduled for deployment later in 1996 and preliminary results for Pentium Pro processor-based platforms running Windows NT are demonstrating improved performance. In the Texas Instruments Pro/E benchmark a lower weighted score is better.

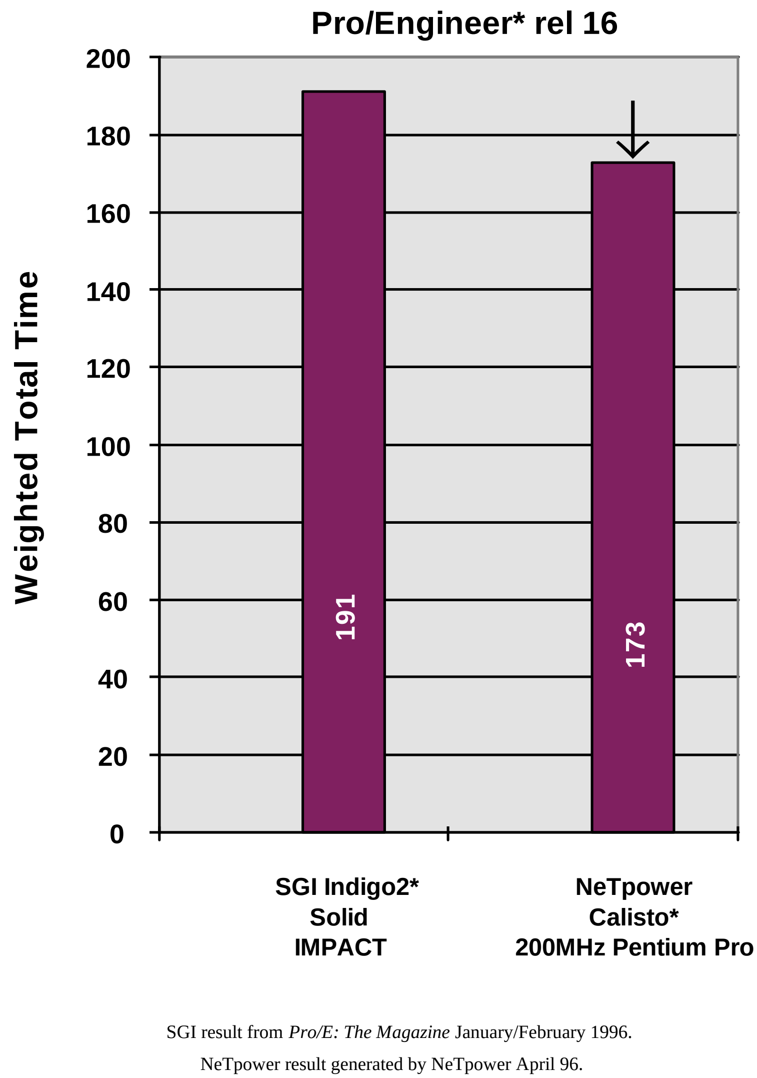


Figure 15. PTC Pro/ENGINEER* Performance

HDL Simulators

A benchmark report from DA Solutions provides detailed comparisons of execution speeds and memory requirements for a variety of simulators. The intent of the benchmark, which focuses on performance rather than ease-of-use issues, is to help users choose simulators while minimizing the amount of evaluation needed. The benchmark exercise included VHDL simulators from Cadence, Ikos, Mentor Graphics, Synopsis and Veda Design Automation, along with Verilog simulators from Fintronic, Mentor Graphics and Intergraph. It encompassed some 19 benchmark circuits ranging up to 3200 gates at the gate level and 48,000 lines of code at the register-transfer level (RTL).

This benchmark exercise was carried out over a nine-month period. While independent evaluators from DA Solutions ran all the tests, vendors provided information about the best options and switches to use for various circuits, and vendor representatives monitored some of the tests. In the following charts the lower the score the better the performance.

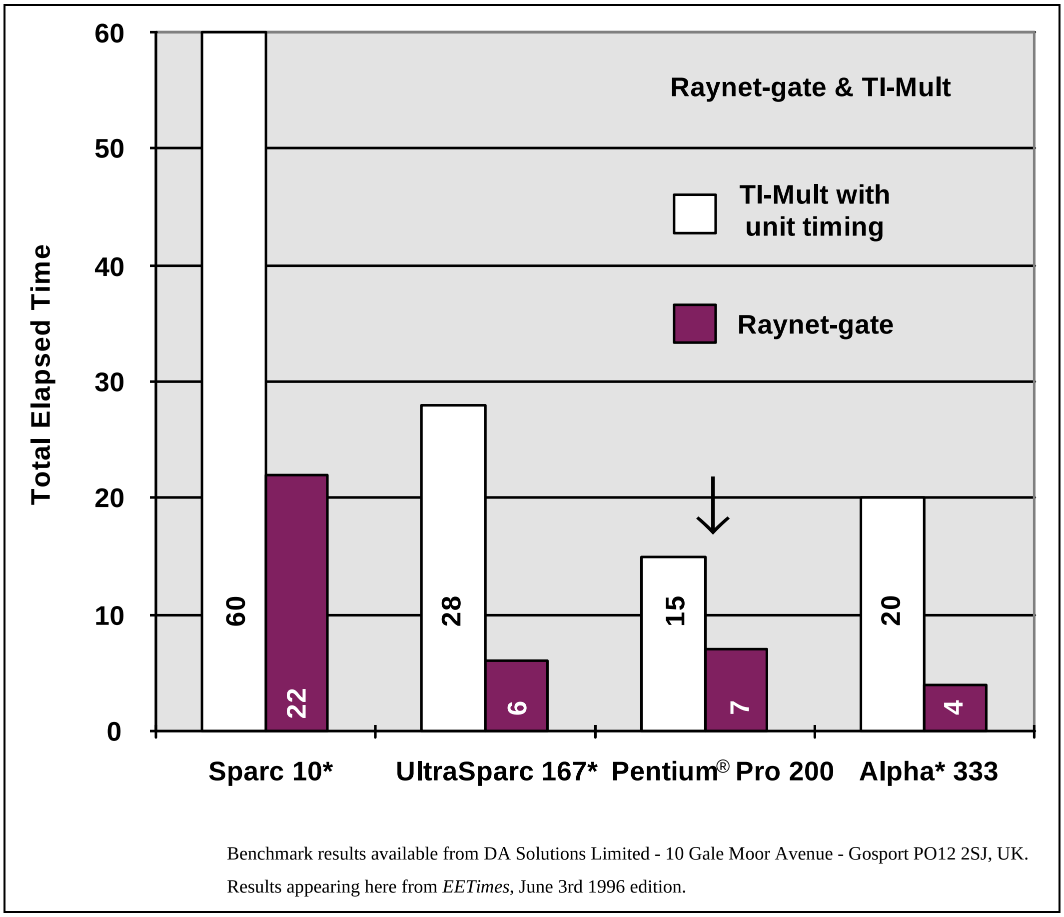


Figure 16. Raynet-gate and TI-Mult

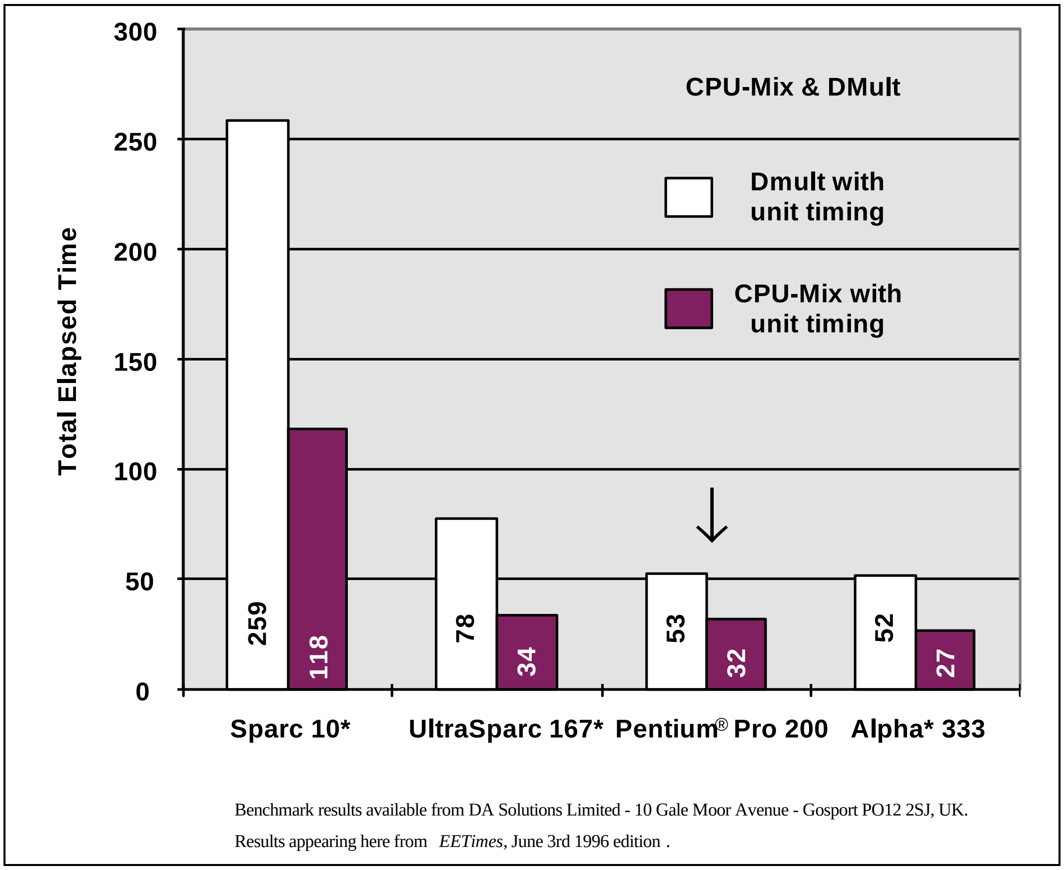


Figure 17. CPU-Mix and Dmult

GRAPHICS PERFORMANCE SUMMARY

Viewperf*

Viewperf* is a benchmark which measures the 3D rendering performance of systems running under OpenGL* which was written and maintained by the OpenGL Performance Characterization (OPC) group. The OPC organization began in 1993 as an ad-hoc project group aimed at establishing graphics performance benchmarks for systems running under the OpenGL application programming interface (API). The group joined the GPC committee in the summer of 1994.

Viewperf measures a mixture of graphics primitives, drawn with different mixtures of primitive attributes. Results of independent tests are then combined into a weighted average to create a composite score for the test. Because of this, it is almost impossible to project a Viewperf score for an accelerator, it must be measured. Improving any one aspect of performance for a card will cause the score to increase. A doubling in performance of triangles won't necessarily translate to a doubling in performance for Viewperf scores. Adding advanced features to an accelerator like anti-aliasing or hardware support for texture acceleration, on the other hand, could cause a score to double even if the shaded triangle rate is held constant. Since applications actually use these advanced features, this still represents a growth in performance for the application so the increase in the Viewperf metric is a correct indicator.

The OPC project group has worked with Independent Software Vendors (ISVs) to obtain tests, data sets and weights that constitute what is called a Viewset. Each Viewset represents the graphics rendering portion of an actual application. Currently, Viewperf5* comprises five standard OPC viewsets:

1. Parametric Technology's CDRS*, which contains seven different Viewperf tests, is a modeling and rendering application for computer-aided industrial design.
2. IBM's Data Explorer* (DX), which has 10 different tests, is a visualization application.
3. Intergraph's Design Review*, which has 10 different tests, is a 3D computer model review package.
4. Alias/Wavefront's Advanced Visualizer*, with 10 tests, is an animation application.
5. Lightscape Technology's Lightscape Visualization System*, with 4 tests, is a radiosity visualization application.

All five Viewsets represent relatively high-end applications. These types of applications typically render large data sets. They almost always include lighting, smooth shading, blending, line anti-aliasing, z-buffering, and some texture mapping.

The ISVs that develop OPC Viewsets have provided percentage weights for each test for which a performance number is reported. ISVs have defined these percentages to indicate the relative importance of a test within the overall application.

Viewperf offers the following characteristics:

- It provides a single-source code for apples-to-apples comparison and performance tuning across different hardware platforms.
- It runs on multiple operating systems, including OS/2, UNIX and Windows NT.
- It runs across different processors, including Alpha, Intel, MIPS and PowerPC.
- It runs on multiple windowing environments, including Presentation Manager*, Windows X* and Windows.
- It encompasses a wide variety of OpenGL features and rendering techniques.
- It is easily accessible through the OPC project subcommittee, ftp and through OpenGL sample disk distribution.

Several factors make Viewperf unique from other benchmarks:

- It uses datasets that are designed for and used by real applications.
- It uses rendering parameters and models selected by ISVs and graphics users.
- It produces numbers based on frames per second, a measurement with which users can readily identify.
- It provides one number for each rendering path using one data set.

Viewperf measures performance for the following entities:

- 3D primitives, including points, lines, line strip, line loop, triangles, triangle strip, triangle fan, quads and polygons.
- Attributes per vertex, per primitive and per frame.
- Lighting
- Texture mapping
- Alpha blending
- Fogging
- Anti-aliasing
- Depth buffering

Viewperf CDRS* Viewset

CDRS is Parametric Technology's modeling and rendering software for Computer-Aided Industrial Design (CAID). It is used to create concept models of automobile exteriors and interiors, other vehicles, consumer electronics, appliances and other products that have challenging free-form shapes. The users of CDRS are typically creative designers with job titles such as automotive designer, products designer or industrial designer. There are seven tests specified that represent different types of operations performed within CDRS. Five of the tests use a triangle strip data set from a lawnmower model created using CDRS. The other two tests show the representation of the lawnmower as a wireframe. The tests are weighted and show the following CDRS functionality:

Table 1. Summary of CDRS* Tests[1]

Test	Weight	CDRS Functionality Represented
1	50%	Vectors used in designing the model. Represents most of the design work done in CDRS. Anti-aliasing turned on to allow the designer to see a cleaner version of the model.
2	20%	Surfaces shown as polygons, but all with a single surface color.
3	15%	Surfaces grouped with different colors per group.
4	8%	Textures added to groups of polygons.
5	5%	Texture used to evaluate surface quality.
6	2%	Color added per vertex to show the curvature of the surface.
7	0%	Same as Test Number 1, but without the anti-aliasing.

Note

1. All results obtained from SPEC/GPC/OPC web page containing results for Viewperf5. Results obtained on or before August 1996.

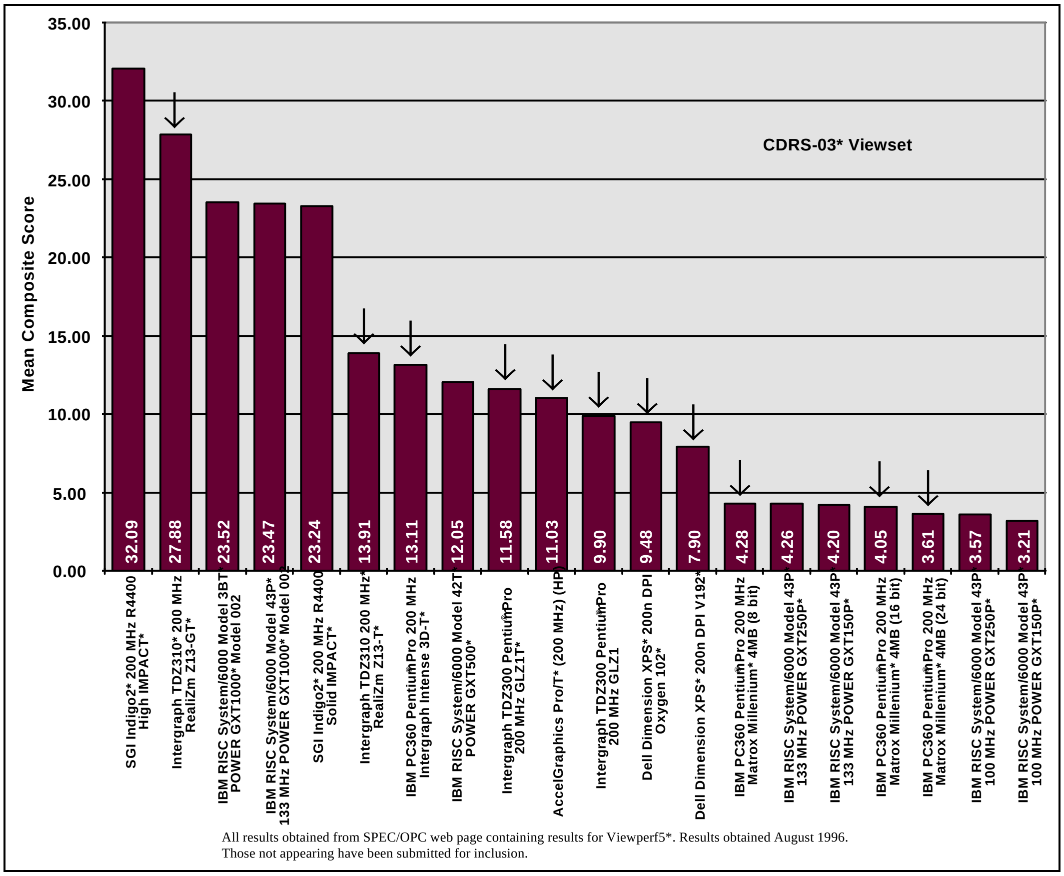


Figure 18. CDRS* Composite Scores

Viewperf Design Review* Viewset

Design Review* is a 3D computer model review package specifically tailored for plant design models consisting of piping, equipment and structural elements such as I-beams, HVAC ducting, and electrical raceways. It allows flexible viewing and manipulation of the model for helping the design team visually track progress, identify interference, locate components, and facilitate project approvals by presenting clear presentations that technical and non-technical audiences can understand.

On the construction site, Design Review can display construction status and sequencing through vivid graphics that complement blueprints. After construction is complete, Design Review continues as a valuable tool for planning retrofits and maintenance. Design Review is a multi-threaded application that is available for both UNIX and Windows NT.

The model in this Viewset is a subset of the 3D plant model made for the GYDA offshore oil production platform located in the North Sea on the southwest coast of Norway.

A special thanks goes to British Petroleum, which has given the OPC subcommittee permission to use the geometric data as sample data for this Viewset. Use of this data is restricted to this Viewset.

Design Review works from a memory-resident representation of the model that is composed of high-order objects such as pipes, elbows valves, and I-beams. During a plant walk-through, each view is rendered by transforming these high-order objects to triangle strips or line strips. Tolerancing of each object is done dynamically and only triangles that are front facing are generated. This is apparent in the Viewset model as it is rotated.

Most Design Review models are greater than 50 MB and are stored as high-order objects. For this reason, and for the benefit of dynamic tolerancing and face culling, display lists are not used.

There are 10 tests specified by the Viewset that represent the most common operations performed by Design Review. These tests are as follows:

Table 2. Summary of Design Review* Tests[1]

Test	Weight	DRV Functionality Represented
1	38%	Walk-through rendering of curved surfaces. Each curved object is rendered as a triangle mesh, depth-buffered, smooth-shaded, with one light and a different color per object.
2	30%	Walk-through rendering of flat surfaces. This is treated as a different test than Number 1 because normals are sent per facet and a flat shade model is used.
3	8%	Walk-throughs require many objects to be clipped. This is the same as Number 1 except clipping is forced.
4	5%	Again, clipping of test Number 2.
5	5%	To easily spot rendered objects within a complex model, the objects to be identified are rendered as solid and the rest of the view is rendered as wireframe (line strips). The line strips are depth-buffered, flat-shaded, and unlit. Colors are sent per primitive.
6	5%	As an additional way to help visual identification and location of objects, the model may have "screen door" transparency applied. This adds polygon stippling to test Number 2.
7	4%	Two other views are present on the screen to help the user select a model orientation. These views display the position and orientation of the viewer. A wireframe, orthographic projection of the model is used. Depth buffering is not used, so multithreading cannot be used in order to preserve draw order.
8	3%	For more realism, objects in the model can be textured. Decal texturing with linear blending and mipmaps is used.
9	1%	Same as test Number 5, except clipping is forced.
10	1%	Same as test Number 8, except clipping is forced.

Note

1. All results obtained from SPEC/GPC/OPC web page containing results for Viewperf5. Results obtained on or before August 1996.

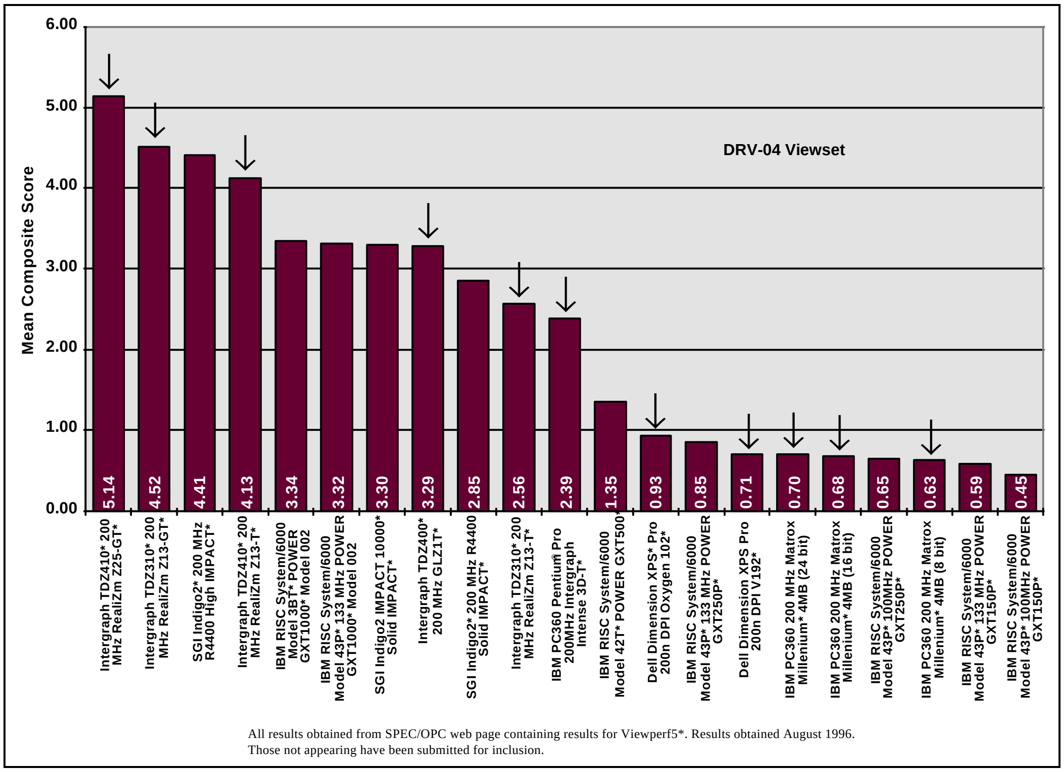


Figure 19. Design Review* Composite Scores

Viewperf Data Explorer* Viewset

The IBM Visualization Data Explorer* (DX) is a general-purpose software package for scientific data visualization and analysis. It employs a data-flow driven client-server execution model and is currently available on UNIX workstations from Silicon Graphics, IBM, Sun, Hewlett-Packard and Digital Equipment. The OpenGL port of Data Explorer was completed with the recent release of DX 2.1.

The tests visualize a set of particle traces through a vector flow field. The width of each tube represents the magnitude of the velocity vector at that location. Data such as this might result from simulations of fluid flow through a constriction. The object represented contains about 1,000 triangle meshes containing approximately 100 vertices each. This is a medium-sized data set for DX. All tests assume z-buffering with one light in addition to specification of a color at every vertex. Triangle meshes are the primary primitives for this Viewset. While Data Explorer allows for many other modes of interaction, these assumptions cover the majority of user interaction.

Table 3. Summary of Data Explorer* Tests[1]

Test	Weight	DX Functionality Represented
1	40%	TMESH's immediate mode
2	20%	LINE's immediate mode
3	10%	TMESH's display listed
4	8%	POINT's immediate mode
5	5%	LINE's display listed
6	5%	TMESH's list with facet normals
7	5%	TMESH's with polygon stippling
8	2.5%	TMESH's with two sided lighting
9	2.5%	TMESH's clipped
10	2%	POINT's direct rendering display listed

Note

1. All results obtained from SPEC/GPC/OPC web page containing results for Viewperf5*. Results obtained on or before August 1996.

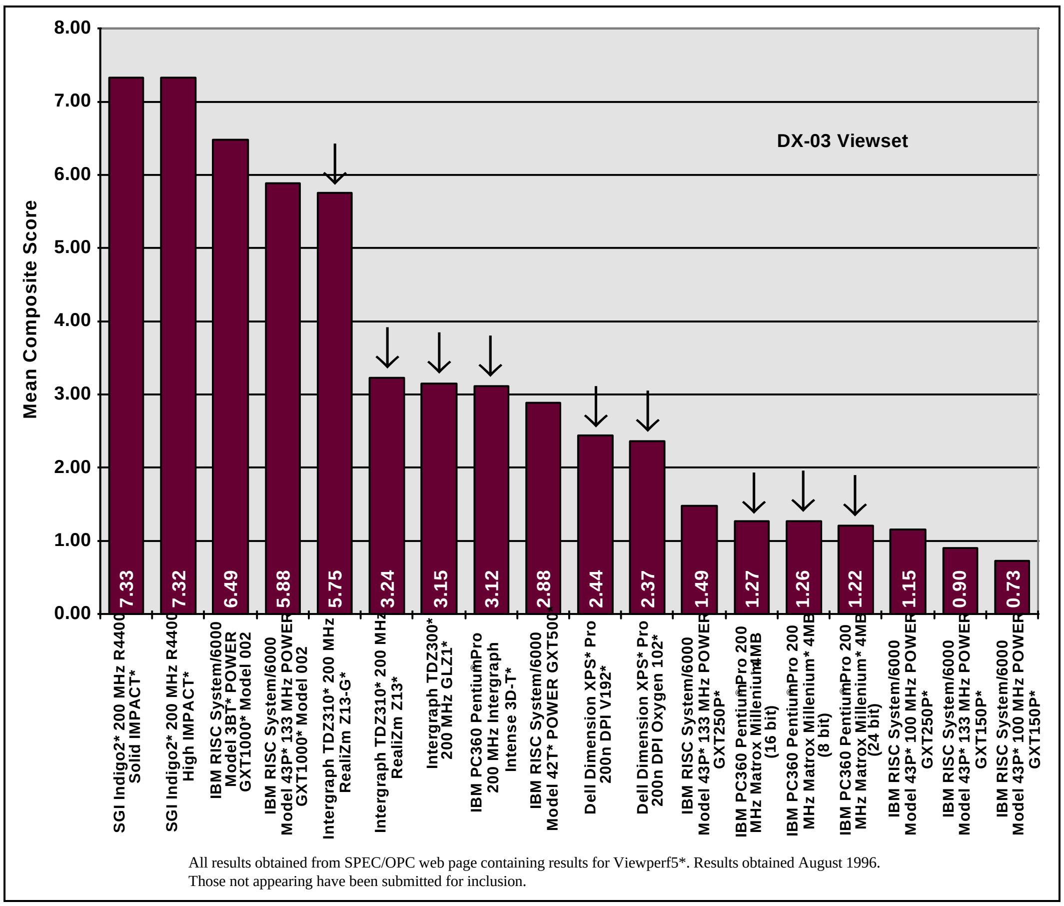


Figure 20. Data Explorer* Composite Scores

Advanced Visualizer* Viewset (AWadvs-01)

Advanced Visualizer* from Alias/Wavefront is an integrated workstation-based 3D animation system that offers a comprehensive set of tools for 3D modeling, animation, rendering, image composition, and video output.

The Advanced Visualizer provides:

- Geometric, analysis, and motion data importation from a wide range of CAD, dynamics and structural systems.
- Automatic object simplification and switching tools for working with ultra-large production data sets.
- Motion for an unlimited number of object, cameras, and lights with Wavefront SmartCurve* editing technique.
- Interactive test rendering and high-quality, free-form surface rendering.
- Software rotoscoping for matching computer animation with live action background footage.
- Realistic imaging effects, including soft shadows, reflection, refraction, textures, and displacement maps, using Wavefront's fast hybrid scanline/raytracing renderer.
- Interactive image layering and output to video with Wavefront's new Recording Composer*.
- Powerful scripting and customization tools, open file formats, and user-defined interfaces.

All operations within Advanced Visualizer are performed in immediate mode with double-buffered windows. There are four basic modes of operation within Advanced Visualizer:

1. 55% material shading (textured, z-buffered, backface-culled, 2 local lights)
   - 95% perspective, 80% trilinear mipmapped, modulated (41.8%)
   - 95% perspective, 20% nearest, modulated (10.45%)
   - 5% ortho, 80% trilinear mipmapped, modulated (2.2%)
   - 5% ortho, 20% nearest, modulated (0.55%)
2. 30% wireframe (no z-buffering, no lighting)
   - 95% perspective (28.5%)
   - 5% ortho (1.5%)
3. 10% smooth shading (z-buffered, backface-culled, 2 local lights)
   - 95% perspective (9.5%)
   - 5% ortho (0.5%)
4. 5% flat shading (z-buffered, backface-culled, 2 local lights)
   - 95% perspective (4.75%)
   - 5% ortho (0.25%)

These are the 10 tests specified by the Viewset that represent the most common operations performed by Advanced Visualizer. The tests are as follows:

Table 4. Summary of Advanced Visualizer* Tests[1]

Test	Weight	Advanced Visualizer* Functionality Represented
1	41.8%	Material shading of polygonal animation model with highest interactive image fidelity and perspective projection
2	28.5%	Wireframe rendering of polygonal animation model with perspective projection
3	10.45%	Material shading of polygonal animation model with lowest interactive image fidelity and perspective projection
4	9.5%	Smooth shading of polygonal animation model with perspective projection
5	4.75%	Flat shading of polygonal animation model with perspective projection
6	2.2%	Material shading of polygonal animation model with highest interactive image fidelity and orthogonal projection
7	1.5%	Wireframe rendering of polygonal animation model with orthogonal projection
8	.55%	Material shading of polygonal animation model with lowest interactive image fidelity and orthogonal projection
9	.5%	Smooth shading of polygonal animation model with orthogonal projection
10	.25%	Flat shading of polygonal animation model with orthogonal projection

Note

1. All results obtained from SPEC/GPC/OPC web page containing results for Viewperf5*. Results obtained on or before August 1996.

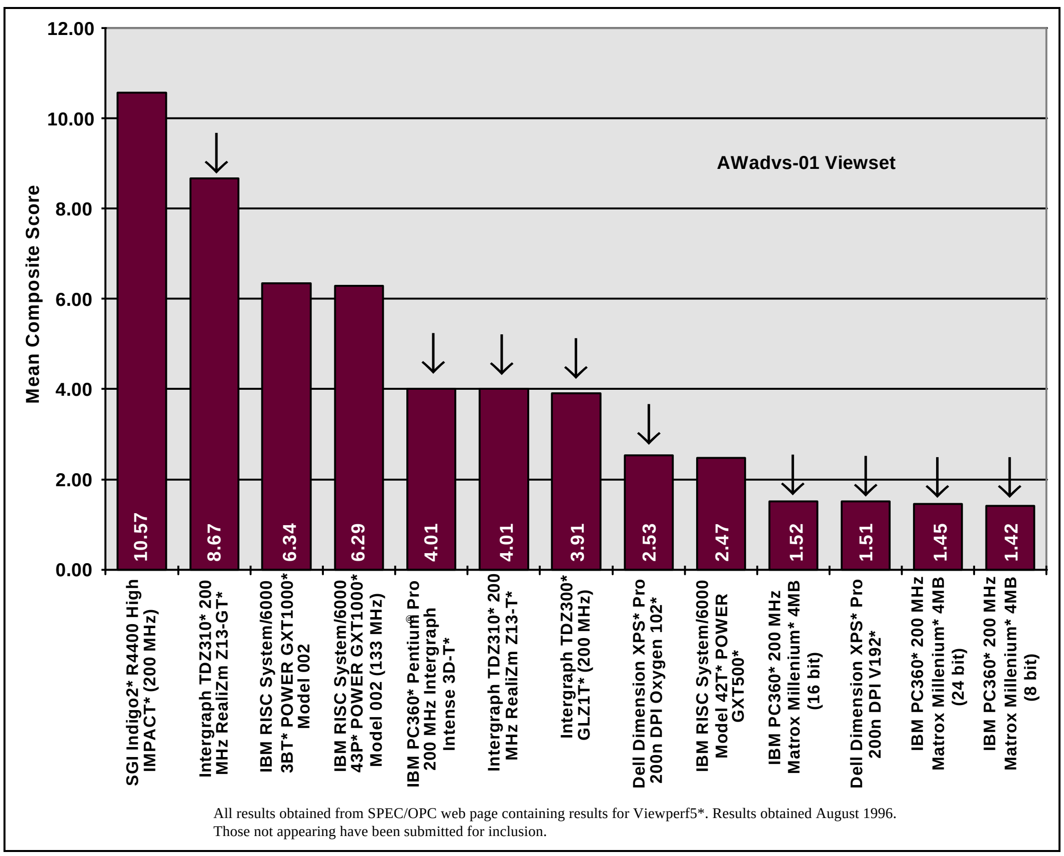


Figure 21. AWadvs-01* Composite Numbers

Lightscape* Viewset (Light-01)

The Lightscape Visualization System* from Lightscape Technologies, Inc. represents a new generation of computer graphics technology that combines proprietary radiosity algorithms with a physically-based lighting interface.

LIGHTING

The most significant feature of Lightscape is its ability to accurately simulate global illumination effects. The system contains two integrated visualization components. The primary component utilizes progressive radiosity techniques and generates view-independent simulations of the diffuse light propagation within an environment. Subtle but significant effects are captured, including indirect illumination, soft shadows, and color bleeding between surfaces. A post process using ray tracing techniques adds specular highlights, reflection, and transparency effects to specific views of the radiosity solution.

INTERACTIVITY

Most rendering programs calculate the shading of surfaces at the time the image is generated. Lightscape's radiosity component precalculates the diffuse energy distribution in an environment and stores the lighting distribution as part of the 3D model. The resulting lighting "mesh" can then be rapidly displayed. Using OpenGL display routines, Lightscape takes full advantage of the advanced 3D graphics capabilities of Pentium Pro processor-based systems with
OpenGL-compliant graphic acceleration boards. Lightscape allows you to interactively move through fully simulated environments.

PROGRESSIVE REFINEMENT

Lightscape utilizes a progressive refinement radiosity algorithm that produces useful visual results almost immediately upon processing. The quality of the visualization improves as the process continues. In this way, the user has total control over the quality (vs. time) desired to perform a given task. At any point in the solution process, users can alter the characteristic of a light source or surface material and the system will rapidly compensate and display the new results without the need for restarting the solution. This flexibility and performance allow users to rapidly test various lighting and material combinations to obtain precisely the visual effect desired.

There are four tests specified by the Viewset that represent the most common operations performed by the Lightscape Visualization System. The four tests are as follows:

Table 5. Summary of Lightscape* Tests[1]

Test	Weight	Lightscape* Functionality Represented
1	25%	Walk-through wireframe rendering of "Cornell Box" model using line loops with colors supplied per vertex
2	25%	Full-screen walk-through solid rendering of "Cornell Box" model using smooth-shaded z-buffered quads with colors supplied per vertex
3	25%	Walk-through wireframe rendering of 750K-quad Parliament Building model using line loops with colors supplied per vertex
4	25%	Full-screen walk-through solid rendering of 750K-quad Parliament Building model using smooth-shaded z-buffered quads with colors supplied per vertex

Note

1. All results obtained from SPEC/GPC/OPC web page containing results for Viewperf5*. Results obtained on or before August 1996.

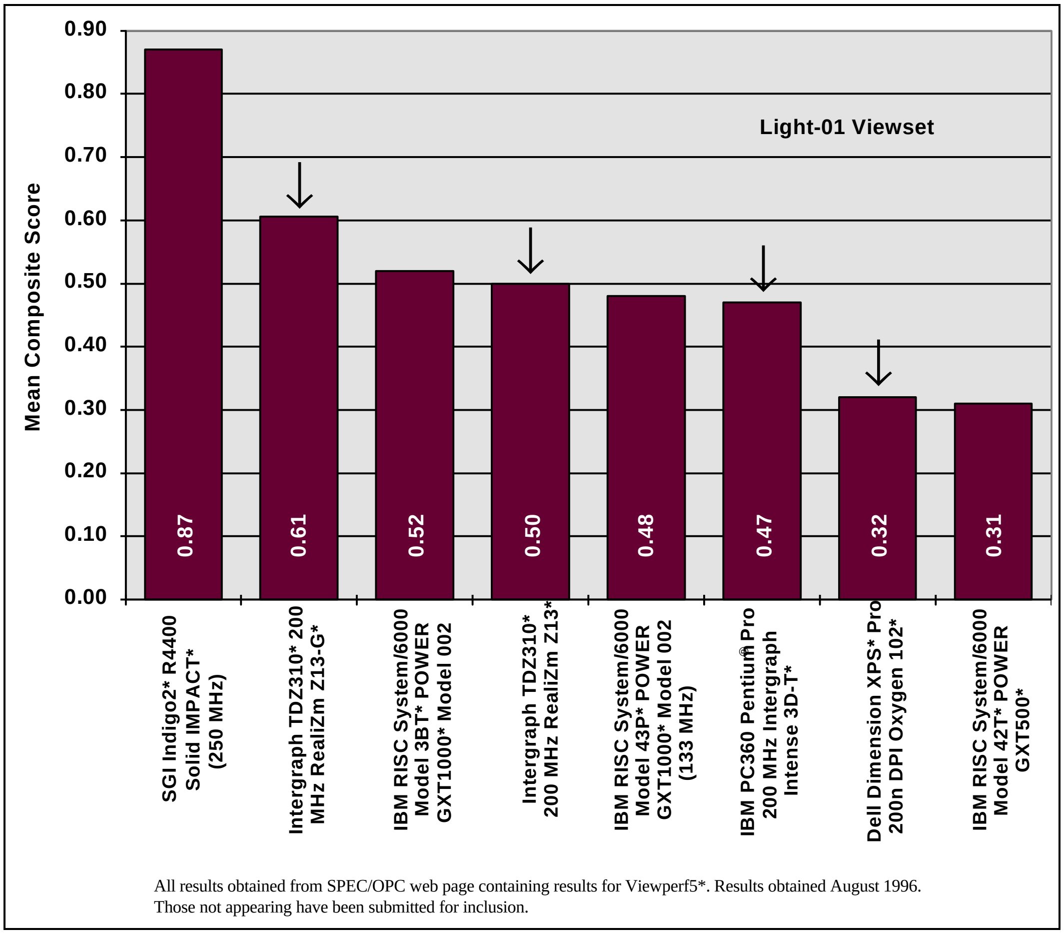


Figure 22. Light-01* Composite Scores

SUMMARY

The Pentium Pro processor family offers superior performance for high-end to entry-level workstations. All the Pentium Pro processor systems listed in this performance brief are priced under $25,000. The performance results show that these systems compare very favorably to higher-priced workstations from non-Intel architecture systems. With SPECint95 rating of 8.71 and SPECfp95 rating of 6.68, the 200 MHz Pentium Pro processor is one of the fastest in the industry. For even higher performance, the Pentium Pro processor offers 4-way glueless multiprocessing. Superior performance, coupled with the availability of advanced operating systems and peripherals, makes the Pentium Pro processor an ideal platform for the most demanding workstation applications.

In particular, the Pentium Pro processor performs extremely well on CAD, scientific modeling and analysis, and other computationally intensive tasks. With the availability of workstation applications such as MSC/NASTRAN, MicroStation and Pro/ENGINEER on the Intel Architecture, the Pentium Pro processor is the platform of choice for mechanical CAD users. The performance on graphics related benchmarks demonstrates that the Pentium Pro processor provides an excellent cost/performance choice for the digital content creation market as well. The outstanding integer performance and the comprehensive library of tools available also make the Pentium Pro processor an ideal platform for the software development environment.

APPENDIX A — TEST CONFIGURATIONS

Note

1. Specific Non-Intel system configuration information may be obtained from the various website URL's referenced and/or other references noted.

	DEC Celebris XL6200*		**HP Vectra* XU/200**		
Pentium ® Pro Processor	200 MHz		200 MHz		
Number of processors	1		2		
Memory	128 MB / 256 MB		128 MB		
Primary Cache	16 KB (8 KB I + 8 KB D)		16 KB (8 KB I + 8 KB D)		
Secondary Cache	256 KB		256 KB		
Motherboard Chipset, Stepping	Intel 82450 Orion		Intel 82450 B0 Orion		
Operating System	Windows NT* Workstation 3.51 (Build 1057)		Windows NT Workstation 3.51 (Build 1057)		
Hard Disk Controller	NCR SDMS PCI SCSI		Adaptec AIC 7880* SCSI		
Hard Disk	Seagate ST15150N*		Seagate ST32550N* (2 GB)		
Internal transfer rate (Mbit/sec)	47.5 to 72		49.4 to 72		
External transfer rate (MB/sec)	10 (burst)		10 (burst)		
Avg (R/W) Seek (msec)	8/9		8/9		
Avg Latency (msec)	4.17		4.17		
Graphics accelerator	AccelGraphics AG/300*	AccelGraphics 3Dpro*	Matrox Millennium*	Elsa*	3DLabs Racer/TX*
Tested Resolution (pixels) at 75 Hz	1280x1024x16	1024x768x15	1280x1024x24	1152x800x15	1152x800x15

	Intergraph TDZ-400*	**NeTpower Calisto***	
Pentium ® Pro Processor	200 MHz	200 MHz	
Number of processors	2	1	
Memory	128 MB / 256 MB	128 MB	
Primary Cache	16 KB (8 KB I + 8 KB D)	16 KB (8 KB I + 8 KB D)	
Secondary Cache	256 KB	256 KB	
Motherboard Chipset, Stepping	Intel 82450 Orion	Intel 82450 B0 Orion	
Operating System	Windows NT* Workstation 3.51 (Build 1057)	Windows NT Workstation 3.51 (Build 1057)	
Hard Disk Controller	Adaptec AIC 7850* SCSI	Adaptec AHA 2940* SCSI	
Hard Disk	Seagate ST31250*	Seagate ST32550N* (2 GB)	
Internal transfer rate (Mbit/sec)	49.4 - 72	49.4 to 72	
External transfer rate (MB/sec)	20 (burst)	10 (burst)	
Avg (R/W) Seek (msec)	8.5	8/9	
Avg Latency (msec)	4.17	4.17	
Graphics accelerator	GLZ2*	AccelGraphics AG/300*	Elite 2*
Tested Resolution (pixels) at 75 Hz	1280x1024x24	1280x1024x16	1152x800x15

	NeTpower Calisto*
Pentium ® Pro Processor	200 MHz
Number of processors	1
Memory	256 MB
Primary Cache	16 KB (8 KB I + 8 KB D)
Secondary Cache	256 KB
Motherboard Chipset, Stepping	Intel 82450 Orion
Operating System	Windows NT* Workstation 3.51 (Build 1057)
Swap Space	400MB
Hard Disk Controller	Adaptec AHA 2940* SCSI
Hard Disk	Seagate ST32550N* (2 GB)
Internal transfer rate (Mbit/sec)	49.4 to 72
External transfer rate (MB/sec)	10 (burst)
Avg (R/W) Seek (msec)	8/9
Avg Latency (msec)	4.17
Pro/E release & build	16/9610
Graphics accelerator	Elite2*
Tested Resolution (pixels) at 75 Hz	1024x768x256

The following lists the configurations used for testing the IHV cards running the Viewperf 5.0 tests:

The Intergraph Intense 3D-T* runs were on a:

IBM PC 360*
200 MHz Pentium Pro processor
64 MB memory
2 GB disk

The system configuration for the Dynamic Pictures* runs was:

Dell XPS Pro/200*
200 MHz Pentium Pro processor
64 MB memory
2.5 GB disk

The AccelGraphics AccelPro TX* was run on:

HP Vectra* XU/200
200 MHz Pentium Pro processor
64 MB memory
1 GB disk

Website References

This list shows URL's where data is available that is contained in this document. It also shows the date of the last update if available on the webpage.

Individual vendor websites:

http://www.alphastation.digital.com/products/a255/performance.html (July 11, 1996)
http://www.alphastation.digital.com/products/a500/performance.html (June 25, 1996)
http://www.alphastation.digital.com/products/a600/Performance1.html (July 11, 1996)
http://www.alphastation.digital.com/products/a600/Performance2.html (July 11, 1996)
http://www.alphastation.digital.com/products/alphaxl/Performance.html (April 29, 1996)
http://www.sun.com/products-n-solutions/hw/wstns/index.html
http://www.sgi.com/Products/Indigo2/IMPACT/Products/i2techspecs.html
http://www.austin.ibm.com/cgi-bin/systems/300series.pl#performance
http://www.austin.ibm.com/cgi-bin/systems/4142series.pl#topic9
http://www.austin.ibm.com/cgi-bin/systems/43p.pl#performance
http://www.austin.ibm.com/cgi-bin/systems/200series.pl#topic3
http://www.hp.com:80/wsg/products/cclstech.html (June 26, 1996)
http://www.hp.com:80/wsg/products/viz_ctec.html (June 4, 1996)

SPEC results are available at:

http://www.specbench.org/osg/cpu95/results/results.html (July 24, 1996)
http://www.sgi.com/Products/Indy/Tech/r5kspecs.html
http://www.mips.com/r5000/R5000_B.html

BAPCo SYSmark NT results are available at:

http://www.bapco.com/ntrslts.htm (July 16, 1996)

Viewperf 5.0 results are available via the GPC newsletter & at the following URL:

http://www.specbench.org/gpc/opc/ (June 12, 1996)

LINPACK results are available at:

http://netlib2.cs.utk.edu/benchmark/

ANSYS Large Scale Benchmark results are available at:

http://www.ansys.com/ (June 14, 1996)
Follow the *product* pointer to reach the benchmark results.

MicroStation 95 Benchmark results:

Taken from *MicroStation Manager* magazine, May 1996 issue. Configuration information is available in this article as well as the test results reported here.