CAD/CAM Industry Service
Mechanical Applications

Dataquest

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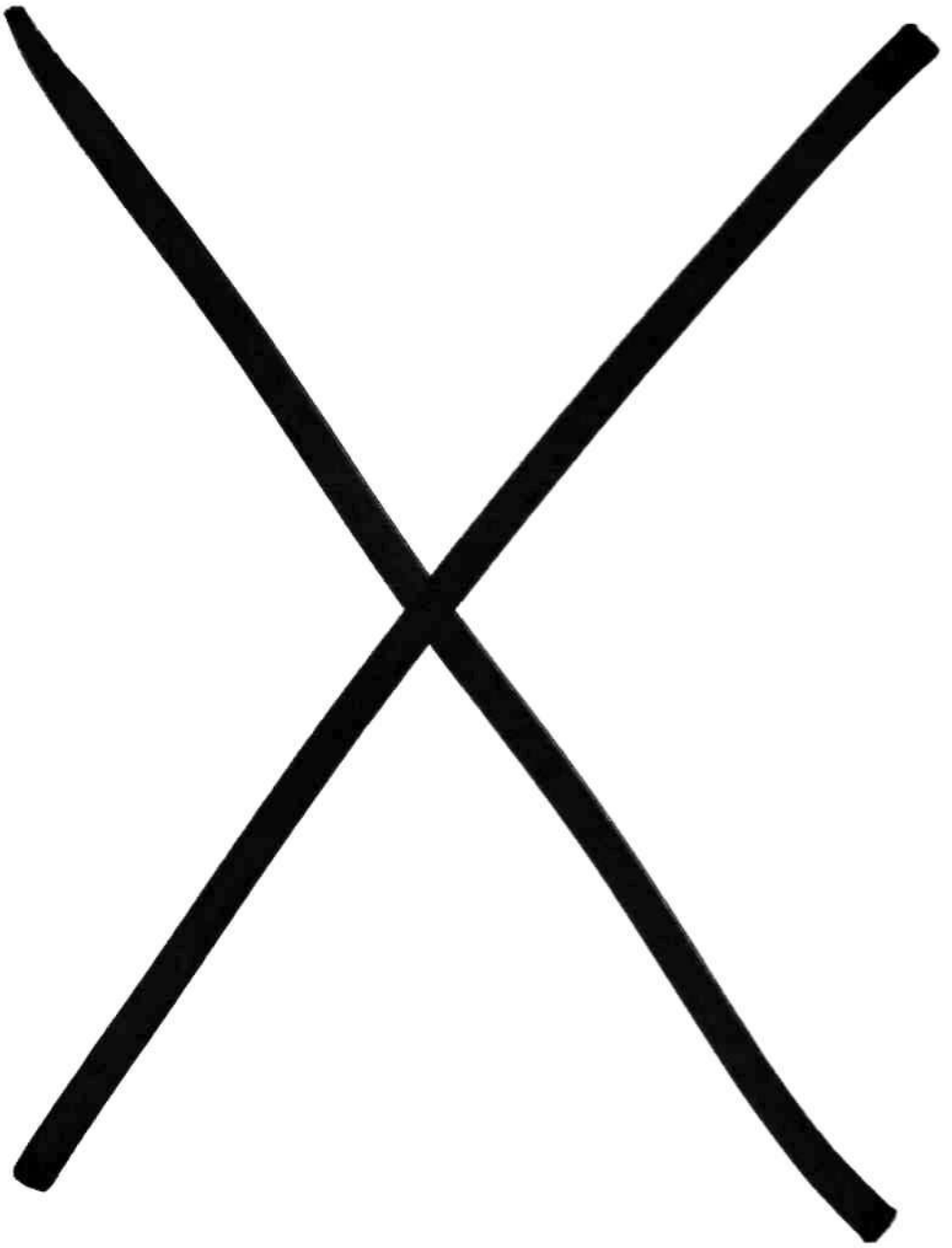

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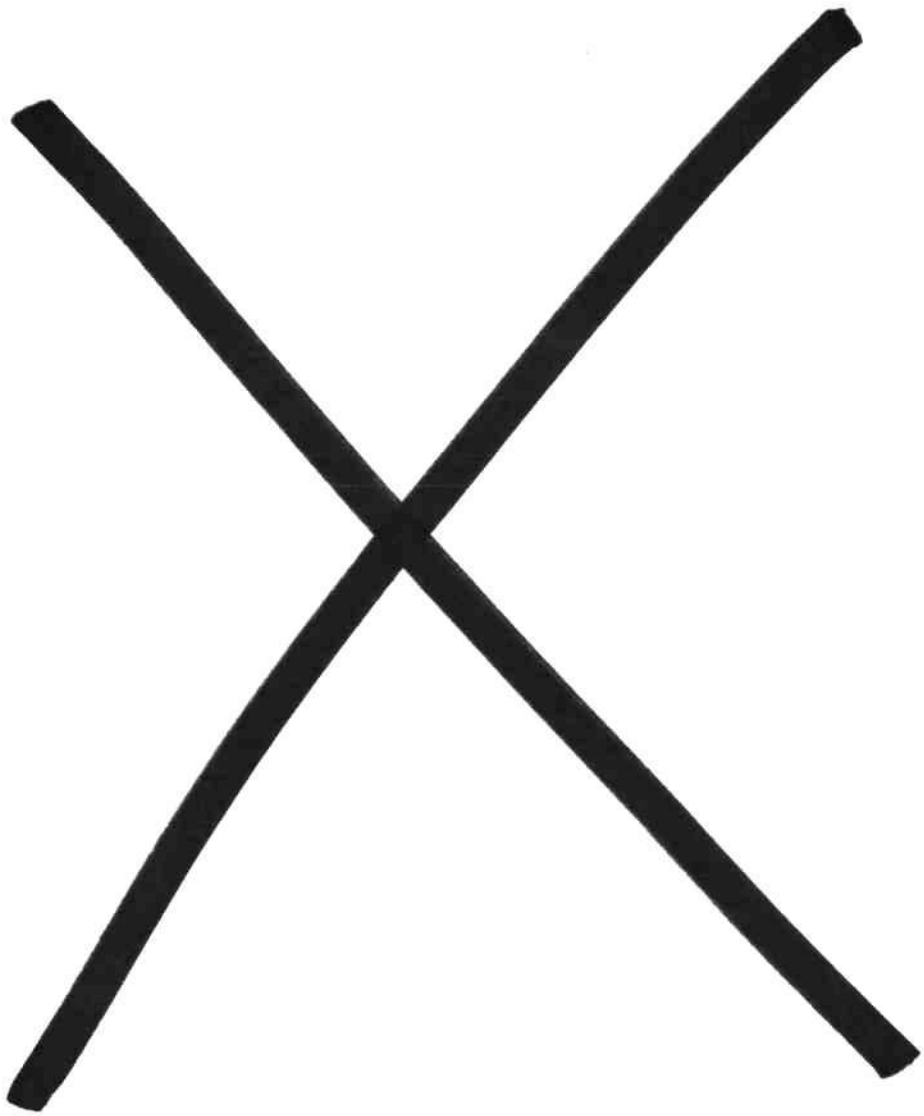


Introduction to the Service

DEFINITION OF THE SERVICE

The CAD/CAM Industry Service (CCIS) is a comprehensive, worldwide information service that performs research on and analyses of the markets, companies, products, trends, and technologies of the CAD/CAM industry. CCIS provides research and decision support in five ways:

- Research notebooks. These notebooks are detailed, frequently updated reference sources on the CAD/CAM industry. Market forecasts and analyses, annual shipments, market shares, and installed base information are provided. Profiles of major competitors are also included.
- Inquiry privilege. This feature provides clients with direct access to the CCIS research analysts. The inquiry privilege allows clients to access the information most applicable to their specific needs.
- Research bulletins. These event-driven publications provide a continual flow of timely information and Dataquest analyses on major industry events and issues.
- Industry conference. An annual conference brings industry participants together to review the state of the CAD/CAM industry and discuss the major issues in an open forum.
- Research library. Clients have access to Dataquest's extensive libraries for independent research.

To support client's decision-making in such areas as developing long-term goals, implementing and executing tactical plans, understanding user environments, and evaluating distribution channels, CCIS offers the following types of information:

- Comprehensive information on markets, products, technologies, applications, and companies in the CAD/CAM industry
- Quantitative data on shipments, installed bases, forecasts, market segmentation, and company performance
- Qualitative insights on technology trends, new product and market developments, company and marketing strategies, product positioning, and competitive postures

NEED FOR THE SERVICE

As the CAD/CAM industry matures, with the compound annual growth rate (CAGR) slowing to 8 percent in 1991, the decision-making process of CAD/CAM professionals becomes increasingly complex. Dataquest's CAD/CAM Industry Service is a resource of industry experts, providing all levels of personnel at our client companies with information and analyses on the CAD/CAM industry so that decisions can be made in an informed and timely manner.

Both general and specific industry data are gathered from a wide variety of sources. The benefits to our clients include:

- A single-source resource for decision-making support in planning, marketing, and development
- An objective, broad coverage of interrelated and international markets
- An external management information source
- A dynamic, ongoing, and long-term relationship
- A decision support tool for tactical and strategic information needs and problems

SERVICE STRUCTURE

CCIS research and analysis is offered to clients in two major parts: core (or general) and application-specific. Refer to Figure 1 for a graphical description of the service structure.

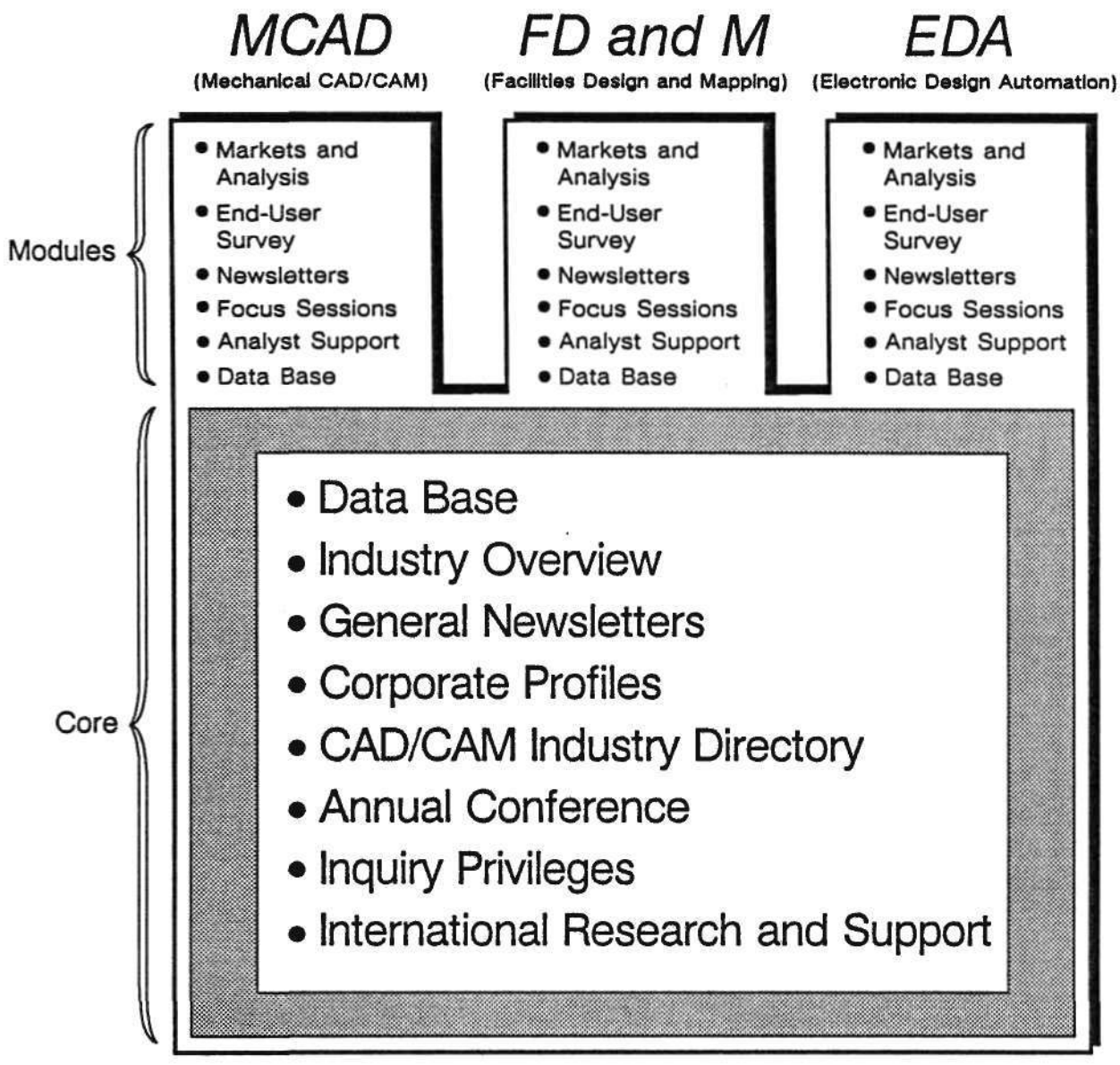
Core Service

The core service is provided to all CCIS clients and contains information and analyses relevant to all CAD/CAM industry participants. The core service is supported by a staff of industry and research experts. It consists of the following elements:

- *Industry Overview*—Analysis of the industry as a whole, including summaries of the major CAD/CAM segments
- *Company Profiles*—Information on the top 20 CAD/CAM suppliers, as well as quarterly and annual financial data on publicly held companies
- *Newsletters*—Event-driven analyses of issues and research of relevance to all CCIS clients

Figure 1

CAD/CAM Industry Service Structure



Source: Dataquest
June 1987

In addition to the above elements, all CCIS clients receive through the core service the following elements:

- Inquiry privileges—Direct access to the CCIS staff of analysts and researchers so that data and analysis may be tailored to specific information requests
- Attendance to the annual industry conference—One free seat at the conference, which must be reserved in advance
- International support—Access to the CCIS staff of researchers in Dataquest's London and Tokyo offices, as well as analysis pertaining to those regions
- *CAD/CAM Industry Directory*—One copy of the annually updated directory, which contains pertinent information on over 600 CAD/CAM suppliers and their products

Application-Specific Modules

The application-specific notebooks are available to CCIS clients that need information on a specific CAD/CAM application.

- *Mechanical CAD/CAM Applications*
- *Electronic Design Automation Applications*
- *Facilities Design and Mapping Applications*

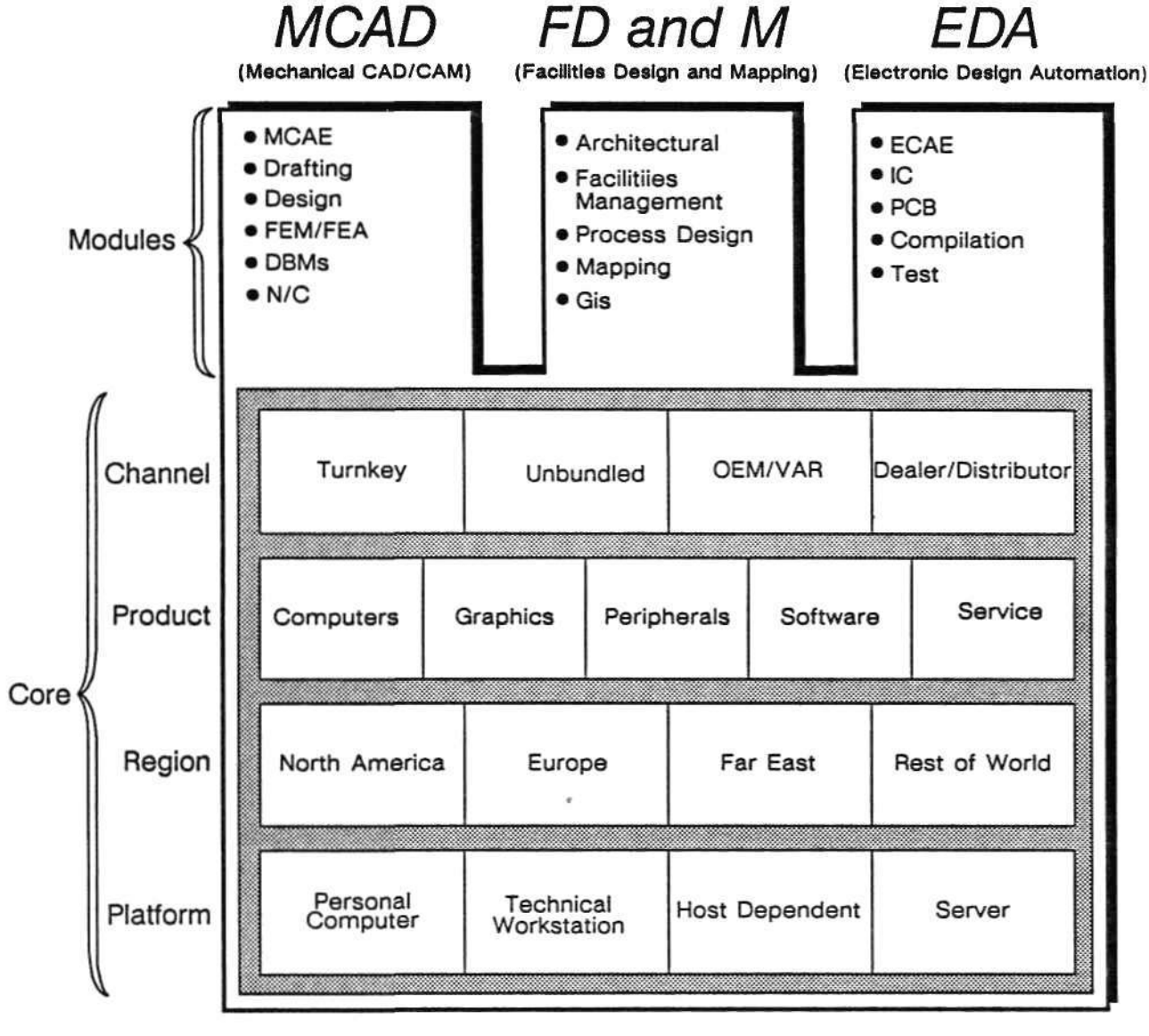
Each application module contains information and analyses particular to the specific application, including newsletters and other event-driven publications, market overview, market shares and forecasts, and specialized research and surveys. Each application module is supported by a staff of CCIS analysts with experience in the specific application.

INFORMATION STRUCTURE

The information available to CAD/CAM Industry Service clients is structured to provide data and analysis that are easily accessible and meaningful. Figure 2 graphically illustrates the CAD/CAM Industry Service information and reporting structure. All core segments, such as channel, product, region, and platform, are analyzed in both a general sense, which can be found in the *Industry Overview* core notebook, and an application-specific sense, which can be found in the respective application modules.

Figure 2

CAD/CAM Industry Service Information Structure



Source: Dataquest
June 1987

Channel

Channel, the first tier of the data base model, identifies how CAD/CAM systems reach the end user. This tier helps to distinguish the various distribution channels and marketing arrangements used when selling CAD/CAM systems.

Turnkey

The turnkey channel encompasses the sale of complete CAD/CAM systems, including computer, graphics workstations, operating systems, application software, and peripherals. Turnkey vendors also typically offer complete service, training, and maintenance for the systems that they sell.

Unbundled

The unbundled channel comprises the sale of CAD/CAM system components, such as application software or hardware, sold independently of each other. Unbundled components may be sold by either a company that specializes in that particular component, such as a software-only company or a computer manufacturer, or by a turnkey vendor, selling its software independently of the system.

OEM/VAR

The original equipment manufacturer (OEM) and value-added reseller (VAR) channel consists of companies that sell their products to another company for resale, which may be to another tier in the distribution channel or to the ultimate end user. Companies in this tier include computer manufacturers that sell their systems to turnkey vendors, who in turn resell the computer to an end user.

Dealer/Distributor

This growing channel consists of a group of companies that resell products developed by another company. Although not limited to personal computers, this platform comprises the majority of products moved through this channel. Dataquest reports on the amount of products moved through this channel but does not measure the market share of individual dealers or distributors.

Product

The product tier deals with tracking the sale of five major subsystems of a CAD/CAM system, including computers, graphics terminals, peripherals, software, and service.

Computers

This area identifies the unit and dollar volume of computer sales in the CAD/CAM industry.

Graphics Terminals

This area identifies the unit and dollar volume of graphics terminal sales in the CAD/CAM industry.

Peripherals

This area identifies the dollar volume of sales of peripherals such as plotters and printers in the CAD/CAM industry.

Software

This area identifies the dollar volume of application software sales in the CAD/CAM industry.

Service

This area identifies the dollar value of hardware, software, and support service sales in the CAD/CAM industry.

Region

The regional segment of the CAD/CAM Industry Service data base defines four regions into which CAD/CAM systems are sold. This segmentation aids in understanding the geographic characteristics of the areas where CAD/CAM systems are sold and delivered.

North America

The North American segment includes sales of CAD/CAM systems in the United States, Canada, and Mexico.

Europe

Europe includes the sale of CAD/CAM systems into the following countries and European areas:

- Benelux countries
- France
- German Region
- Italy
- Scandinavian countries
- United Kingdom
- Rest of Europe

Far East

The Far Eastern region includes the sale of CAD/CAM systems into the following countries:

- Hong Kong
- Japan
- Korea
- People's Republic of China (PRC)
- Singapore
- Taiwan

Rest of World

The Rest of World (ROW) segment includes the sale of CAD/CAM systems from territories not included in the European, Far Eastern, or North American regions.

Platform

Platform segmentation identifies three major architectures being delivered into the CAD/CAM market. This segmentation aids in understanding the trends related to the types of systems being purchased.

The three types of products are personal computers, technical workstations, and host-dependent systems. The major distinction among these product types is that personal computers and technical workstations contain their own CPUs and operating systems and therefore are classified as being fully distributed systems. Host-dependent systems, however, are considered shared-logic systems because their CPUs and operating systems are used as shared resources. For counting purposes, Dataquest treats personal computers and technical workstations as both system units and workstation units.

Personal Computers

A personal computer-based workstation is defined as having the following characteristics:

- DOS or OS/2 operating system
- Local 8/16-bit CPU
- Single processing capability

Examples of personal computer-based workstations are the Apple Macintosh and the IBM PC AT.

Technical Workstations

A technical workstation is defined as having the following characteristics:

- Resident operating system
- Full virtual operating system, such as UNIX or VMS
- Multitasking
- Networked communications support
- Integrated graphics

Examples of technical workstations are Apollo's DN 3000, Daisy's Logician, Intergraph's Interpro 32, and Sun's 2/120.

Host-Dependent

The host-dependent architecture is defined as having the following characteristics:

- CPU external from the workstation
- No local operating system at the workstation level
- Conditioned environment requirements

Examples of host-dependent products are Computervision's CDS 4000, Digital's VAX 11/780, and IBM's 4361.

Server

A server is defined as a networked resource that is used to control or accelerate a process, such as a file or peripheral server, so that more than one user may access a shared resource, or it can be used as an accelerator. A server is also typically used as a shared resource to speed up a computationally-intense process.

COMPANIES

Dataquest continues to expand the number of companies included in our forecast model. Our data base includes only end-user revenue of CAD/CAM companies. In this way, we avoid double counting and accurately represent CAD/CAM purchases by ultimate end users. The model consists of two groups of companies: those listed individually, or "main companies," and those consolidated into the "other" category. A company is listed individually only if its total CAD/CAM end-user revenue is $15 million or more. Conversely, a company is in the "other" category if its total CAD/CAM end-user revenue is less than $15 million.

Main Companies

The following companies, whose end-user revenue is $15 million or more, are listed individually in Dataquest's forecast model:

- Apollo
- Applicon
- Auto-Trol
- Autodesk
- CISI
- Cadnetix
- Calay
- Calcomp
- Calma
- Cimlinc
- Computervision
- Control Data
- Daisy
- Digital
- Exapt
- Ferranti
- Fujitsu
- Futurenet
- Gerber Systems
- Graftek
- Hewlett-Packard
- Hitachi

- Hitachi Zosen
- Holguin
- IBM
- Intergraph
- MacNeal-Schwendler
- Matra Datavision
- McDonnell Douglas
- Mentor
- Mitsubishi Electric
- Mutoh Industries
- NEC
- Norsk
- Otsukashokai
- Pafec
- Prime
- Racal-Redac
- Robo Systems
- SDRC
- Scientific Calculations
- Seiko I&E
- Sharp System Products
- Siemens
- Silvar-Lisco
- Sun
- Synercom
- Syscan
- Tektronix
- Telesis
- Toshiba
- Valid
- Zuken
- Zycad

Other North American Companies

These companies, whose end-user revenue is less than $15 million, are based in North America and are in the "other" category:

- A/SA
- ACDS
- Accugraph
- Advanced Geographic Systems
- Aptos
- Automated Systems
- Cadam
- Caeco
- Cascade Graphics
- Case Technology

- Cubicomp
- DFI
- DeNies
- ECAD
- ESRI
- Engineered Software
- Evans & Sutherland
- Factron
- Foresight Resources
- Gateway Design Automation
- Genrad
- Geobased Systems
- Geovision
- Gerber Scientific
- HHB Systems
- HOK/CSC
- Holguin
- ICAD
- Infinite Graphics
- Kork Systems
- LSI Logic
- MAGI
- MARC
- Manufacturing Consultants
- Maptech
- Megacad
- Metasoftware
- Metheus
- Micro Control Systems
- NCA
- Orcad
- PDA Engineering
- Paragon
- Personal CAD
- Phoenix Data Systems
- Point Line Company
- Quadtree
- SDA
- Seattle Silicon Technology
- Secagraphics
- Shape Data
- Sigma Design
- Silicon Compilers
- Silicon Design Labs
- Silicon Solutions
- Simucad
- Shok Systems
- Sperry

- Supercad
- Swanson Analysis
- Teradyne
- Test Systems Strategies
- The Great Softwestern Co.
- Transformer CAD
- Unicad
- VLSI Technology
- Versacad
- Via Systems
- View Logic
- Visionics
- WPS Development
- Xerox

Far East-Based Companies

Dataquest collects information on the following Japanese companies. If a company does not represent a United States-based company's Japanese distributor and if its total end-user CAD/CAM revenue is $15 million or more, it is also included in the "main companies" category. This list represents all of the Far Eastern companies from which Dataquest's CCIS collects data:

- Aida Engineering
- Andor
- Asahi Optical
- Asahig Giken
- Autodesk Japan
- C. Itoh Techno-Science
- CPU
- Century Research Center
- Computervision Japan
- Data I/O Japan
- Design Automation
- Fuji Xerox
- Fujitsu
- Graphtec
- Hakuto
- Hitachi
- Hitachi Zosen
- Hitachi Seiko
- IBM Japan
- Info. Services Int'l Dentsu
- Kanematsu Semiconductor
- Marubeni Hytech
- Mentor Graphics Japan
- Mitsubishi Electric
- Mitsui Engineering
- Mutoh Industries

- NEC
- Nippon Univac Kaisha
- Nissec Schlumberger
- Otsukashokai
- Prime Computer Japan
- Racal-Redac Japan
- Rikei
- Seiko I&E
- Sharp System Products
- Silvar-Lisco Japan
- Technodia
- Tokyo Keiki
- Toshiba
- Toyo Information Systems
- Uchida Yoko
- Univac Information Systems
- Ustation
- Wacom
- Yamashita Electric Design
- Yokogawa Electric
- Yokogawa Hewlett-Packard
- Zuken

European-Based Companies

Dataquest collects data from our London office on the following European-based companies. Their market shares are called out individually only if their total end-user CAD/CAM revenue is $15 million or more:

- Cad Centre
- CADlab
- Calay
- CISI
- Dassault
- EIE
- Exapt
- Ferranti
- Marconi
- Matra Datavision
- Norsk
- Olivetti
- Pafec
- Racal-Redac
- Robo Systems
- Secmai
- Siemens
- Superdraft
- Syscan

HOW TO USE THE SERVICE

Due to the vast amount and dynamic nature of the information that is disseminated, the Dataquest CAD/CAM Industry Service offers four means of access to our research:

- Research notebooks
- Newsletters
- Inquiry privilege
- Annual conference

Research Notebooks

The six CCIS research notebooks contain the nucleus of the CAD/CAM Industry Service research.

Core Notebooks

The three core notebooks are available to all CCIS clients and cover the entire CAD/CAM industry. These notebooks include the following:

- *Industry Overview*—An overview of the entire CAD/CAM industry, with a summary of the forecasts and trends on each of the tiers and segments illustrated in Figure 2
- *Newsletters*—An archive for all CCIS newsletters, with tabs for specific applications
- *Company Profiles*—Company and product information on the top twenty United States-based CAD/CAM vendors

Application Modules

The three application modules are available to CCIS clients that need in-depth information specific to an application. They include:

- *Mechanical CAD/CAM Applications*—Trends and analyses of mechanical applications, including mechanical computer-aided engineering, drafting, design, finite element modeling and analysis, data base management systems, and numeric control
- *Electronic Design Automation Applications*—Trends and analyses of electronic applications, including electronic computer-aided engineering, IC layout, PCB layout, compilation, and test

- *Facilities Design and Mapping Applications*—Trends and analyses of the facilities design and mapping application segments, including architectural, facilities management, process design, mapping, and geographic information systems

Newsletters

CCIS Research Newsletters contain information that is either industry event-oriented (e.g., major product announcements) or based on a Dataquest primary research effort (e.g., end-user surveys). The Dataquest CAD/CAM Industry Service typically publishes two to five newsletters per month. These go into the *Newsletters* notebook and are classified as either general CAD/CAM or mechanical, electronic design automation, or facilities design and mapping applications.

Inquiry Privilege

The inquiry service allows clients to have direct access to any of the CCIS research staff for up-to-the-minute information and analyses via telephone, telex, facsimile, or visits. This also allows clients to obtain information on a specific question or topic not found in the printed publications. To support this direct-line access, Dataquest has a highly professional research staff with an in-depth background in the CAD/CAM industry. We maintain contact with a large company base through sophisticated sampling and interviewing techniques. To contact the staff, please write, call, telex, FAX, or visit the following address:

Dataquest Incorporated
1290 Ridder Park Drive
San Jose, California 95131
Telephone: (408) 971-9000 Telex: 171973
FAX: (408) 971-9003

Also available to CCIS clients through the inquiry privilege is the use of Dataquest's extensive CAD/CAM and corporate libraries. Library visits may be scheduled by calling the CAD/CAM Industry Service directly.

Annual Conference

The annual CCIS conference is a two-day, in-depth conference held in the calendar second quarter at a resort location. The purpose of the conference is to provide a forum for the Dataquest research staff and other industry experts to share their thoughts and ideas on the CAD/CAM industry. One of the key elements of the conference is the presentation of Dataquest's current market numbers and market shares along with our projections for the next five years. All of the presentations are organized in a large loose-leaf binder and distributed at the conference.

Dataquest's CAD/CAM Industry Service clients are entitled to one free reservation at the conference. Additional employees from client companies can attend at reduced rates. Due to limited space, all clients are encouraged to register early to reserve the free seat to which they are entitled.

FORECASTING METHODOLOGY

Dataquest's CAD/CAM Industry Service market estimates and forecasts are derived using one or more of the following techniques:

- "Bottom up" or component aggregation. This method involves adding all relevant vendor contributions to arrive at total market estimates for all historical data.

- Segment forecasting. This method involves creating individual forecasts for each application segment, including regional and platform forecasts for that application. In this way, each application segment incorporates its own set of unique assumptions.

- Demand-based analysis. This method involves tracking and forecasting market growth based on the present and anticipated demand of current and future users. This requires the development of a total available market (TAM) model and a satisfied available market figure to accurately assess the levels of penetration.

- Capacity-based analysis. This method involves identifying future shipment volume constraints. These constraints, or "ceilings," can be the result of component availability, manufacturing capacity, or distribution capacity. In any case, a constraint in one of these areas is capable of keeping actual shipments below the demand level.

Dataquest's revenue and shipment estimates are based on the following sources:

- Information supplied by company management or gathered from publicly available published sources

- Information supplied by other Dataquest industry services relating to components/subsystems of CAD/CAM systems

- Information provided by OEMs or resellers of the manufacturers' products

- Large-scale end-user surveys

- Senior staff estimates based on reliable historical data

The CAD/CAM Industry Service data are based on revenue and unit data of systems sold to end users. Great care is taken with our actual unit and revenue numbers to avoid double counting.

Despite the care taken in analyzing the available data and attempting to categorize it in a meaningful way, we offer a few caveats regarding interpretation of the data:

- Certain assumptions, definitions, or conventions implicit in our forecasts may differ from those of others. Please refer to our *Industry Overview* and application notebooks glossary for definition of forecasting terms and analysis and interpretation of the data in order to understand our definitions and assumptions.

- Our shipment estimates of systems and workstations include only those delivered to paying customers, not the total that is manufactured (the backlog).

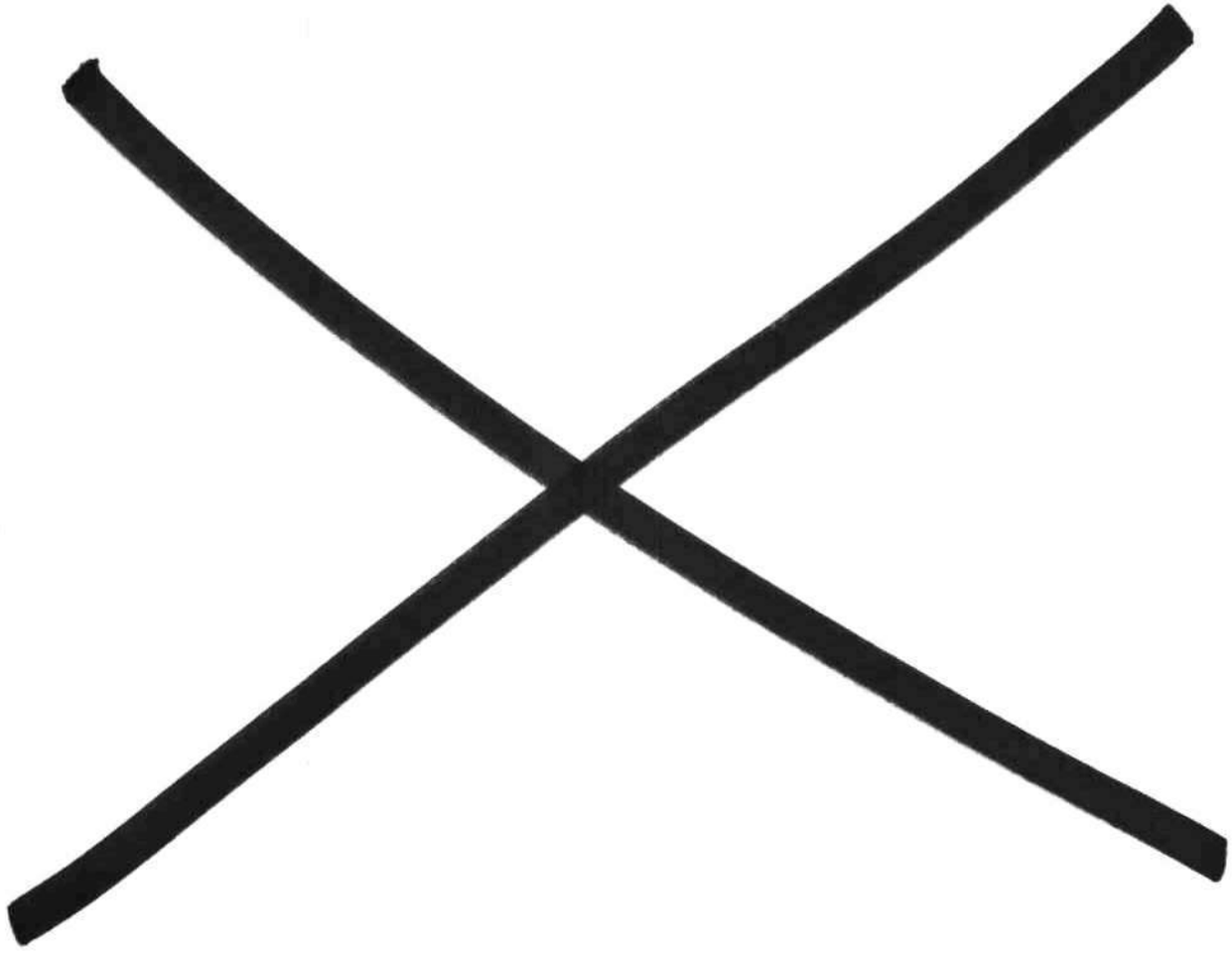
- Revenue and average selling price estimates are based on transaction prices, not list prices.

- All data elements have been adjusted to reflect the forecast period, which is the calendar year.

- Many manufacturers do not release their actual unit sales, application distribution, geographic distribution, or platform distribution. In order to provide our clients with the most accurate forecasts, we have given careful consideration to estimating these companies' data.

- Prior to 1983, Dataquest did not segment revenue geographically other than into U.S. and non-U.S. markets. To accommodate the expanded geographic segmentation, we have added all non-U.S. data into the ROW segment for 1981 and 1982.

- Prior to 1983, Dataquest did not differentiate products based on hardware type. To accommodate our expanded product type segmentation, we have grouped all product types prior to 1983 into the host-dependent category. Although not all systems shipped prior to 1983 were of the host-dependent variety, the vast majority were.



1.1 Mechanical Definitions

The mechanical segment refers to CAD/CAM products that are typically used to support the design and manufacturing of components and mechanisms. The users are most often engineers, designers, or draftsmen involved in the design and documentation process. The following paragraphs give detailed definitions of the scope of the market comprised of end-user industries and the evolution of major CAD/CAM applications. Later sections include an executive summary, a market overview, a market forecast, a market share analysis, and an in-depth assessment of emerging technologies.

DEFINITION OF MECHANICAL CAD/CAM MARKET

Dataquest has defined the mechanical CAD/CAM market in terms of the users of the technology and applications being used. The users are categorized by industry groupings, with typical products and organizations described. The major CAD/CAM system applications define a framework that allows a full analysis of the total CAD/CAM application area.

Refer to the following sections for a detailed definition and analysis of the mechanical CAD/CAM market:

- Definition by End-User Segment
- Definition by Major System Application

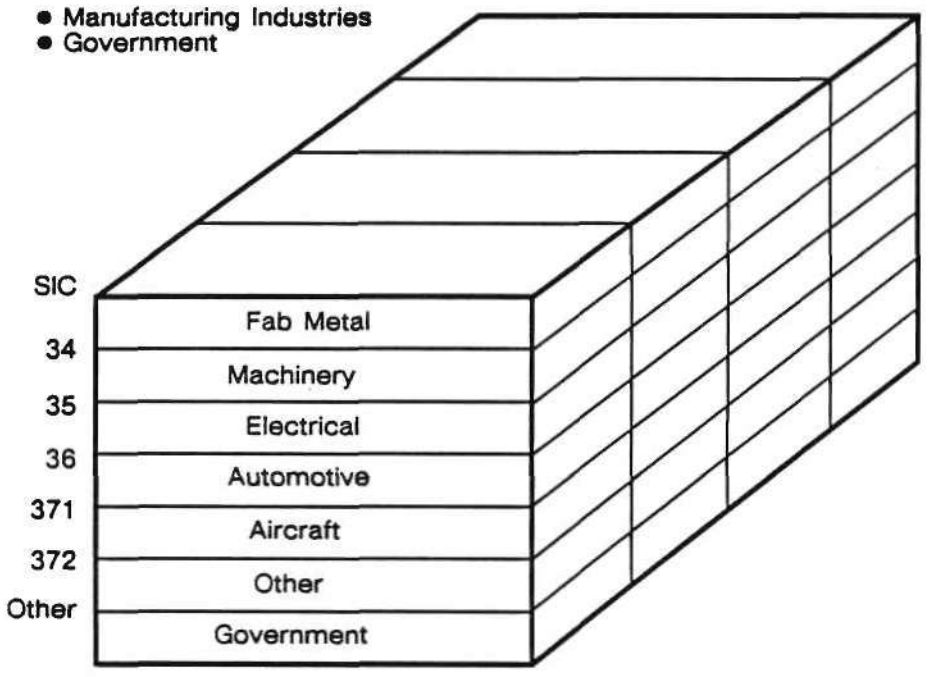
Definition by End-User Segment

The mechanical CAD/CAM market is defined to include all of the manufacturing industries as shown in Figure 1.1-1. In the United States, another major segment of the mechanical CAD/CAM market is represented by the federal government.

Some of the manufacturing industries certainly have a stronger need than others, but it is difficult to find any industry that does not use some mechanical component in its products or in manufacturing its products. Dataquest uses the U.S. Department of Commerce's Standard Industrial Classification (SIC) codes to define the major industries using mechanical CAD/CAM tools. The top five manufacturing industries plus the Other group define the CAD/CAM market. The corresponding industry and SIC numbers are aircraft (Code 372), automotive (Code 371), machinery (Code 35), electrical (Code 36), and fabricated metal (Code 34).

Figure 1.1-1

Mechanical CAD/CAM Market



Source: Dataquest
July 1988

Aircraft

CAD/CAM techniques are ideally suited to the aircraft/aerospace environment. The large documentation requirements representing thousands of parts and assemblies are well suited to production by CAD systems. Complex design tasks are compounded by the proliferation of airframe models and features. In reality, each plane or vehicle is unique, requiring its own set of documentation for manufacturing and maintenance. The complete process from conceptual design through detail design, analysis, test, fixturing, manufacturing, and service/repair now uses CAD/CAM technology. The early stages of conceptual design are aided by solid modeling and realistic visualization techniques. As the design moves into the analysis and detail design phase, finite element stress analysis becomes important as a design tool. Manufacturing gets involved designing tooling, fixtures, and processes that manufacture and bring all the components together in final assembly. Numerical control part programming has been one the strongest CAM development areas in the aerospace industry. Computer-aided testing and quality assurance play an important function in guaranteeing that the original design was accurately built. The use of computer-aided tools does not end here. Computer graphics,

technical publication, and artificial intelligence procedures are being combined into interactve portable service, diagnostic, and repair workstations. The ongoing service and repair operations are becoming more efficient as a result.

The brief examples above are typical of the aggressive use of CAD/CAM techniques in the aerospace design and manufacturing operation. Because CAD/CAM techniques are used from start to finish, many benefits are realized by sharing data from one step to the next. Reduced errors, faster response to changes, and better control are some of the significant benefits.

Automotive

The benefits of proven CAD/CAM applications are found in abundance in the automotive industry. Similar to the aerospace industry, large documentation requirements and complex design tasks are common. A very competitive worldwide market, governmental controls, and rapidly increasing complexity in technology and material requirements are making the automotive industry more dependent on CAD/CAM tools.

A description of the automotive design process starts with the stylist. The computer-aided engineering tools for vehicle concept and styling development are evolving. Conceptual simulation and analysis software is being combined with visualization software to produce photographic-quality images of rendered surfaces. Animation techniques are being used to add motion to the realistic images. Engineering, advertising, and styling all can benefit from the moving simulations. But much more than pretty pictures are developed. Using the resulting mathematical data base, the same models can be tested for driver visibility, packaging, and, with more detail, for simulation of ride and performance characteristics.

When the body, power train, and chassis design groups get involved, the new car project is scheduled for production in as little as 18 months. The detailed design progresses, working from the outer surface toward the center of the fire wall. The 6,000 or more parts that make up a typical automobile are detailed, assembled, and verified. If designed properly, the doors will open, the lights will light, and the wheels will not fall off after the first chuckhole.

The manufacturing process is a complex choreography of purchased and manufactured parts with thousands of time-dependent milestones, resulting in the right part being at the right place for assembly. Manufacturing engineering is responsible for production tooling, including design for dies, molds, and sheet metal parts.

The manufacturing and assembly group is responsible for assembly layout, tool fabrication, and programming for the decision support and control computer systems. Numerical control part programming, material resource planning, computer-aided processing, robot programming, and process control programming are just a few of the supporting functions of this group.

Machinery

The products produced in the general machinery industry start with the most common parts such as nuts, screws, and washers. These are combined with cast, molded, and other machined components to make up the next tier of finished goods, which include saws, polishers, sprayers, drills, and mixers.

The mechanical CAD/CAM applications used in the aerospace and automotive industries are typical of those used in the general machinery industry but at a higher level of complexity. The manufacturing tolerances in the general machinery industries are not as stringent, the materials used are not as exotic, and the overall level of product sophistication is not as complex. There are exceptions, however, in medical, food, and other processing applications. The CAD/CAM tools are involved in all aspects of product, assembly, and component design as well as in manufacturing support for tooling, fixtures, and processes.

Electrical

Electrical and electronic machinery includes almost everything that runs on electricity, such as appliances, cooking equipment, sewing machines, lighting fixtures, radios, television sets, and X-ray equipment.

The mechanical CAD/CAM applications required to design, document, and manufacture these products cover the full spectrum of today's capabilities. Castings, forgings, and sheet metal enclosures are typical components in appliances and cooking equipment. Many molded cabinets, housings, and piece parts are used in consumer electronics and commercial equipment. Dataquest survey data estimate that approximately a third of all mechanical design and analysis activity includes electrical or electronic components in the design.

The added complication of designing products with both mechanical and electronic components requires close attention to the design goal and coordination throughout the manufacturing process. The design and manufacture of the electronic components is discussed in detail in later sections of the Market and Analysis binder.

Fabricated Metal

Typical products produced in this industry include industrial fasteners, screw machine parts, valves, pipe fittings, and ball/roller bearings. Castings, forgings, extrusions, and bar stock are turned, coined, swaged, bent, and twisted to make these parts.

The CAD tools used to support the design and manufacture of these products range from basic drafting-only systems to full CAD/CAM and computer-aided engineering systems. Use of computerized tools has led to greater efficiency in small lot production.

Numerical control (NC) machine tools can effectively produce one-off prototype parts or small production runs of up to several hundred parts. The increased precision in NC manufacturing has allowed some valve manufacturers to upgrade the pressure and temperature specifications of their valves. The use of CAD/CAM tools allows quicker response to customer requests, giving the small manufacturer a significant advantage.

Other

The other manufacturing industries comprise a great variety of sometimes large industries that have varying levels of experience and success in using CAD/CAM technology. As a group, the number of users is fairly large, but the CAD/CAM applications used are extremely diverse. A brief list of manufacturing industries in this group will illustrate the issue. These industries include: food, apparel, lumber products, furniture, bathroom fixtures, railroad equipment, instruments, watches, games, and caskets. The opportunity for niche product development in this group is large. Vendors interested in developing effective tools for these markets must have extensive user-application experience to guarantee useful results.

Government

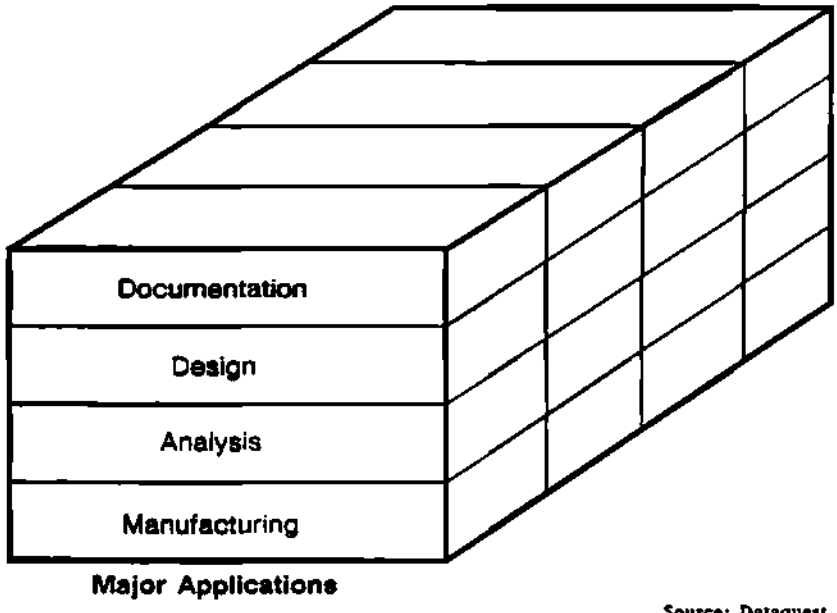
The U.S government has emerged as an important user of CAD/CAM technology. The Navy, Bureau of Land Reclamation, and Army Corps of Engineers are all examples of current users. Virtually all CAD/CAM applications are in use in the government. The design and manufacturing requirements for mechanical applications are expanding, which is increasing the use of CAD/CAM tools. The Navy in particular has a strong need to interface electronically with subcontractors who build and manufacture components for the sea and air weapons systems.

DEFINITION BY MAJOR SYSTEM APPLICATION

Dataquest uses four common system usage groups for comparison, aiding in the organization of information in each of the CAD/CAM application segments. These groups are documentation, design, analysis, and manufacturing, as shown in Figure 1.1-2.

Figure 1.1-2

Mechanical CAD/CAM Market
Major Applications



Source: Dataquest
July 1988

Documentation

Considering the diversity of complex machinery that has been designed and tediously drafted with pen and paper, it is no surprise that a step forward in automating the drafting process has been received with open arms. The drafting process is defined by simulating the manual process of generating layout, detail, and assembly drawings in a CAD system. Each line, circle, and piece of text is created and placed with the appropriate system command, allowing the user to build the drawing. Advantages inherent in CAD technology allow rapid revision of the stored data with fast duplication and overlay techniques.

The major documentation, drafting, and schematic applications are:

- Detail drafting
- Layout
- Schematics

- Technical illustration
- Charts

Design

The general trend in computer graphics is toward design simulation. Design in this context is typically a three-dimensional problem where component parts are fit together, defining the assembly. The amount of detail in these models varies from a few lines and circles to very complex assemblies with every surface and corner precisely defined.

An essential system function is the ability to view the design from any orientation. Combining the ability to model part geometry with the viewing functions gives the designer a powerful design tool. The common user expectation is to be able to produce a better design using CAD but with the same time investment. The major design applications are:

- Part modeling
- Visualization
- Assembly design and verification
- Clearance and assembly studies
- Linkage/mechanism design

Analysis

Analysis is entwined in the design process. Making sure all the parts fit together and meet the design goals is the most common type of analysis. As the modeling process has improved, so have the analytical tools to evaluate the models. An example is finite element mesh modeling and analysis. This general technique has at its roots a divide-and-conquer procedure for simplifying the calculation required to evaluate thermal or structural properties of the design. These calculations can be performed for two- or three-dimensional analysis. By defining the conditions of the structure where it attaches to other components, the design can be twisted, pulled, and shaken, all using computer simulation. The tedious effort of setting up a typical test and waiting for the results has been shortened from days to hours. Unfortunately, hours can seem like days when the axles are breaking off your trucks and you do not know why. If the analysis could be done in minutes, more analyses would be done earlier in the design process, improving product reliability.

Major analysis applications include:

- Mass properties
- Structural
- Fatigue
- Thermal
- Vibration
- Magnetics
- Composite materials

Manufacturing

In many respects, the applications and benefits of using computer-aided drafting, design, and analysis all apply to the manufacturing operation. Sharing the product design data base is a good start in improving the operation, but it is just the beginning. Many drawings are generated for production equipment construction and documentation. Tools and fixtures need to be designed or redesigned for the next product revision. The full range of simulation and analysis tools are valuable in optimizing the manufacturing process. Part geometry is being used to define the tool cutting path on a numerically controlled mill, lathe, drill, or other machine tool. Robotic work cell simulation is a major CAM application in development. In general, the use of CAM in manufacturing has the biggest potential for productivity gains, resulting in improved profitability for the user company.

Major manufacturing CAD/CAM applications are divided into two groups: manufacturing engineering and process simulation/interface.

Manufacturing engineering includes:

- Tool design
- Fixture design
- Sheet metal development
- NC post processing

- Pattern nesting
- Quality control analysis

Process simulation includes:

- Numerical-controlled machine tool programming (DNC and CNC)
- Nesting and flame cutting
- Tube bending
- Coordinate measuring machine
- Robotics (machine loading, assembly, and spot welding)
- Material-handling systems
- Programmable controllers

Other important computer applications are in use in the manufacturing environment but are not included in the CAD/CAM evaluation. These other applications are:

- Manufacturing resource planning
- Production and inventory control
- Shop floor control

1.2 Mechanical Executive Summary

This summary highlights the key points discussed throughout this chapter. Please refer to the chapter in its entirety for a comprehensive analysis of the mechanical application segment. The following points are significant:

- Mechanical CAD/CAM revenue was $4,968 million in 1987 and is anticipated to grow to $5,849 million in 1988 and to $7,936 million in 1992.
- The estimated total number of mechanical CAD/CAM workstation units shipped in 1987 was 128,400. Dataquest anticipates that 162,000 units will be shipped in 1988 and 276,000 units in 1992.
- Dataquest anticipates that workstation units in the mechanical CAD/CAM market will grow at a 16.6 percent compound annual growth rate (CAGR) for the next five years.
- The personal computer has grown from a minimal workstation share in 1982 to represent 56 percent of the workstations shipped in 1987.
- The introduction of the IBM OS/2 operating system will allow the 80386-based systems to bridge the gap between personal computers and technical workstations. The later UNIX-based 386 products will be counted as technical workstations.
- The host-based computer will continue as a major mechanical CAD/CAM computational resource. Product development at the high end and the low end will continue to attract upgrade, add-on, and new user installations. Large organizations with existing successful host-based installations will be the source of most growth in host-based products. Small host-based systems with two or three workstations are also popular for small work groups.
- Technical workstations will continue as the fastest-growing computing platform, gaining share from both PC- and host-based systems. The widest range of scalable solutions is available on this platform.
- The average turnkey mechanical workstation price dropped to $49,400 in 1987; it is projected to drop to $46,200 in 1988 and to $35,300 in 1992.
- The desktop environment is being viewed by vendors as the prime market for attracting wide use for CAD/CAM products. High user acceptance of the total solution will require full applications support, networking, and easy-to-use, reliable products.
- The primary difference in application usage, considering platform type, is based on problem complexity, not type of work.

- Some of the fastest growing application areas in the next two years will be:
  - Computer-aided engineering for mechanical applications, including design simulation and analysis
  - The combined electrical and mechanical application (Vendors who have historically focused on the mechanical or electrical applications will provide integrated packages, better serving this segment of the market.)
- Computer-aided styling (CAS) is quickly gaining momentum as industrial designers with computing skills learn to use the available CAS tools. Development to provide more intuitive tools for the remaining designer/artists will fuel the rapid growth of this application, bringing CAS techniques into the mainstream of MCAD.
- Advanced modeling techniques are slowly gaining momentum as the preferred modeling choice. Feature-based modeling, parametric design, and object-oriented modeling systems will blossom as prices come down, performance goes up, and application software becomes available.
- As the distinction between personal computers and technical workstations continues to blur, operating system features remain the most significant point of differentiation, supporting or limiting application use.

1.3 Mechanical CAD/CAM Overview

HISTORY

The early and mid-1960s saw the emergence of computer graphics as a practical tool. Some of the earliest graphics work was developed for the military using mainframe computers. Massachusetts Institute of Technology was an early contributor, providing a training ground for pioneers in this field such as S. Coons, I. Sutherland, and S. Chasen. In the late 1960s, the basic elements of computer, display, and software came together to form the first commercial turnkey CAD systems. The first systems were focused on printed circuit layout and were able only to draw straight horizontal and vertical lines. The users immediately began asking for more features. An early enhancement, two-dimensional drafting, made CAD practical for mechanical applications. Applicon and Computervision were formed in 1969 to supply these primitive two-dimensional CAD tools.

The early 1970s witnessed essential development for the mechanical applications as P. Bezier, H. Gouraud, E. Catmull, and W. Gordon completed their basic research in curve surface definition and display. By the mid-1970s, this research was being used in the first three-dimensional design systems. The designer could now string wires and some surfaces in three dimensions. Fontaine Richardson, Patrick Hanratty, Gerry Devere, and David Albert are some of the key figures who took the research of the day and turned it into usable CAD products.

Industry giants such as General Motors, Lockheed, Matra, and Nisson early understood the value of computer graphics and developed internal systems that are still in use today. In fact, some of their original products are the basis of today's successful commercial CAD products, such as CADAM and Euclid. The 500 plus companies that currently make up the mechanical CAD/CAM industry accumulated more than $4.9 billion in revenue in 1987.

THE PRESENT

Economic Health of Manufacturing Industries

Today's CAD/CAM market is emerging as an essential ingredient in the worldwide trend toward factory automation. The progress of this trend is based on the basic economic health of the user industry, on the level of penetration that the technology has made, and on the level of functionality of the tools that are needed to do the job. The following sections outline the progress in these areas. Table 1.3-1 defines the size and growth rate of each major industry.

Table 1.3-1

Analysis and Forecast of Major Industries
Using Mechanical CAD/CAM

	1985	1986	1987	1988	CAGR 1986-1988
Aerospace Industry					
(SIC 372, 376)					
Value of Shipments	$ 90,795	$ 97,064	$102,864	$110,371	6.6%
Value of Imports	$ 6,080	$ 7,881	$ 7,693	$ 8,829	5.8%
Value of Exports	$ 18,726	$ 19,727	$ 21,422	$ 22,062	5.7%
Total Employment	746,000	786,000	814,000	836,000	3.1%
Motor Vehicle Composite					
(SIC 371x)					
Value of Shipments	$130,604	$140,095	$128,283	$135,270	(1.8%)
Value of Imports	$ 26,600	$ 33,450	$ 40,000	-	-
Value of Exports	$ 2,072	$ 2,388	$ 2,742	-	-
Total Employment	296,000	275,000	270,000	265,000	(1.8%)
General and Special Industrial Machinery					
(SIC 35xx)					
Value of Shipments	$ 59,321	$ 57,748	$ 56,364	$ 57,605	(0.1%)
Value of Imports	$ 8,615	$ 10,030	$ 11,260	-	-
Value of Exports	$ 12,193	$ 10,686	$ 10,372	$ 11,007	1.9%
Total Employment	544,100	517,700	506,300	-	-
General Components and Automotive Stampings					
(SIC 34xx)					
Value of Shipments					
Components	$ 20,476	$ 20,236	$ 20,099	-	-
Stampings	$ 15,038	$ 15,790	$ 16,422	$ 16,914	3.4%
Value of Imports	$ 2,521	$ 2,730	$ 2,902	$ 3,046	5.5%
Value of Exports	$ 1,303	$ 1,262	$ 1,375	$ 1,516	9.5%
Total Employment	241,000	231,000	218,000	-	-
Electronic Components and Equipment					
(SIC 367)					
Value of Shipments	$42,920	$43,893	$47,549	$51,427	8.2%
Value of Imports	$8,545	$9,329	$10,422	$11,568	11.4%
Value of Exports	$6,190	$7,126	$8,551	$9,577	15.9%
Total Employment	558,000	531,000	529,000	563,000	3.0%

*Forecast based on ITA forecast

Source: Source: U.S. Industrial Outlook—1988 International Trade Administration (ITA)

Aerospace

The inflation-adjusted value of U.S. aerospace shipments is projected to climb at about 3.3 percent in 1988. Total shipments surpassed $100 billion, with aircraft representing 72 percent and guided missiles and space vehicles being the remaining 28 percent. The slower growth rate in 1987 (compared to 1986) was partially due to decreased government spending in this sector, although military sales continue to outpace the civilian sectors.

Military use accounted for more than 60 percent of the total value of the 1987 shipments. However, a steady backlog of orders for civilian aircraft portends a larger share of civilian sales over the next three years. Of particular interest to CAD/CAM companies is the fact that U.S. manufacturers in the aerospace industry spent an estimated $3.3 billion on new plants and equipment compared to $3.8 billion in 1986.

In terms of long-term prospects, the International Trade Administration is forecasting good growth, particularly in the large commercial aircraft sector. This hinges chiefly on the growth of air traffic, particularly in the Asian region. Boeing projects that a 5.3 percent average annual rate of growth for air passenger traffic between 1986 and 2000 will create a demand for 5,286 new commercial large transport aircraft. This translates into $265 billion in 1987 dollars.

Metalworking

The metalworking industry produces many types of capital equipment and engineering services essential to manufacturing. The more established elements of the industry, generally plagued by import competition, experienced relatively slow (and in some cases even negative) growth in 1987. Little improvement in growth is expected in the future. The newer high-tech components of the industry's products are growing at a much faster rate, but eventually will also be threatened by foreign competitors in the world market.

The structure of the U.S. metalworking industry is rapidly changing. Many foreign manufacturers have invested in existing domestic machine tool builders and other metalworking firms. Others have planned or begun to establish new U.S. sales subsidiaries to distribute their foreign-produced products.

Some U.S. producers are directly importing foreign products. Others are establishing offshore manufacturing facilities. However, the great majority of domestic producers have chosen to use joint ventures with foreign firms and manufacturing license arrangements in order to share the cost advantages of overseas production. As domestic productive capacity continues to shrink, domestic manufacturers are losing market share. This applies particularly to those metalworking equipment categories associated with high technology products such as a machining and turning center. The reduced value of the dollar is eroding the significant price advantage enjoyed by foreign competitors. This is aiding the domestic suppliers who are expecting to export more product and enjoy a slight growth in the domestic market.

General Components

In 1987, total shipments by this sector decreased 1.4 percent (in 1982 dollars) and amounted to about $20.1 billion. In 1988, general component industry shipments are expected to grow approximately 2 percent (in 1982 dollars). The foreign trade balance for general components will continue to be in deficit in 1988.

The ball bearings portion of this industry has suffered considerably from competition with Europe and China. However, the Department of Defense (DoD) may provide the industry with assistance. Proposals currently under consideration would require use of bearings manufactured in the United States and Canada in all DoD procurement. Other protectionist proposals include:

- Funding industry modernization programs
- Limiting the number of licensing agreements to prevent transfer of important bearings-related technology to other countries

Motor Vehicles

Product shipments of motor vehicles and car bodies fell approximately 9 percent to an estimated $120.9 billion in 1987. In constant dollar terms, the decrease amounted to 9.5 percent, compared with a gain of 4.3 percent. Behind the reversal were further market encroachments from imports, faster growth in car prices than incomes, and decreasing effectiveness of sales incentive programs. Such programs (e.g., below market rate financing) have effectively conditioned buyers to postpone buying until an incentive period.

However, U.S. producers of motor vehicles and parts will experience across-the-board growth in 1988 as car sales rebound from a disappointing 1987. Significant new model introductions indicate an increase in product quality.

Special Industrial Machinery

Overall, performance in this industry sector remains disappointing. Total trade in special machinery showed a deficit for the first time in 1987. Exports are estimated at $5.2 billion, down 8 percent from the 1986 level, while imports are up 14 percent to $5.6 billion. Although the oil field and mining machinery industries maintain favorable trade balances, the value of imports significantly exceeds the values of exports for the others.

Shipments of special industrial machinery are expected to increase approximately 3 percent in 1988 (measured in 1982 dollars), after falling about 2.6 percent in 1987. Exports are expected to rise by more than 7.5 percent in 1988 and account for more than 30.0 percent of U.S. shipments. On the other hand, imports are expected to rise 10.5 percent and will equal about 26 percent of the U.S. supply of special industrial machinery.

Electronic Components

The value of shipments by the electronic components industry (SIC 367) in 1988 should increase 8.2 percent from 1987 and 17.0 percent from 1986. The increased demand from the computer industry coupled with the strong military demand for electronic components accounted for growth in semiconductors, capacitors, connectors, and printed circuit boards in 1987. SIC 367 is expected to grow 10 percent per year between 1988 and 1992.

The Government

The U.S. government has been an important market for the CAD/CAM industry since the beginning of CAD/CAM. All major applications are represented with many programs developed to address special application areas in CAD/CAM. The government represents more than 19 percent of the U.S. population of engineers and technical professionals. This number is expected to drop slightly to 17 percent in 1991.

The U.S. Navy has released a request for proposal (RFP) for vendor bids that is designed to create an electronic environment for users to communicate and manage the design, support, and maintenance of the Navy sea and air weapons systems. The contract value could easily exceed $1 billion over the next five years. The positive impact of this acquisition will be to increase the emphasis on standards of communication, hardware interfaces, data base management, and user interaction. Recent delays and downsizing of this proposal make its future unclear at this time.

NASA is also introducing a large CAD/CAM system to aid in the design and manufacture of the manned space station program. The approved $19 billion R&D budget for Strategic Defense Initiative (SDI), better known as Star Wars, will also include some CAD/CAM activity. All of the major CAD/CAM vendors have implemented sales and support groups targeting the government sector.

Work Environment

The current CAD/CAM work environment in each of the major SIC code areas is very similar, but with some unique variations. Drafting standards are well defined for all industry segments. Design tasks for a car door and a cargo bay hatch are quite similar, depending on size or performance characteristics. Unique design and manufacturing problems do occur, but the CAD/CAM systems are generally flexible enough to be custom tailored for the job.

Today's complex product design and manufacturing environment requires a staff with many talents. Mechanisms, electronics, hydraulics, and pneumatics often are used in the same design. New materials and manufacturing processes are being developed to lower the cost and to maintain acceptable performance. More stringent legislation for noise or emission pollution is creating many design challenges.

The present manufacturing environment is tough, with shorter product life cycles and a rapidly growing list of competitors from all over the world. The best chance a company has for success is to build the right products at the right time and to operate more efficiently than its competitors. More and more product design and manufacturing groups are turning to CAD/CAM to help make it happen, and many success stories have been documented. It is no longer a question of will CAD/CAM work but of which system should be used and how the operation will improve as a result.

Penetration

Market penetration is a crucial factor in understanding the future growth of CAD/CAM. CAD/CAM tools have improved in performance and functionality since the early 1970s, increasing the size and degree of market acceptance. Today, the total available market (TAM) includes all engineers and technical professionals. The U.S. census has provided a good estimate of the TAM in this country. A worldwide TAM for mechanical applications is estimated to be 150 percent of the U.S TAM.

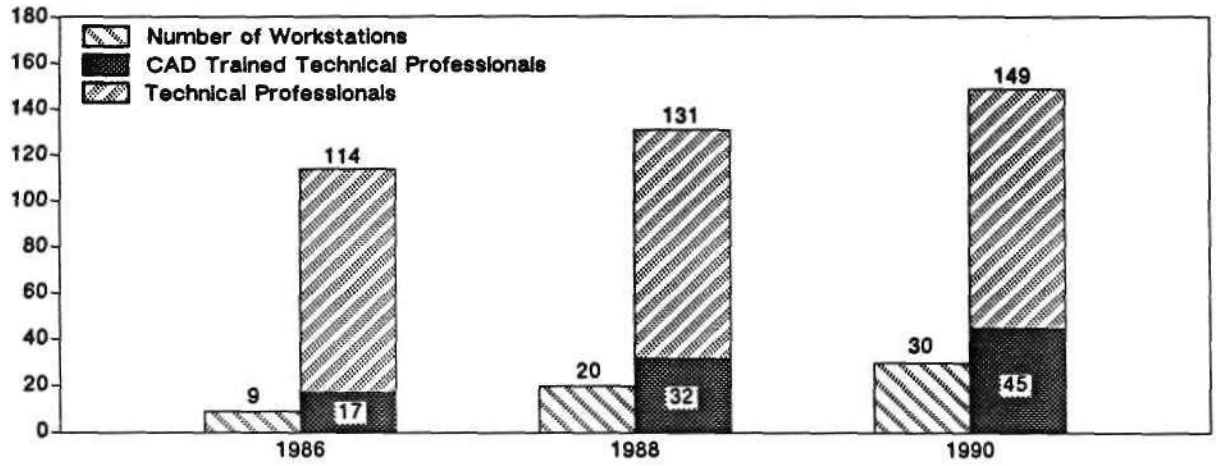
The total population of engineers and technical professionals is the primary market for mechanical CAD/CAM tools. This population was set at 639,000 in the United States in 1986 and is expected to grow to approximately 700,000 in 1992. Approximately three-quarters of all mechanical engineers and technicians are found in the manufacturing industries in this country. If the total market is defined as everyone who may have a part-time or casual use of mechanical CAD/CAM tools, the market population can be increased by a factor of two or three. This large group of part-time or casual users will focus on very low-cost products for use in the home or office. It is virtually untapped at this time.

Penetration of the technical market is more easily defined. Dataquest has surveyed this group on several occasions to define user profile by industry, company size, and other parameters. Figure 1.3-1 illustrates the change in penetration by site.

Generally speaking, the system managers surveyed expect mechanical CAD/CAM penetration levels to just about double during the next four years. Figure 1.3-1 shows the mean data for the average site in the 1987 mechanical CAD/CAM system managers survey. On the average, 9 workstations are used by 17 trained users out of a population of 114 technical professionals. Growth is expected in each area, including the total available market, where the population of technical professionals is expected to grow more than 6 percent per year. The ratio of trained users to technical professionals indicates the penetration of the technology. This ratio is expected to grow from 15 to 30 percent in 1990. The ratio of trained users to the number of workstations is dropping from 1:9 to 1:5. The trend is clearly toward one workstation on every desk, but it will take some time to get there. The ratio of the number of workstations installed to technical professionals is a good indicator of the penetration level in the total potential market. Current penetration levels are approximately 8 percent, growing to 20 percent in 1990.

Figure 1.3-1

Mechanical CAD/CAM Market Penetration Forecast



Penetration	1986	1988	1990
Trained Users/ Technical Professional	15%	24%	30%
Trained Users/ Number of Workstations	1.9	1.6	1.5
Number of Workstations/ Technical Professional	8%	15%	20%

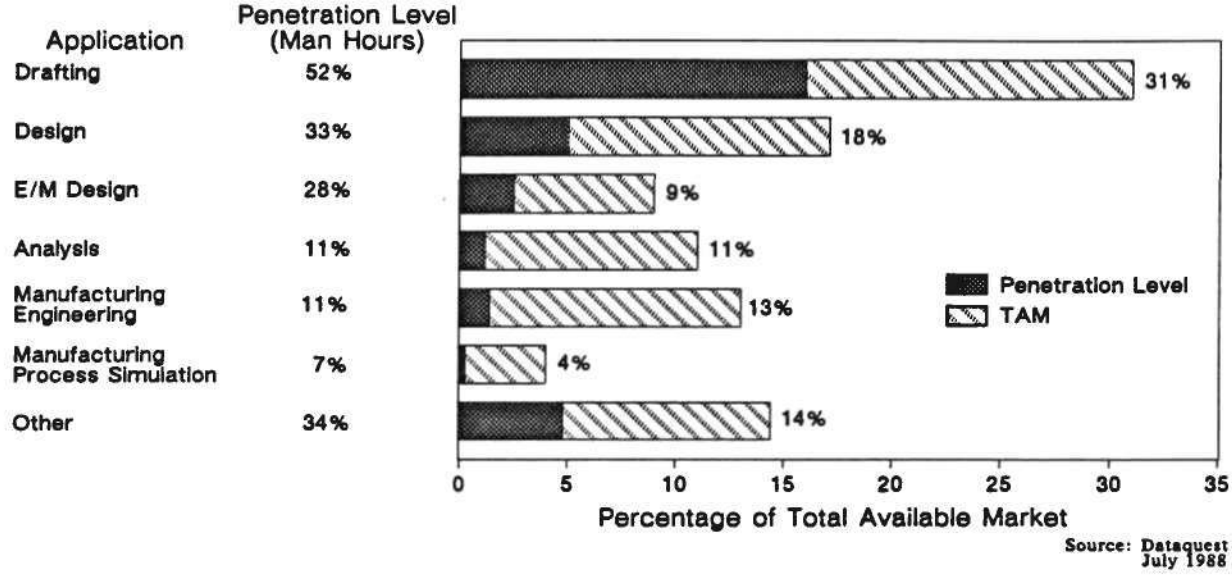
Source: Dataquest July 1988

Figure 1.3-2 illustrates the market penetration by application. The survey asked how many people at the site could use CAE/CAD/CAM tools in each of the major application disciplines. Another question asked for an estimate of the percentage of this work that could be done using CAE/CAD/CAM tools. A few calculations define the TAM in terms of potential man-hours of work. This is compared with the distribution of current work activity to determine the penetration level by application.

Drafting and design applications represent about 30 percent of the total work potential. Electro/mechanical design applications represent about one-third of the total design potential. Manufacturing engineering applications are the next most prevalent at 14 percent, followed by all analysis applications at 11 percent. Process simulation applications represent about 4 percent of the total. This would result in MCAE having a 38 percent share of the total market with a 25 percent penetration rate.

Figure 1.3-2

Distribution of Documentation Application



System Usage

The following paragraphs present a brief analysis of each major application area.

Documentation

The importance of the engineering document cannot be overemphasized. It represents the legal description and bible of knowledge that fully specifies the product and every manufacturing process required to produce it. Each department in a manufacturing organization receives some form of drawing, puts in its value added in the form of detail or specifications, and passes on the package of documents to the next group. The sketch of a new product or product revision starts the process. The owner manual or installation guide shipped with the product is the end of the process. A design revision starts another cascade of documents through the organization.

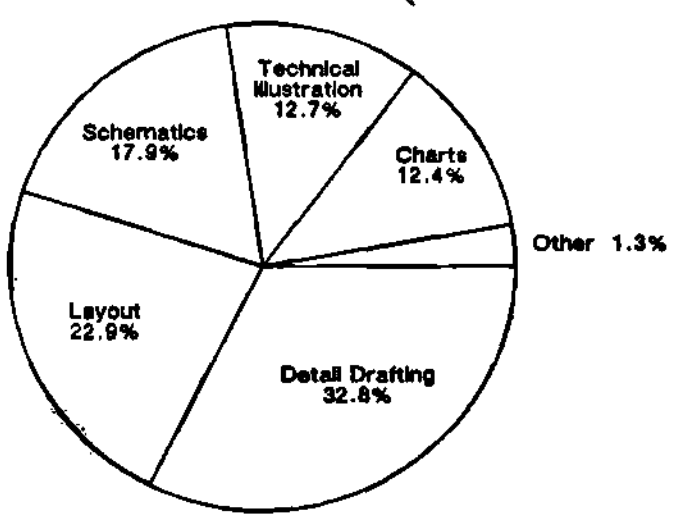
The CAD vendors have gone to considerable lengths to develop effective systems to expedite the design-to-drawing generation process. At least 50 percent of the design work is done in conjunction with the drawing. This is true in the aerospace, automotive, machinery, and fabrication industries.

Continued dependence on the drawing is a strong factor in the dramatic increase in low-cost drafting CAD systems. As users become more experienced, they increase their need for more functionality. This applies to enhanced drafting operation and performance as well as expansion into other CAD/CAM applications.

Figure 1.3-3 illustrates the variety of work tasks in the documentation area. Detail drafting is the most popular application, representing almost one-third of all documentation activity. This percentage is based on a mechanical CAD/CAM system manager survey, October 1987. See Dataquest Research Newsletter 1987-25 for more detail regarding this survey. Layout drafting is the next most common task, followed by schematics, technical illustration, and charts. Low-cost desktop publishing systems can be expected to take over some of the tasks performed using the installed CAD/CAM systems.

Figure 1.3-3

Distribution of Design Application



Source: Dataquest July 1988

Design

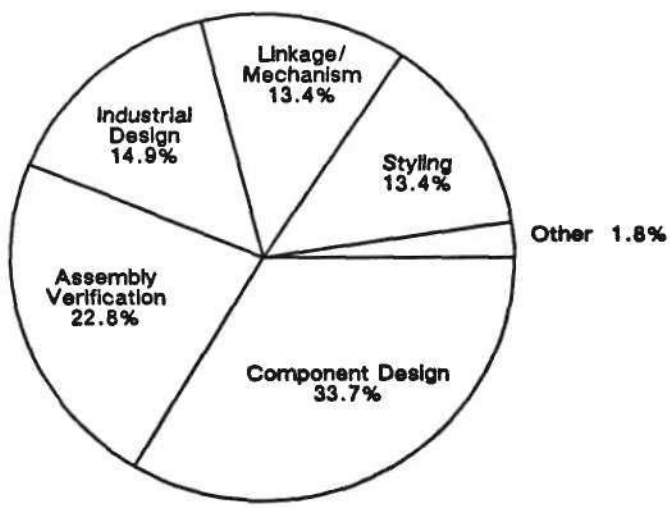
Product design falls into two fairly distinct groups—new product development and existing product enhancement. The significant difference between the two groups is characterized by starting with a clean sheet of paper versus enhancing an existing design that is already in production. CAD tools are equally suited for either activity. In fact, a real opportunity exists to improve design process productivity by sharing the CAD data base between new product design and existing product development.

The design process begins with a problem. The solution can take a few moments or years, with the real possibility of no practical solution being found. For an experienced designer, it sometimes seems that all that is required is the back of an envelope and a tough problem to start the creative juices flowing. The "ah-ha," or moment of inspiration, begins the design process. The CAD system provides an efficient means of documenting the design process and assists in proving the concept, which is its primary benefit.

The two most common design applications are component design and assembly verification. These represent more than half the design activity and should continue to do so. Industrial design, styling, and linkage/mechanism design each represent approximately 13 percent of the total. These applications have a lower interest for the general user but are good examples of niche market opportunities. The survey showed that these applications are very important tools to those who use them. Figure 1.3-4 provides application distribution data.

Figure 1.3-4

Distribution of Analysis Application



Source: Dataquest
July 1988

Analysis

Analysis starts shortly after the moment of inspiration occurs in the design process. Analysis begins with "what-if" scenarios and continues with an impressive array of analytical tools that simulate everything from the weight and color of a part to its modal signature as it vibrates.

Low-cost and high-performance general-purpose computers are ideally suited to complement the design process with responsive and affordable analysis processing. The list of analysis applications is getting longer and now includes stress, thermal, mechanism, dynamic, electromagnetic, and mass properties. The major analysis applications are used to simulate the product in its as-used environment and as it progresses through the various stages of manufacturing. Analytical tools are useful in every stage of the product design and manufacturing processes.

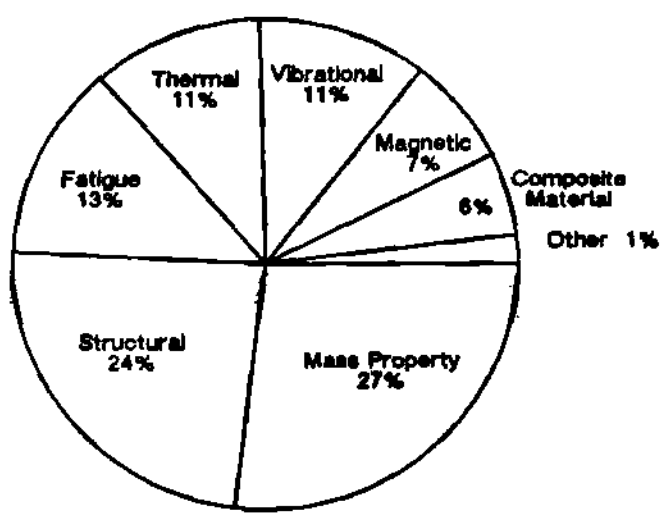
The combination of CAD/CAM tools for design and analysis is named Mechanical Computer-Aided Engineering (MCAE). This was the topic of Dataquest Research Newsletter Number 1986-11 and of a panel discussion at the 1986 annual conference. Please refer to the newsletter for more information on this application area.

A recent discussion with a major U.S. automotive manufacturer indicated that only 2 percent of the parts used in the current model had been analyzed by finite element techniques. The manufacturer also expressed a desire to analyze 100 percent of the parts, if possible. More workstations, trained users, and more effective software are required to address this issue.

The most common analysis calculation defines the mass properties of a part or assembly. This includes the weight, center of gravity, and Moments of Inertia. Most of the other analysis tasks mentioned in the survey are based on finite element analysis techniques. Of these, structural and fatigue failure analysis are the most popular, followed closely by thermal and vibration analysis. Figure 1.3-5 shows the distribution of these applications.

Figure 1.3-5

Distribution of Analysis Application



Source: Dataquest
July 1988

Manufacturing

The manufacturing process takes the result of design and analysis and turns it into chips and pallets of finished parts waiting for assembly. A large support team of professionals—including tool makers, maintenance personnel, and quality-assurance personnel—keeps the operation running smoothly. The automotive industry has been the most aggressive in replacing the blue-collar worker with flexible machining centers and automated material-handling equipment, but competitive pressures are now forcing the factory automation issues in all major industries. CAD/CAM systems are an integral part of this operation.

Simulation of numerically controlled machine tools generates the program to control the actual manufacturing process as one of the most common CAM applications. The use of CAD/CAM tools in manufacturing is much more than numerical control (NC) part programming. Jigs, fixtures, tooling, test equipment, material handling, packaging, and dozens of other manufacturing-related tasks use CAD/CAM.

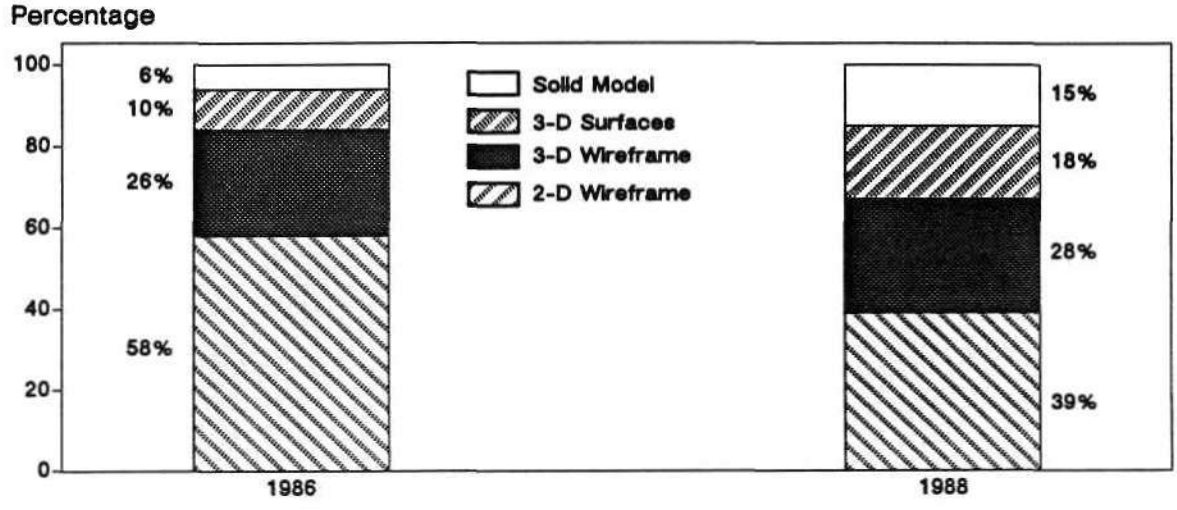
The combination of computer graphics with data for shop control, schedules, material resource planning, and bill of materials generation is having a positive effect on the smooth operation on the shop floor. A significant opportunity is available for vendors to provide integrated systems for these applications.

Modeling Type Distribution

The 1985 Dataquest survey was used to determine the level of interest in solid modeling. The survey indicated that the interest was very strong; in fact, more than 25 percent of the system managers were using solid modeling at their sites. Another 37 percent had plans to use solid modeling in the future. The 1987 Dataquest MCAD survey pushed this issue further. Again, the level of penetration was the issue. A reasonable means of evaluating the level of use of solid modeling and the other modeling techniques was established by asking what percentage of the stored data base was based on solid modeling, 3-D surfaces, 3-D wireframe, or 2-D wireframe. The expected levels of use were also estimated for 1988. Figure 1.3-6 illustrates the response to this question.

Figure 1.3-6

Mechanical CAD/CAM Data Base
Distribution by Type



Source: Dataquest
July 1988

The next two-year period should see a dramatic increase in the use of solid and 3-D surface modeling techniques. The amount of CAD/CAM data that is based on solid modeling will increase almost threefold. The users estimated that the level of data stored as solid and surface models will match the level of 2-D data by the end of 1988. An interesting question that followed the 1987 analysis was how much of the 2-D data was generated from the 3-D data. The answer was only 17 percent. This indicates that almost half of all CAD/CAM use is directed toward the generation of 2-D documentation and drawings. It also indicates a challenge to the vendors to produce an integrated design/analysis/documentation system that works well enough to replace 2-D modeling.

TRENDS

Applications

"One person/one computer" is a growing theme of many of the leading industrial manufacturers. The recent technical specification of the Navy CAD2 acquisition provides a road map for the application of this theme to a large-scale operation. The economics of scale and efficiencies of allowing an engineering community to communicate electronically is the driving force behind this effort. Dataquest survey data support this, indicating a drop in the ratio of trained users to workstations, going from 1:9 in 1985 to 1:5 in 1987.

Dataquest believes that drafting documentation will remain the major selling application in CAD/CAM for the next few years, due to the following:

- The low-cost drafting system is functional.
- The 2-D geometry construction capability can be used for design and analysis applications.
- It is easy to justify.
- It is not threatening.

Design tools are being developed that meet the real needs of the designer. The trends in this evolution include three-dimensional modeling of any realizable object using realistic imaging and conceptual-design techniques. The resulting accurate data base supports the manufacturing and documentation applications that will follow. Rule-based design tools are also being developed to aid the designer in similar part design and design procedures.

Mechanical computer-aided engineering (MCAE) is the fastest growing segment in mechanical applications. Products from turnkey and software-only vendors are being developed to meet the conceptual and product design and analysis needs of the engineer and designer.

The systems discussed above will provide a solid foundation for a staggering array of applications software. The major CAD/CAM applications have been implemented; they are being enhanced and are becoming easier to use and more productive. New applications will address more extensive design and simulation tasks. Full application integration will be provided to minimize the system overhead and improve user interface. Customization by the user will be necessary in order to take full advantage of these tools.

Major factory automation projects are under way in all major manufacturing industries. The full implementation of computer-aided technology in the manufacturing environment is moving from the test tube to the real world. The automotive industry is the leader in developing and implementing robotics, flexible machining centers, just-in-time plant inventory, and shop-floor communications data format.

Technology

Dataquest expects the total system package price to continue in a downward trend following component prices. Value-added hardware and applications software will tend to keep system prices above the commodity level. The trend in personal computer-based products to upgrade to higher-performance processors, memory, storage devices, and display is causing an increase in average system configuration. At the same time, the drop in component prices is resulting in a near-constant package price for a PC-based system.

Other technology trends include the following:

- The need to rapidly communicate accurate engineering information among many organizational groups is driving the development of low-cost local area networks. The hardware is available, but the software lacks the ability to provide full system security and management control functions.

- Integrated systems using personal computers, standalone workstations, and mainframe computers are evolving, taking advantage of the best each has to offer.

- Developments in computational resources, including application-specific integrated circuits, are raising performance to levels that were only dreamed of previously.

- Graphic display performance is improving and is being offered at a lower package price; application-specific integrated circuits and low-cost display memory are supporting this evolution.

User Expectations

The easy-to-use user interface typical of PC-based software is creating an expectation in the minds of the users. Software should be low in cost and easy to use, with minimal training required and built-in tutorial functions.

We expect integration to improve at the data base, user interface, application, and system management levels. Furthermore, hardware options are increasing in primary system components as well as in peripherals. Computational servers, laser printers, and scanners are a few of the new-generation peripheral options.

The functional level of the system is improving in all price groups for all applications. System reliability and support are improving also as vendors respond to the basic expectations of the users.

Many of the graduating engineers and technicians have used CAD/CAM technology in school and are demanding these tools when they enter the job market. Users are more interested in becoming system integrators, pulling together systems with off-the-shelf hardware and software. If the price premium for a package deal or turnkey solution is not too high, the benefits of a single-source supplier are still desirable.

DRIVING ISSUES

Industries

All major mechanical industry sectors are expecting increased levels of product shipments in the next few years. Non-U.S. competition is growing, focusing added pressure on the critical long-term issues of cost control, improved product quality, and products that offer enhanced customer appeal. The use of new materials is improving design flexibility but is forcing the development of more sophisticated design, analysis, and manufacturing processes.

CAD/CAM Technology

CAD/CAM technology has been identified as an integral component in the modernization of manufacturing industries. Integration of application software is a strong driving factor in CAD/CAM system development; i.e., hardware and a wide variety of application software must function as a unified system. Improved user interfaces must allow effective system use that logically supports the complete design and manufacturing process.

Continued enhancements in the semiconductor industry are improving the performance of computers and related peripherals. The price/performance ratio is expected to continue to improve by a factor of two every other year for the foreseeable future. (This prediction may be a bit conservative in the short term.)

Standards in graphics displays, data base transfer formats, and communications protocol are being used. Large users are demanding that vendors support standards that allow communication among different vendor systems. More emphasis is being placed on the availability of management tools for the control and manipulation of information systems. Company-to-company graphics data transfer is becoming a common requirement, particularly in the automotive sector.

OPPORTUNITIES

Applications

Matrix application development (MAD) involves a growing interest in integrated vertical-niche application development. The vertical niches can be large, such as drafting or design, or small, such as plastic gear design. Development that aids the integration side of the matrix is directed toward data base management, record acquisition and management, and a growing list of applications not directly related to CAD/CAM, such as electronic mail, word processing, and spreadsheet analysis. The one person/one computer trend is increasing the importance of integration for all applications.

Mechanical computer-aided engineering (MCAE) is the fastest growing major application in mechanical CAD/CAM. This opportunity is reviewed in detail in Section 3 following this market overview.

Computer-aided styling (CAS) is quickly evolving throughout the industrial sector as a new computer application area. The primary purpose of this technology is to provide visualization tools to aid in the conceptual design task. Everything from cereal boxes to automobiles is being reviewed in this emerging market. CAD modeling tools were once seen as restricting the artistic freedom of the stylist or industrial designer. Significant improvements are required in user-interface modeling techniques before there will be a significant move away from pen and ink or airbrush.

New peripherals and processes include the following:

- Stereo lithography
- Scanners
- Color printers
- CD-ROM
- Large screen/projection displays
- Stereo imaging
- Laser plotters

Stereo lithography provides instant hard copy for a CAD/CAM data base by feeding the data into a black box where an accurate scale model is produced in minutes. This process has been a dream of system users for years and is now available from 3-D Systems. Dataquest's Research Newsletter 1987-9 is available for further review on this subject.

Scanners have been a part of CAD/CAM since the early 1970s. If one considers a digitizing table as a form of manual scanning, it could be argued that scanning technology was the basis for the beginnings of CAD/CAM. Now, the need for an electronic document storage and retrieval system had increased interest in scanning technology. Such system functions range in complexity from storing facsimile image data to semiautomatic generation of intelligent data bases. A recent MCAD user survey indicated a strong interest in adding scanning equipment, with a planned threefold increase in the population of equipment in the next two years.

Low-cost, high-resolution color printers will become available in the next year and will provide low cost (less than $20,000 and less than $1/copy), high resolution (400 dots per inch), full color, and an A or B size format. These devices will significantly improve

the feasibility of color documentation for engineering applications and for desktop publishing in general. The opportunity for application synergy is good between vendors involved in each application area.

CD-ROM is an exciting technology that has quietly evolved in the music business. The technology has evolved there to provide inexpensive, mass-produced, high-quality digital data storage. More than 60,000 pages of information can be stored on one CD-ROM. Joining this massive data storage medium to a computer provides a great deal of reference information at a minimal cost. The CAD/CAM applications of this technology can combine archived data with interactive programs. A good example would be for a designer to use a design program for a ball bearing, picking the right size and type for a particular design problem. The designer could use the CD-ROM to find out who sells the corresponding bearing and at what price. Training applications are obvious as well.

Large screen/projection displays have been around for awhile. The emerging opportunity in CAD/CAM will be to scale down the package for the single user. The display can be mounted on the wall, freeing up the desktop. As prices come down and resolution goes up, this display type will become more attractive for the engineering office environment.

Stereo imaging has also been around for awhile. True three-dimensional viewing has a definite value. The hassle of wearing special glasses and the lack of software to take advantage of this display have slowed acceptance of this technology. The key benefit of stereo imaging is improved depth visualization. This could be used effectively in computer-aided styling applications.

Laser plotters similar in speed and resolution to laser printers are becoming available. These will generate high-quality engineering documentation in large format on a variety of media. This drawing-on-demand resource is an important advancement if combined with a document management and distribution system. The cost-savings potential in a large installation is significant.

1.4 Mechanical CAD/CAM Forecasts

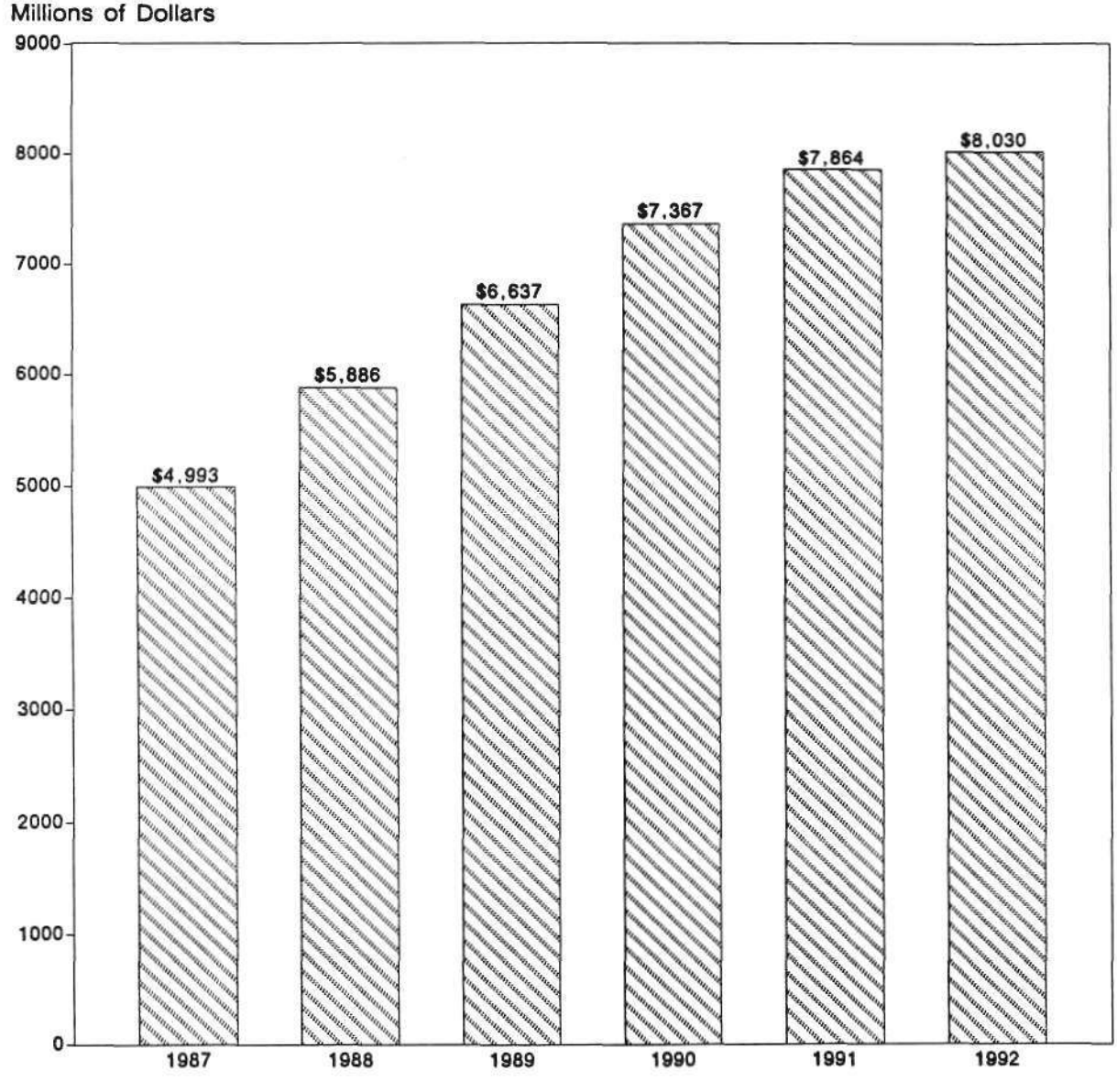
TOTAL MECHANICAL CAD/CAM MARKET

Figures 1.4-1 and 1.4-2 and Table 1.4-1 present Dataquest's forecast and analysis for the total mechanical CAD/CAM market for all regions and platforms, as follows:

- The mechanical segment had an estimated $4,993 million in revenue in 1987 and is forecast to grow to $8,030 million in 1992, at a compound annual growth rate (CAGR) of 10.0 percent.
- Dataquest estimates that mechanical segment revenue will increase more than 17 percent in 1988, reaching $5,886 million.
- Workstation shipments in 1987 were an estimated 127,152 units; shipments are expected to reach 273,900 units in 1992, growing at a 16.6 percent CAGR.

Figure 1.4-1

Mechanical CAD/CAM Worldwide Forecast
Revenue



Source: Dataquest
July 1988

Figure 1.4-2

Mechanical CAD/CAM Worldwide Forecast
Shipments

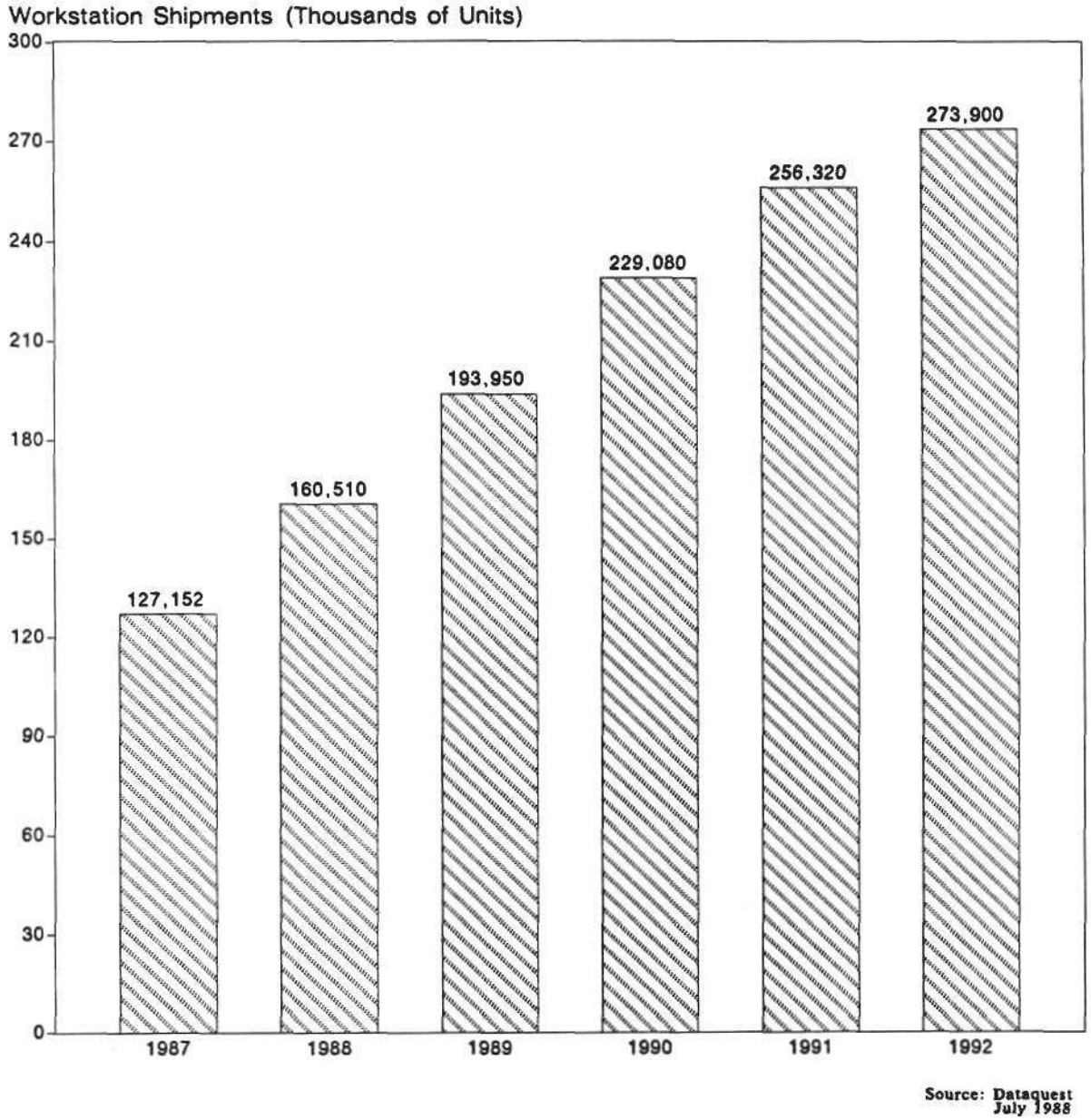


Table 1.4-1

Mechanical CAD/CAM Worldwide Forecast
(Millions of Dollars, Actual Units)

	1987	1988	1989	1990	1991	1992	CAGR
Revenue	4,993	5,886	6,637	7,367	7,864	8,030	10.0%
Systems	102,287	132,450	164,230	198,860	227,630	248,890	19.5%
Workstations	127,152	160,510	193,950	229,080	256,320	273,900	16.6%

Source: Dataquest
July 1988

REGIONS

Dataquest's forecasts and analysis of the mechanical CAD/CAM market, segmented by region, are presented in Figures 1.4-3 and 1.4-4 and Tables 1.4-2 and 1.4-3. The following should be noted:

- We estimate that the expected 17 percent growth in revenue from 1987 to 1988 will be evenly distributed over four market regions. Dataquest expects European and Rest of World regions to make a slight gain in market growth at the expense of the North American and Far Eastern regions.

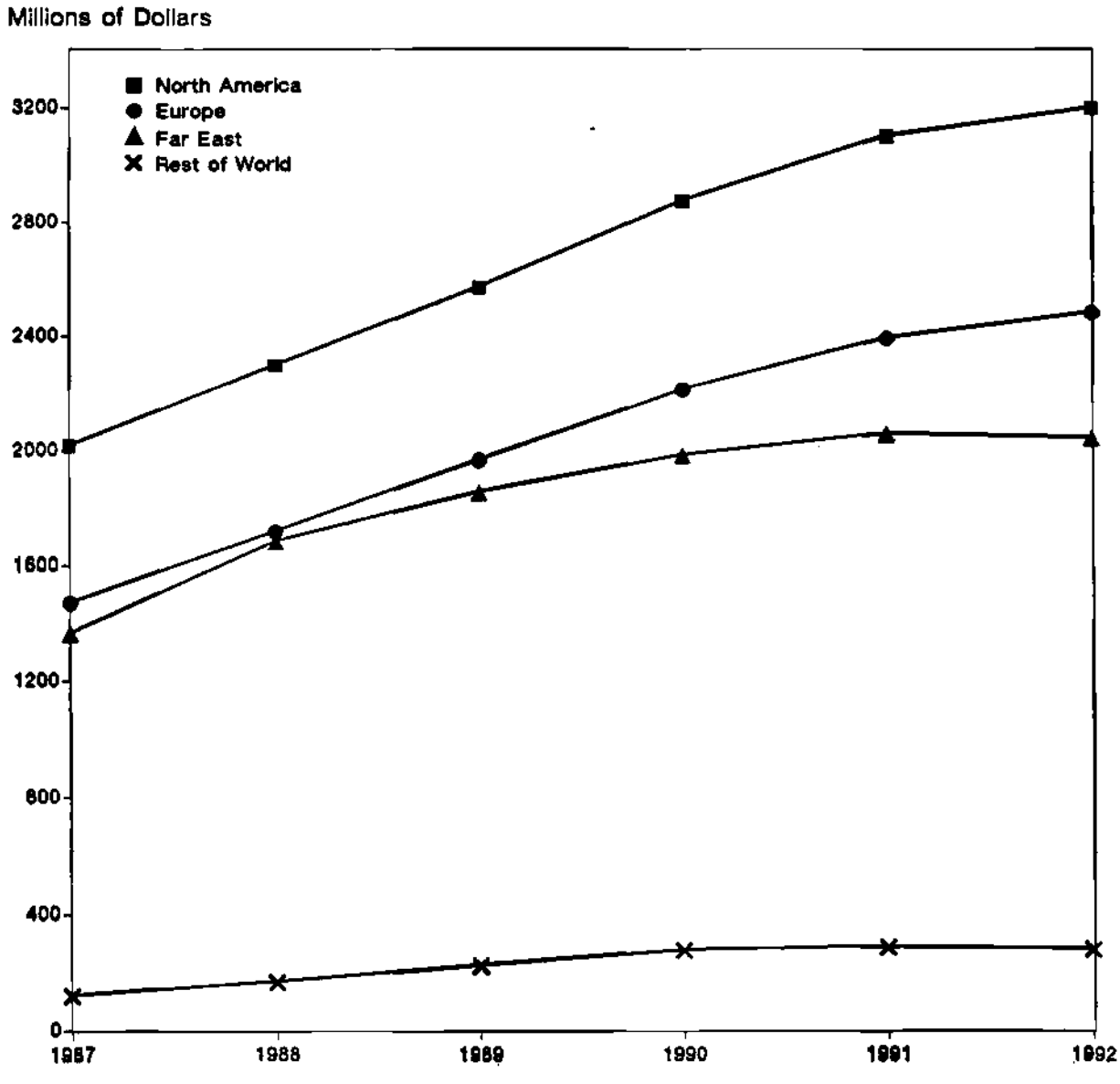
- We expect 46 percent of the annual revenue and 45 percent of the workstation shipments to be in the United States in 1986.

- The growing number of non-U.S. vendors is expected to do well in their home markets, displacing U.S. products. Native-language support, documentation, and user interface are strong points of differentiation.

- Domestic vendors will require a concerted effort and strategic alliances with local distributors in Europe and Japan to maintain a significant market share. However, the next two years will provide the largest window of opportunity to gain market recognition and share.

Figure 1.4-3

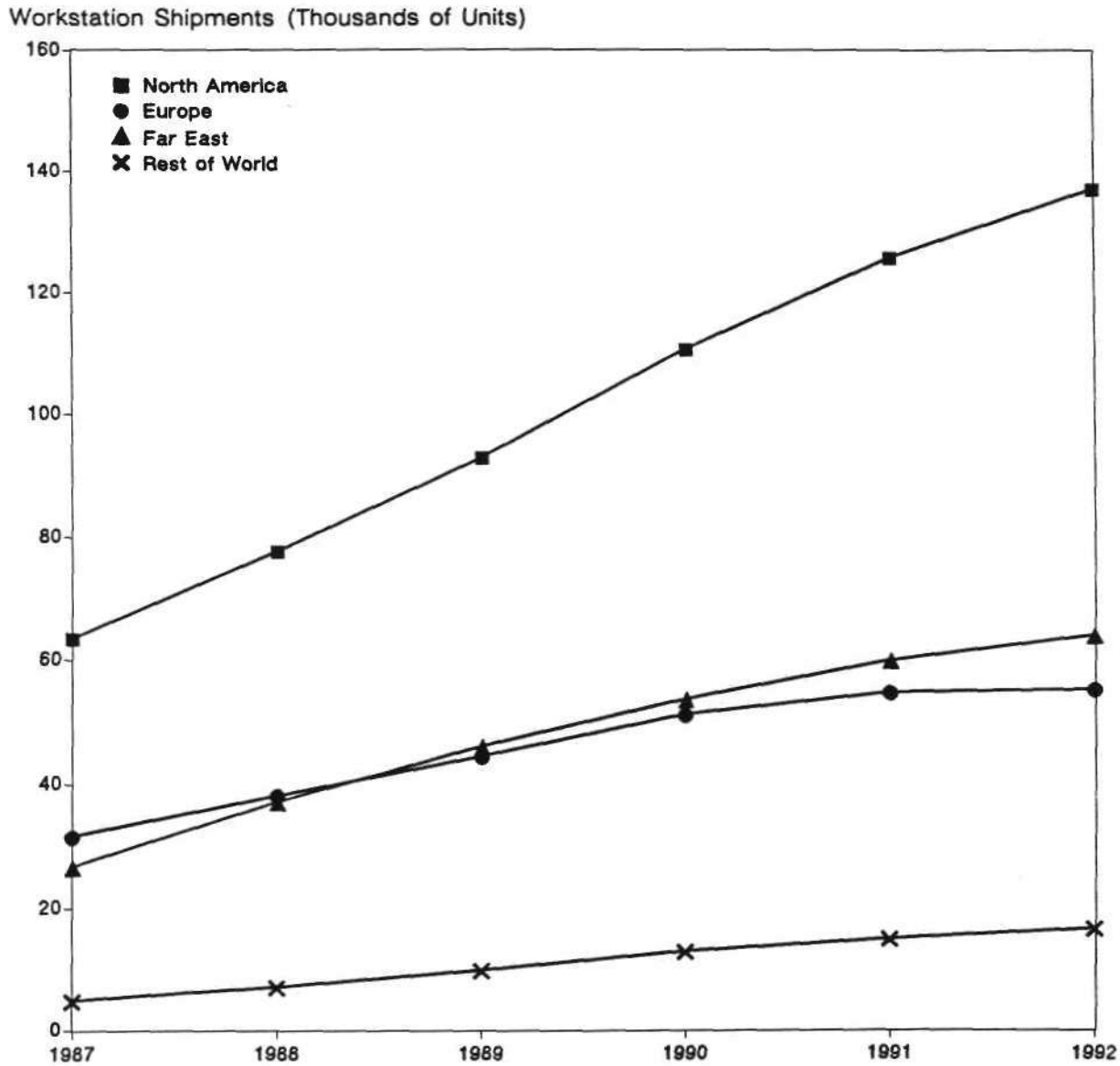
Mechanical CAD/CAM Regional Forecast
Revenue



Source: Dataquest
July 1988

Figure 1.4-4

Mechanical CAD/CAM Regional Forecast
Shipments



Source: Dataquest
July 1988

Table 1.4-2

Mechanical CAD/CAM Regional Forecast
(Millions of Dollars, Actual Units)

	1987	1988	1989	1990	1991	1992	CAGR
Total Market							
Revenue	4,993	5,886	6,637	7,367	7,864	8,030	10.0%
Systems	102,287	132,450	164,230	198,860	227,630	248,890	19.5%
Workstations	127,152	160,510	193,950	229,080	256,320	273,900	16.6%
North America							
Revenue	2,022	2,303	2,578	2,879	3,106	3,203	9.6%
Systems	53,450	67,120	82,250	99,960	115,560	128,210	19.1%
Workstations	63,656	77,760	93,090	110,830	125,980	137,350	16.6%
Europe							
Revenue	1,475	1,723	1,971	2,218	2,401	2,491	11.0%
Systems	24,876	31,260	37,640	44,560	48,820	50,200	15.1%
Workstations	31,704	38,320	44,610	51,360	55,030	55,430	11.8%
Far East							
Revenue	1,370	1,688	1,861	1,989	2,066	2,051	8.4%
Systems	19,599	27,820	35,560	42,700	49,510	54,850	22.9%
Workstations	26,829	37,290	46,290	53,820	60,190	64,260	19.1%
Rest of World							
Revenue	126	172	228	281	291	286	17.8%
Systems	4,363	6,250	8,780	11,640	13,730	15,630	29.1%
Workstations	4,964	7,130	9,960	13,070	15,130	16,860	27.7%

Source: Dataquest
July 1988

Table 1.4-3

Mechanical CAD/CAM Regional Forecast
(Percentage of Total)

	1987	1988	1989	1990	1991	1992
North America						
Revenue	40%	39%	39%	39%	39%	40%
Systems	52%	51%	50%	50%	51%	52%
Workstations	50%	48%	48%	48%	49%	50%
Europe						
Revenue	30%	29%	30%	30%	31%	31%
Systems	24%	24%	23%	22%	21%	20%
Workstations	25%	24%	23%	22%	21%	20%
Far East						
Revenue	27%	29%	28%	27%	26%	26%
Systems	19%	21%	22%	21%	22%	22%
Workstations	21%	23%	24%	23%	23%	23%
Rest of World						
Revenue	3%	3%	3%	4%	4%	4%
Systems	4%	5%	5%	6%	6%	6%
Workstations	4%	4%	5%	6%	6%	6%

Source: Dataquest
July 1988

PLATFORMS

Dataquest's forecasts and analysis of the mechanical CAD/CAM market, segmented by platform, are shown in Figures 1.4-5 and 1.4-6 and Tables 1.4-4 and 1.4-5. Please note the following:

- CAGR in total revenue from 1987 through 1992 is expected to be 10.0 percent. This growth will take the $4,993 million in revenue in 1987 to $8,030 million in 1992.

- In the short term, from 1987 to 1988, the growth rate is expected to be 17 percent.

- System shipments are expected to grow 26 percent from 1987 to 1988 and at more than 16 percent CAGR from 1987 through 1988.

- The technical workstation-based systems are gaining percentage shares from both PC and host-based systems.

- The growth rate in units shipped for personal computer-based systems will be 20 percent from 1987 to 1988. This is a dramatic slowdown from the 150 percent growth rates of 1985. The trend is expected to continue with less than a 13 percent gain from 1988 to 1989. The CAGR for 1987 through 1992 is expected to be 3.9 percent in revenue and 8.1 percent in units shipped.

- The technical workstation market is more dramatic, showing estimated growth from 1987 to 1988 of 53 percent in revenue and 64 percent in units shipped. The sustained high growth rate from 1988 to 1989 is expected to be a still significant 40 percent in revenue and 53 percent in unit shipments. This expected growth will result in the highest CAGR by product type from 1987 through 1992, which is forecast to be 32 percent in revenue and 43 percent in shipments.

- Host-dependent systems have reached a plateau, holding relatively constant revenue and unit volume and peaking in 1988 or 1990. A gradual decline from there results in a negative 4.5 percent CAGR in revenue and a positive 0.8 percent growth in workstation shipments from 1987 through 1992.

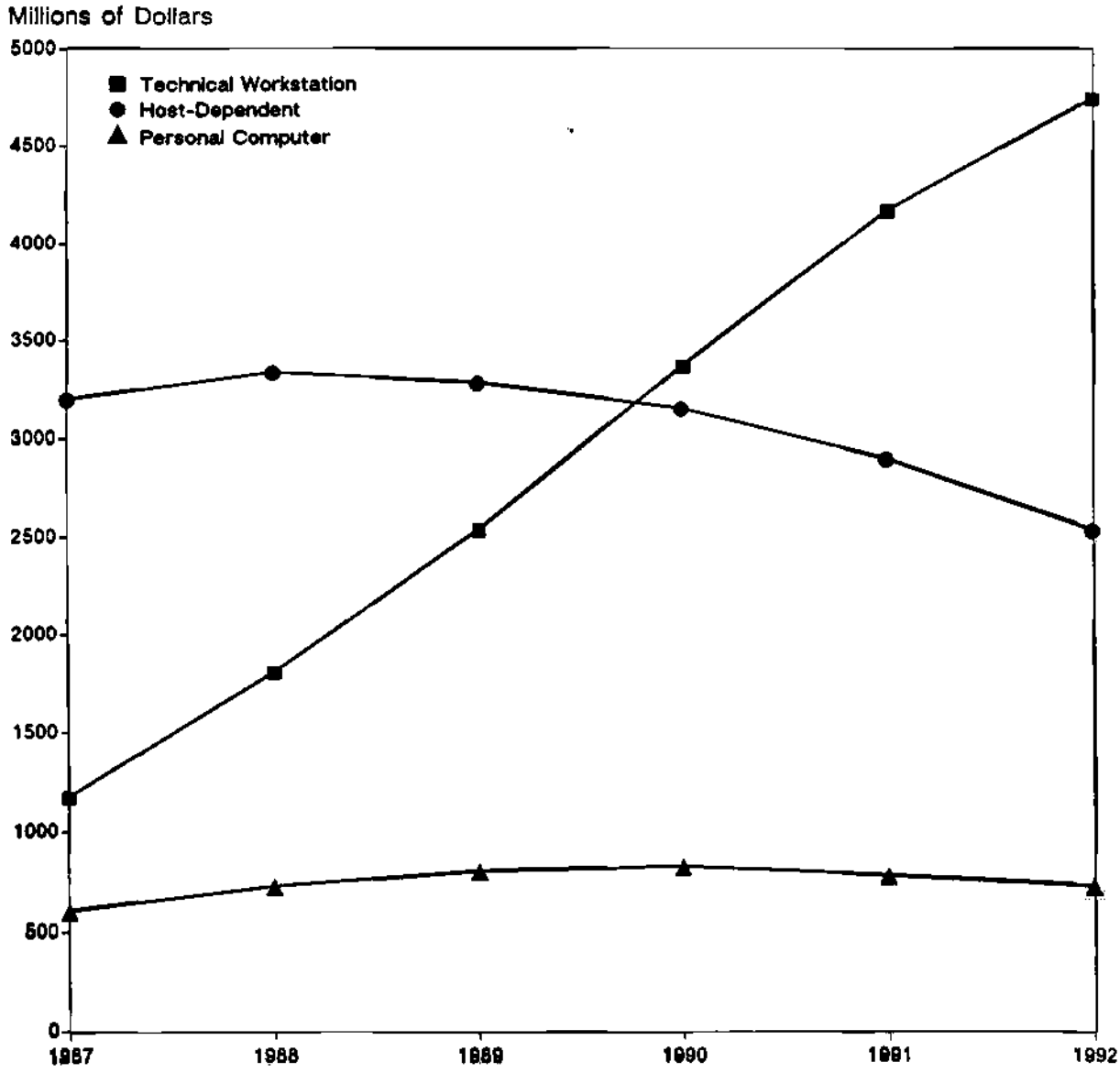
- The host-dependent products dominated 1987 revenue by a significant 64 percent. Host-dependent systems are expected to represent the highest revenue share throughout the period until 1990. The estimated 43 percent share in total revenue in 1990 will be derived from a small 18 percent of workstation unit sales.

- Personal computers have also reached a plateau in revenue, reaching a 12 percent market share in 1987. The share of total workstation shipments is expected to have peaked in 1987 at 56 percent, then gradually will drop to a 39 percent share in 1992.

- The growth leader is forecast to be technical workstations, representing 24 percent revenue and 17 percent workstation shipments in 1987. This is expected to expand to 59 percent revenue and 49 percent workstation units in 1992.

Figure 1.4-5

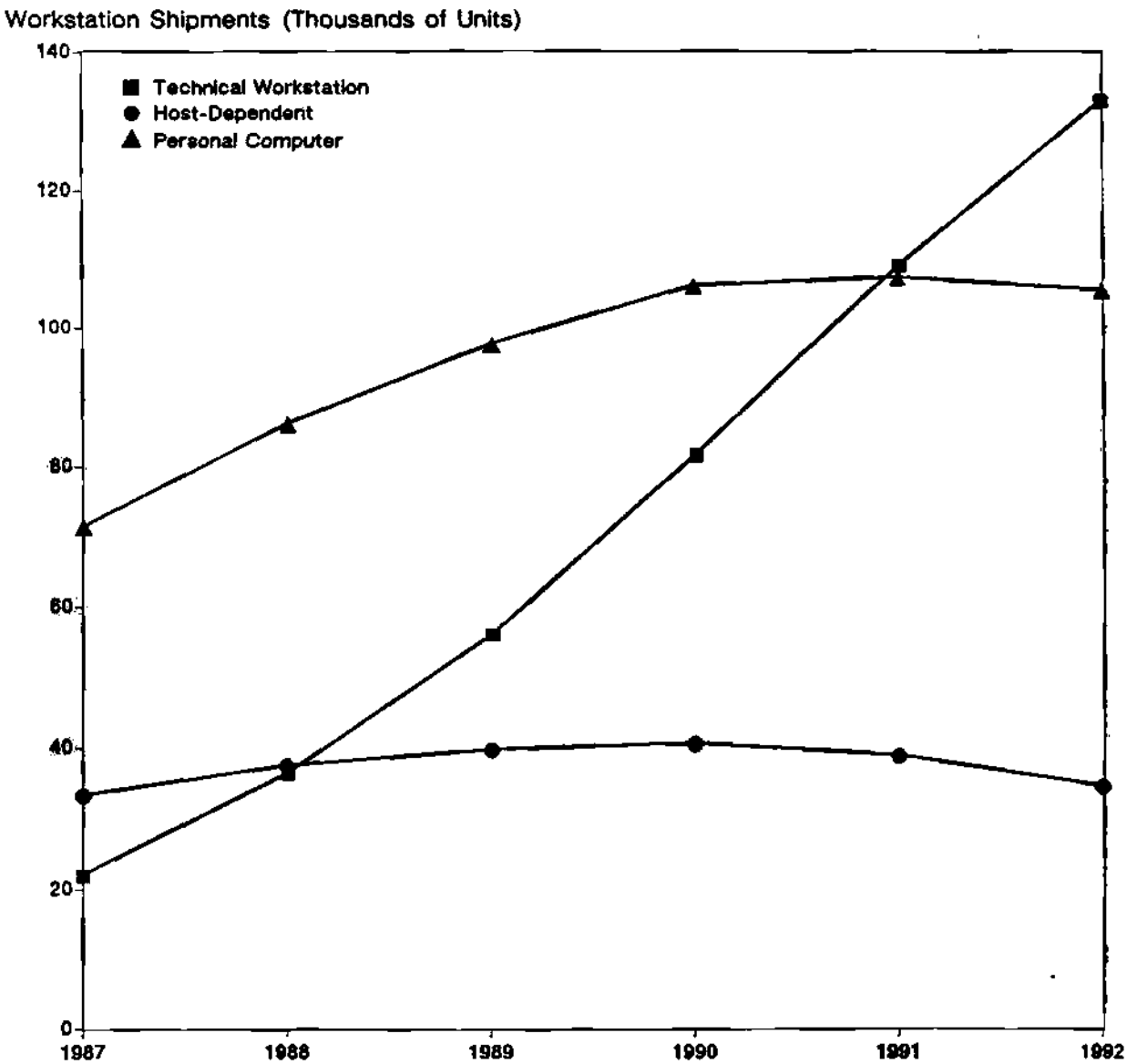
Mechanical CAD/CAM Worldwide Forecast by Platform
Revenue



Source: Dataquest
July 1988

Figure 1.4-6

Mechanical CAD/CAM Worldwide Forecast by Platform
Shipments



Source: Dataquest
July 1988

Table 1.4-4

Mechanical CAD/CAM Worldwide Forecast by Platform
(Millions of Dollars, Actual Units)

	1987	1988	1989	1990	1991	1992	CAGR
Total Market							
Revenue	4,993	5,886	6,637	7,367	7,864	8,030	10.0%
Systems	102,287	132,450	164,230	198,860	227,630	248,890	19.5%
Workstations	127,152	160,510	193,950	229,080	256,320	273,900	16.6%
Technical Workstation							
Revenue	1,182	1,811	2,540	3,375	4,172	4,750	32.1%
Systems	22,182	36,560	56,160	81,820	109,430	133,260	43.1%
Workstations	22,182	36,560	56,160	81,820	109,430	133,260	43.1%
Host-Dependent							
Revenue	3,203	3,345	3,289	3,161	2,904	2,545	-4.5%
Systems	8,550	9,610	10,190	10,570	10,470	9,820	2.8%
Workstations	33,415	37,670	39,910	40,790	39,160	34,830	.8%
Personal Computer							
Revenue	608	730	809	831	788	735	3.9%
Systems	71,556	86,280	97,880	106,470	107,740	105,810	8.1%
Workstations	71,556	86,280	97,880	106,470	107,740	105,810	8.1%

Source: Dataquest
July 1988

Table 1.4-5

Mechanical CAD/CAM Worldwide Forecast by Platform
(Percentage of Total)

	1987	1988	1989	1990	1991	1992
Technical Workstation						
Revenue	24%	31%	38%	46%	53%	59%
Systems	22%	28%	34%	41%	48%	54%
Workstations	17%	23%	29%	36%	43%	49%
Host-Dependent						
Revenue	64%	57%	50%	43%	37%	32%
Systems	8%	7%	6%	5%	5%	4%
Workstations	26%	23%	21%	18%	15%	13%
Personal Computer						
Revenue	12%	12%	12%	11%	10%	9%
Systems	70%	65%	60%	54%	47%	43%
Workstations	56%	54%	50%	46%	42%	39%

Source: Dataquest
July 1988

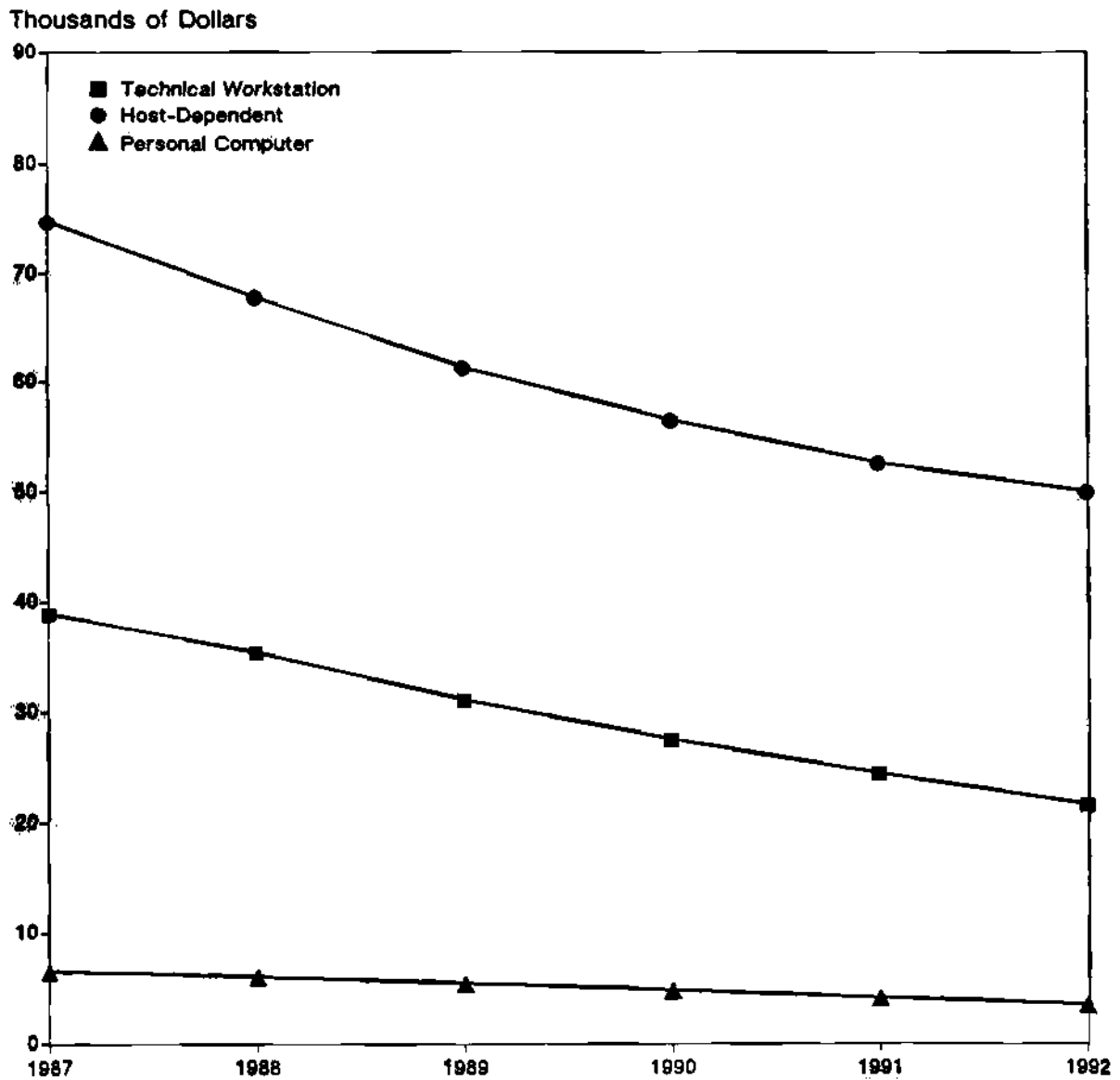
AVERAGE PRICE PER SEAT

Figure 1.4-7 and Table 1.4-6 present Dataquest's forecasts and analysis of the average price per seat by platform for the mechanical CAD/CAM market, as follows:

- The average price per seat is dropping for all product types. The general trend toward increased functionality in hardware and software is raising the value of the average configuration, but not enough to offset rapid price reduction for hardware components and software.
- In 1988, the average price per seat is expected to drop 9.5 percent.
- From 1987 to 1992, host-based and technical workstations are expected to drop in average price per seat, at negative 7.7 and negative 11.1 percent per year, respectively.
- The personal computer-based product is expected to follow a similar price erosion profile as technical workstations, dropping 11.4 percent over the five-year period from 1987 to 1992. Dataquest assumes that the typical personal computer will continue to improve in performance, graphics display, software applications, and networking, maintaining the package price.
- The increasing share of software in total system revenue is the primary cause of differences in price erosion between turnkey systems and hardware-only workstations.

Figure 1.4-7

Mechanical CAD/CAM Worldwide Average Price per Seat by Platform



Source: Dataquest
July 1988

Table 1.4-6

Mechanical CAD/CAM Worldwide Average Price per Seat by Platform (Thousands of Dollars)

	1987	1988	1989	1990	1991	1992	CAGR
Turnkey & Hardware-Only							
Technical Workstation	39.0	35.5	31.2	27.6	24.5	21.7	-11.1%
Host-Dependent	74.8	67.9	61.4	56.6	52.7	50.1	-7.7%
Personal Computer	6.6	6.1	5.5	4.9	4.2	3.6	-11.4%
All Platforms	30.2	27.3	24.5	22.2	20.2	18.4	-9.5%
Turnkey							
Technical Workstation	47.0	45.0	41.7	38.5	35.6	33.0	-6.8%
Host-Dependent	68.9	66.7	63.9	61.6	59.4	57.6	-3.5%
Personal Computer	19.6	18.2	16.9	15.7	14.6	13.6	-7.0%
All Platforms	50.8	47.5	43.8	40.8	38.4	35.9	-6.7%
Hardware-Only							
Technical Workstation	24.6	22.3	20.1	18.4	16.5	14.8	-9.7%
Host-Dependent	90.4	70.5	57.3	49.8	44.3	41.2	-14.5%
Personal Computer	3.9	3.6	3.3	3.0	2.7	2.4	-9.3%
All Platforms	16.5	14.8	13.6	12.7	11.9	10.9	-7.9%

Source: Dataquest
July 1988

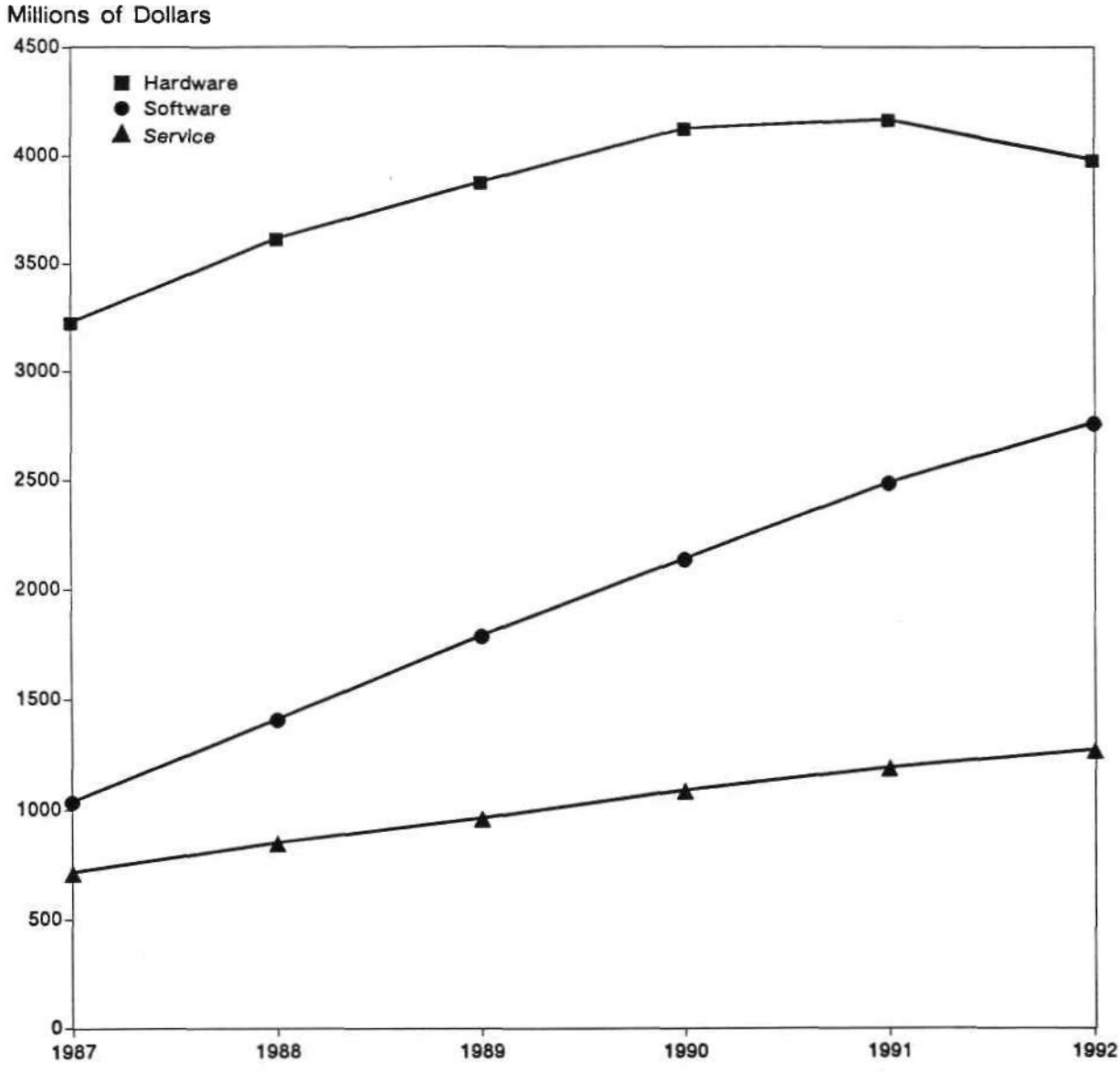
REVENUE SOURCES

Figure 1.4-8 and Tables 1.4-7 and 1.4-8 present Dataquest's forecasts and analysis of the mechanical CAD/CAM market, segmented by revenue source for each platform. Please note the following:

- Hardware historically has represented the major portion of system cost. In fact, the cost was set artificially higher than necessary to offset the undervalued software. The current trend toward value pricing and unbundling make comparisons more realistic.
- The distribution of hardware revenue varies by processor type. In 1987, the hardware revenue content ranged from 55 percent for the technical workstation to 69 percent for the host-dependent computer. Overall, 65 percent is the average.
- The software content is rising faster than expected in earlier forecasts in all categories.
- Personal computers are expected to retain the highest value content in software, increasing to 53 percent in 1992.
- Service revenue is growing in total revenue share as systems become more complex, requiring service by higher-cost, more experienced service personnel. More reliable hardware with self-diagnostic features is keeping service revenue lower than previously expected.

Figure 1.4-8

Mechanical CAD/CAM Revenue Sources—Worldwide



Source: Dataquest
July 1988

Table 1.4-7

Mechanical CAD/CAM Revenue Sources by Platform—Worldwide
(Millions of Dollars)

	1987	1988	1989	1990	1991	1992	CAGR
All Platforms							
Hardware	3,233	3,620	3,879	4,129	4,174	3,985	4.3%
Software	1,041	1,413	1,794	2,145	2,493	2,768	21.6%
Service	718	853	964	1,094	1,198	1,277	12.2%
Total	4,993	5,886	6,637	7,367	7,864	8,030	10.0%
Technical Workstation							
Hardware	649	995	1,358	1,758	2,077	2,222	27.9%
Software	344	531	784	1,080	1,416	1,716	37.9%
Service	189	284	398	538	679	811	33.8%
Total	1,182	1,811	2,540	3,375	4,172	4,750	32.1%
Host-Dependent							
Hardware	2,204	2,232	2,125	1,991	1,763	1,478	-7.7%
Software	509	597	659	677	683	661	5.4%
Service	489	515	505	493	458	407	-3.6%
Total	3,203	3,345	3,289	3,161	2,904	2,545	-4.5%
Personal Computer							
Hardware	380	393	397	379	334	285	-5.6%
Software	188	284	351	388	394	391	15.8%
Service	40	53	61	63	61	58	7.9%
Total	608	730	809	831	788	735	3.9%

Source: Dataquest
July 1988

Table 1.4-8

Mechanical CAD/CAM Revenue Sources by Platform—Worldwide (Percentage of Total)

	1987	1988	1989	1990	1991	1992
All Platforms						
Hardware	65%	61%	58%	56%	53%	50%
Software	21%	24%	27%	29%	32%	34%
Service	14%	14%	15%	15%	15%	16%
Total	100%	100%	100%	100%	100%	100%
Technical Workstation						
Hardware	55%	55%	53%	52%	50%	47%
Software	29%	29%	31%	32%	34%	36%
Service	16%	16%	16%	16%	16%	17%
Total	100%	100%	100%	100%	100%	100%
Host-Dependent						
Hardware	69%	67%	65%	63%	61%	58%
Software	16%	18%	20%	21%	24%	26%
Service	15%	15%	15%	16%	16%	16%
Total	100%	100%	100%	100%	100%	100%
Personal Computer						
Hardware	63%	54%	49%	46%	42%	39%
Software	31%	39%	43%	47%	50%	53%
Service	7%	7%	7%	8%	8%	8%
Total	100%	100%	100%	100%	100%	100%

Source: Dataquest
July 1988

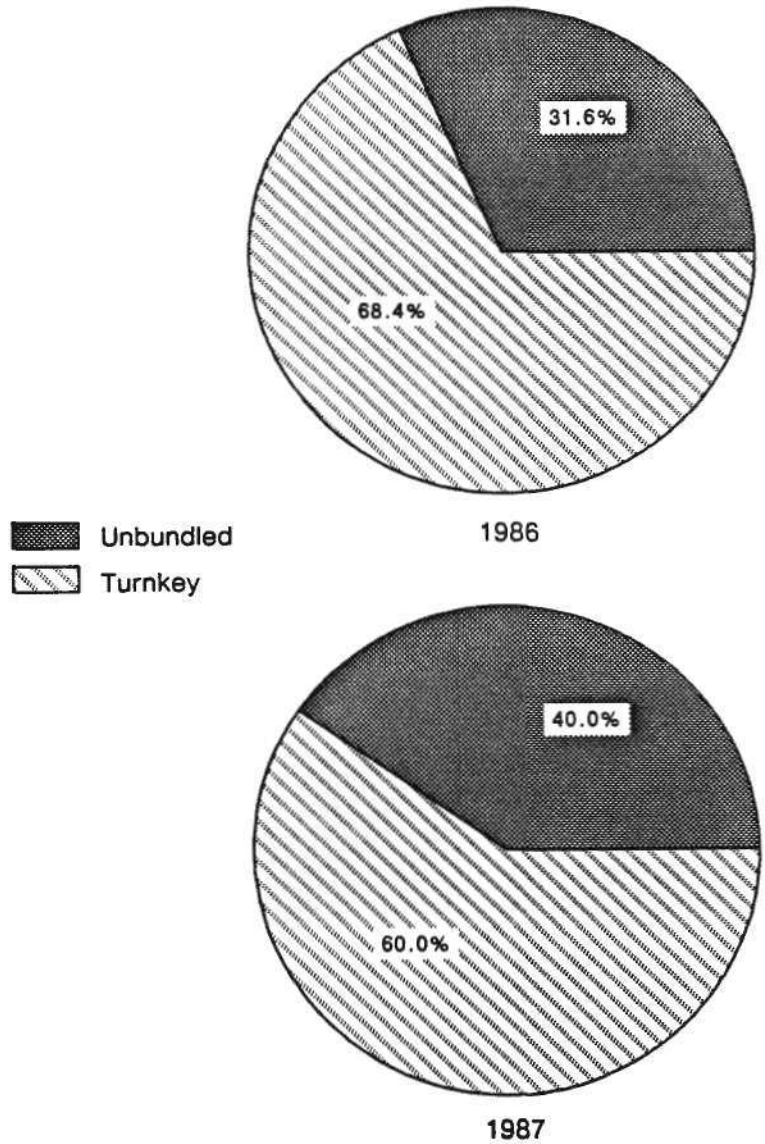
TURNKEY VERSUS UNBUNDLED

This section covers the turnkey versus unbundled mechanical CAD/CAM revenue for hardware and software. Figure 1.4-9 and Tables 1.4-9 and 1.4-10 show the change in market share from 1985 to 1986. The following should be noted:

- The turnkey distribution channel has a dominant but eroding market share in total hardware and software revenue, moving from 79 percent in 1985 to 68 percent in 1986, and 60 percent in 1987.
- The corresponding 1988 CAGR for turnkey revenue is 12.7 percent.
- The 1988 unbundled share is growing at a 25.4 percent annual rate.
- Software and hardware revenue for each group was analyzed, and similar growth patterns were found.
- The turnkey distribution channel has lost share in workstation shipments, dropping from 49 percent in 1986 to 40 percent in 1987.

Figure 1.4-9

Mechanical CAD/CAM Turnkey Versus Unbundled
(Total Hardware and Software Revenue)



Source: Dataquest
July 1988

Table 1.4-9

Mechanical CAD/CAM Turnkey Versus Unbundled
(Millions of Dollars, Actual Units)

	1987	1988	1989	1990	1991	1992	CAGR
Total Hardware and Software Revenue							
Turnkey	2,578	2,906	3,052	3,148	3,125	2,918	2.5%
Unbundled	1,696	2,127	2,621	3,125	3,541	3,835	17.7%
Total	4,274	5,033	5,674	6,273	6,666	6,753	9.6%
Hardware Revenue							
Turnkey	1,971	2,147	2,188	2,188	2,098	1,878	-1.0%
Unbundled	1,263	1,472	1,691	1,941	2,076	2,107	10.8%
Total	3,233	3,620	3,879	4,129	4,174	3,985	4.3%
Software Revenue							
Turnkey	607	759	864	960	1,028	1,040	11.4%
Unbundled	434	655	930	1,185	1,465	1,728	31.8%
Total	1,041	1,413	1,794	2,145	2,493	2,768	21.6%
Workstation Shipments							
Turnkey	50,785	61,140	69,710	77,100	81,440	81,160	9.8%
Unbundled	76,368	99,370	124,240	151,990	174,890	192,740	20.3%
Total	127,152	160,510	193,950	229,080	256,320	273,900	16.6%

Source: Dataquest
July 1988

Table 1.4-10

Mechanical CAD/CAM Turnkey Versus Unbundled
(Percentage of Total)

	1987	1988	1989	1990	1991	1992
Total Hardware and Software Revenue						
Turnkey	60%	58%	54%	50%	47%	43%
Unbundled	40%	42%	46%	50%	53%	57%
Total	100%	100%	100%	100%	100%	100%
Hardware Revenue						
Turnkey	61%	59%	56%	53%	50%	47%
Unbundled	39%	41%	44%	47%	50%	53%
Total	100%	100%	100%	100%	100%	100%
Software Revenue						
Turnkey	58%	54%	48%	45%	41%	38%
Unbundled	42%	46%	52%	55%	59%	62%
Total	100%	100%	100%	100%	100%	100%
Workstation Shipments						
Turnkey	40%	38%	36%	34%	32%	30%
Unbundled	60%	62%	64%	66%	68%	70%
Total	100%	100%	100%	100%	100%	100%

Source: Dataquest
July 1988

1.5 Mechanical Market Share

Figures 1.5-1 through 1.5-4 and Table 1.5-1 present Dataquest's analysis of the mechanical CAD/CAM market share measured in total revenue, hardware and software revenue, and workstation shipments, as follows:

- IBM dominates the worldwide mechanical market with a 22.9 percent market share, and the company also leads market share in hardware, software, and workstations shipped.
  - CADAM continues to be the most popular IBM-based mechanical CAD/CAM software, with Catia a close second and CAEDS growing in popularity on the mainframe platform.
  - Technical workstation revenue has been low in mechanical CAD/CAM, but the recent enhancement of the RT and the later delivery of the 80386-UNIX-based technical workstation are expected to increase unit shipments on these platforms.
- Digital Equipment Corporation derives most of the revenue shown from hardware and service-only sales directly to end users; however, a growing interest in bundled sales will result in some revenue in 1988 from this channel, primarily with Autocad software.
- Computervision is third in total mechanical revenue, maintaining a second-place market share in Europe where it gathered more than half of its total revenue. Computervision is tied with IBM in market share in software revenue.
- Intergraph made slow revenue progress in 1987, growing 5.9 percent in mechanical applications.
  - Intergraph came in fourth in software revenue and twelfth in the number of workstations shipped.
  - Vendors with a strong personal computer offering represented many of the top 10 market share positions in workstation shipments.
- McDonnell Douglas is in fifth position in total revenue market share, having moved up to third in software revenue. The mechanical market is a strategic market for McDonnell Douglas.
- Control Data Corporation is virtually tied with McDonnell Douglas for fifth position in total revenue; Control Data is fifth in hardware revenue as well.
- Prime Computer came in sixth in revenue growth, with an 18 percent growth. Prime leads the top 10 in service revenue with 26 percent of total revenue coming from that source.

- Applicon (Schlumberger) lost total market share in revenue, dropping to eighth place behind Prime. Applicon moved up to fourth place in software revenue, however, with a healthy 34 percent increase in software revenue resulting from the move toward unbundled software.

- Hitachi remained in the top 10 after breaking into this select group in 1985.

  — Hitachi's 20 percent total revenue growth shows strong momentum.

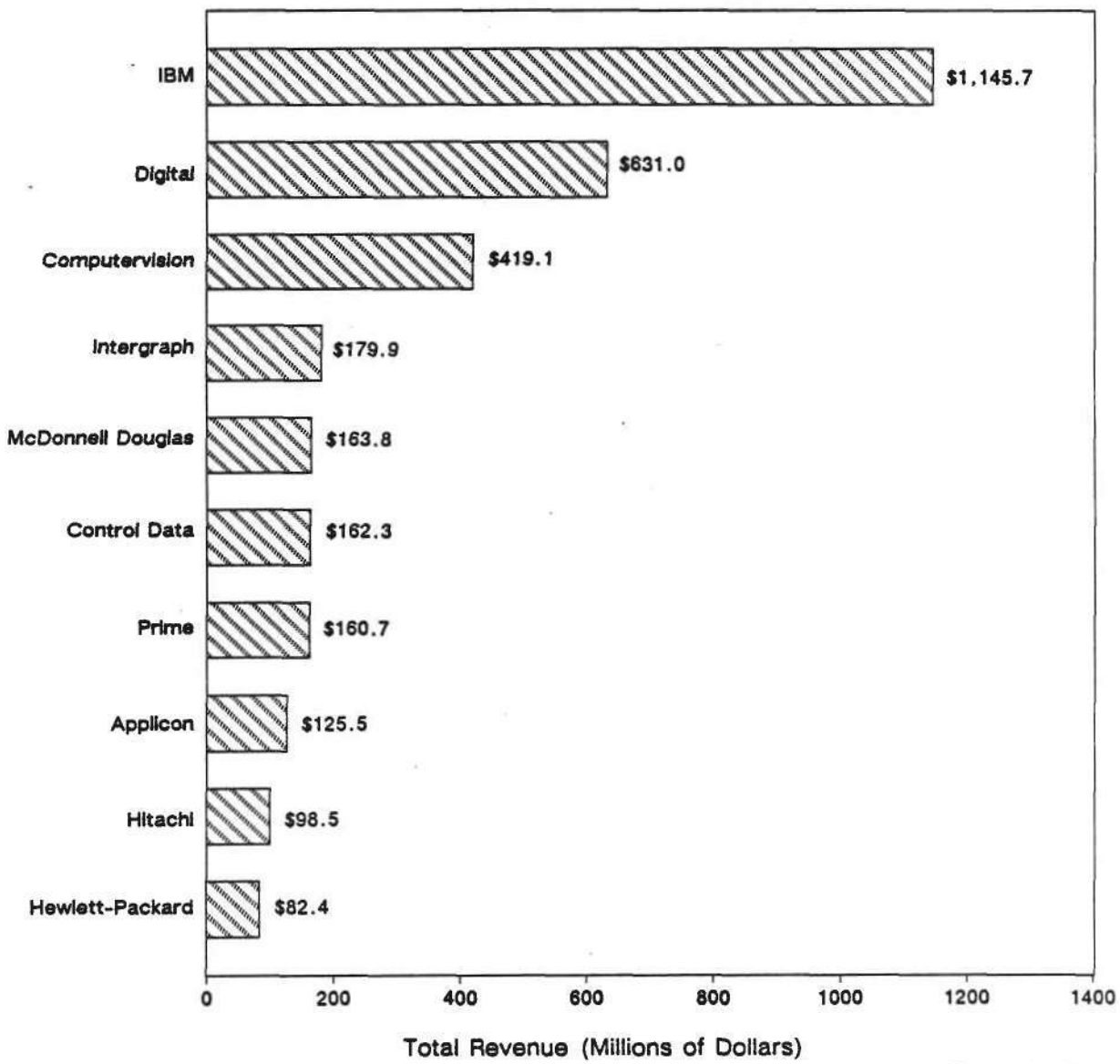
  — Hitachi dropped to tenth in software revenue, although this number is inflated slightly due to the devaluation of the dollar in Japan.

- Hewlett-Packard (HP) also stayed in the top 10 after first appearing in 1985. Its 124 percent workstation unit shipment growth is strong testimony to the mechanical application focus of HP.

- MacNeal Schwendler posted a fifth position in software revenue, resulting from a 31 percent growth in revenue.

Figure 1.5-1

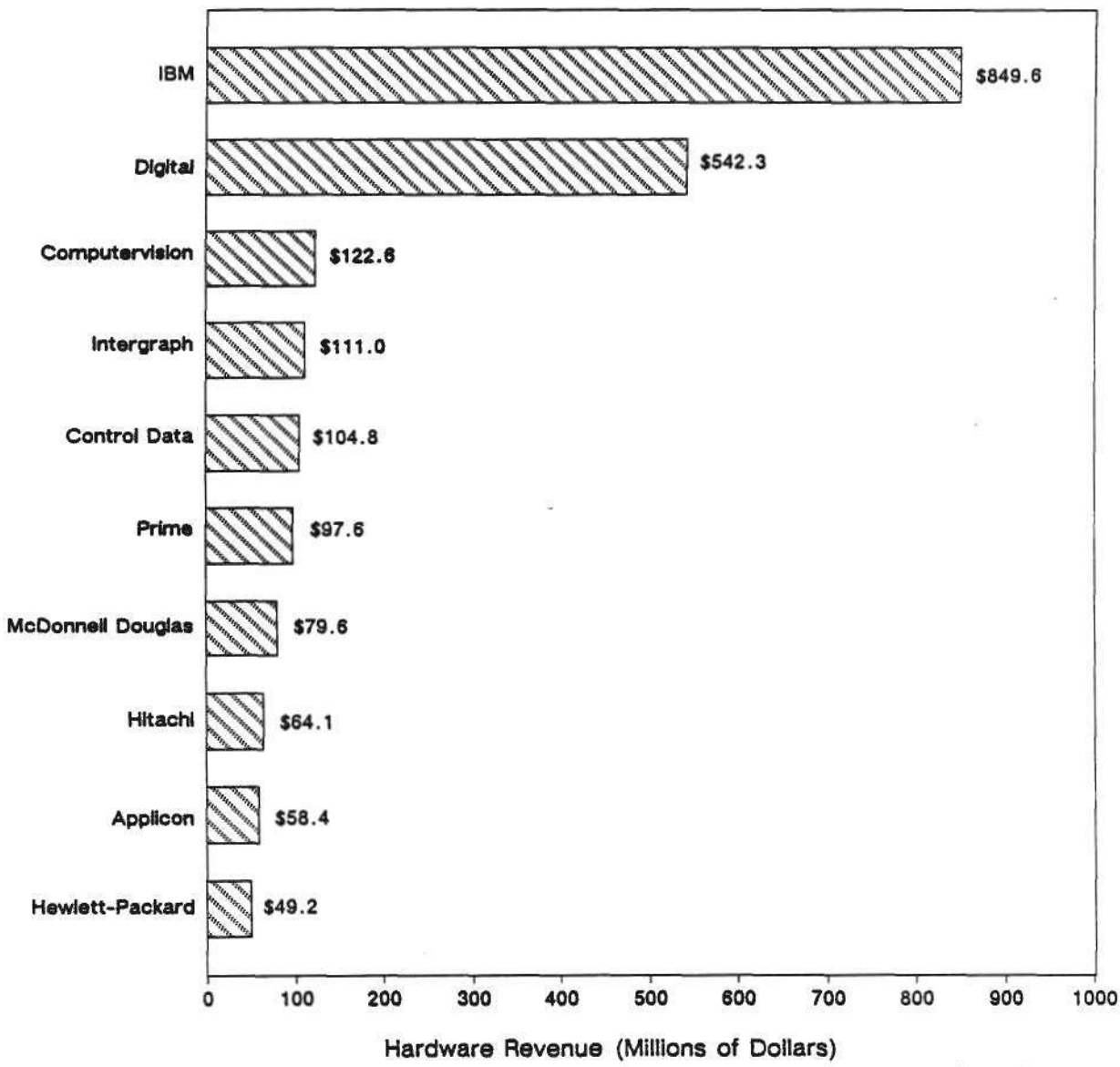
Mechanical CAD/CAM 1987 Worldwide Market Share
Total Revenue



Source: Dataquest
July 1988

Figure 1.5-2

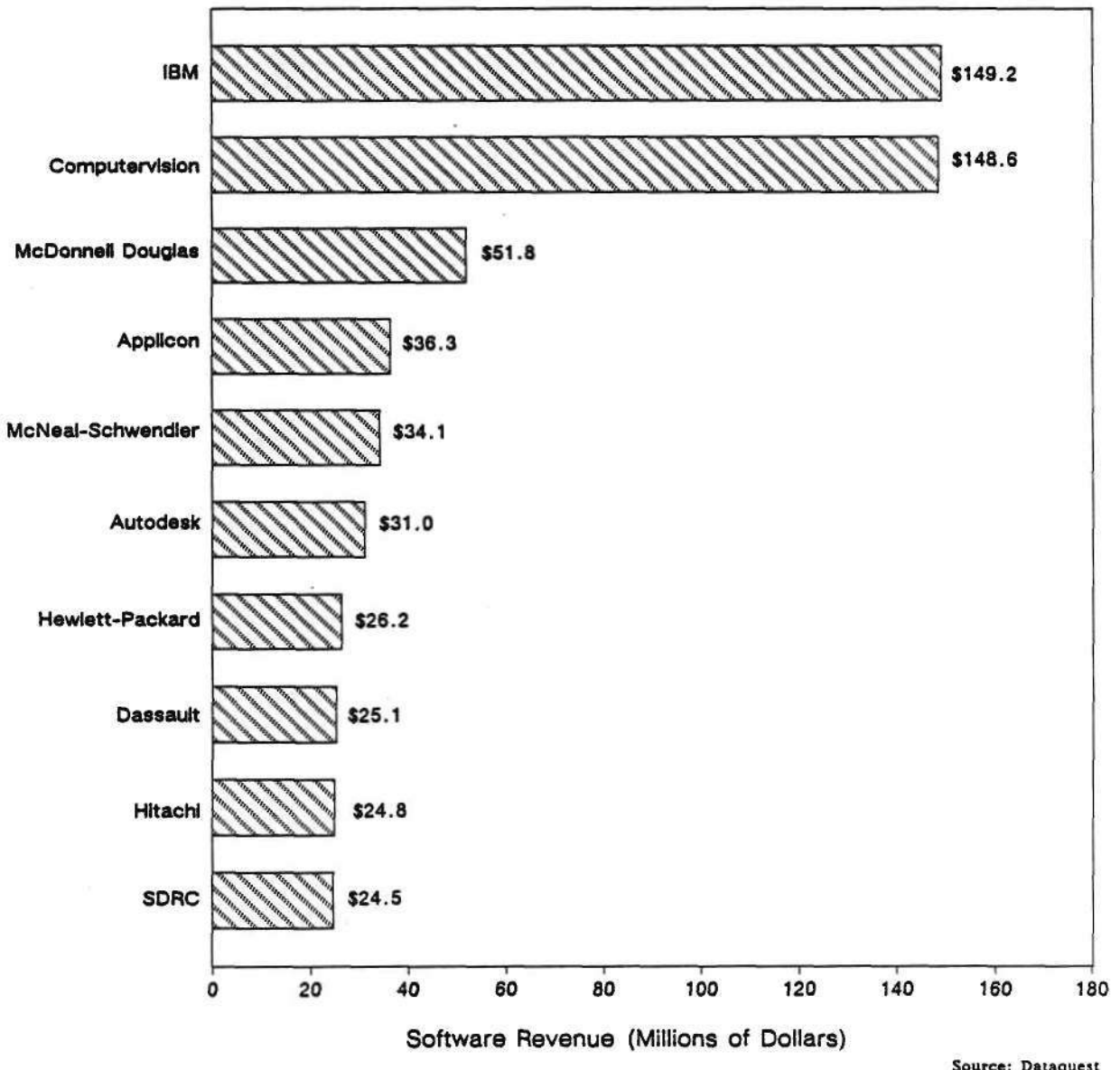
Mechanical CAD/CAM 1987 Worldwide Market Share
Hardware Revenue



Source: Dataquest
July 1988

Figure 1.5-3

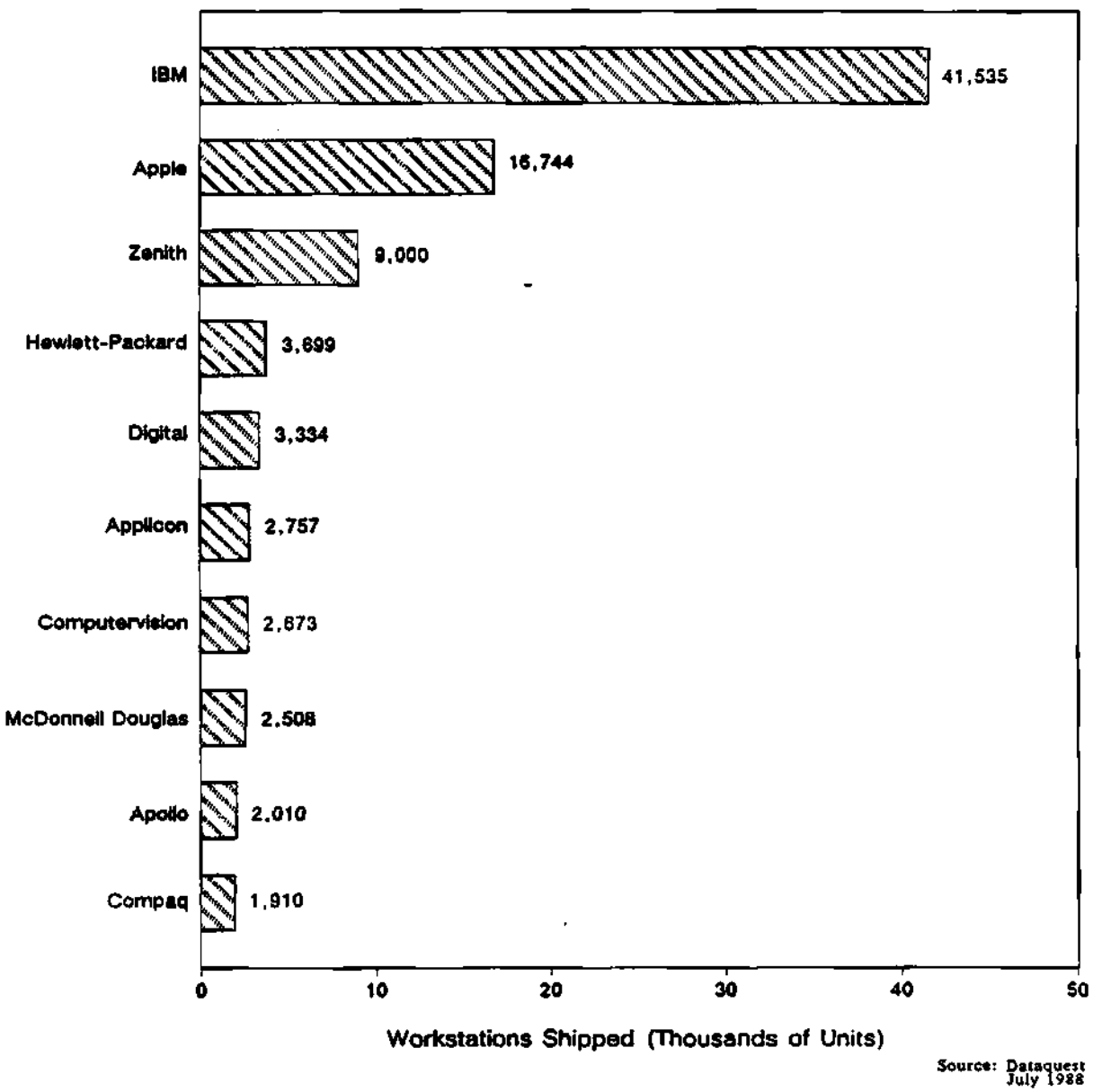
Mechanical CAD/CAM 1987 Worldwide Market Share
Software Revenue



Source: Dataquest
July 1988

Figure 1.5-4

Mechanical CAD/CAM 1987 Worldwide Market Share
Workstation Shipments



Source: Dataquest
July 1988

Table 1.5-1

Mechanical CAD/CAM 1987 Worldwide Market Share
(Millions of Dollars, Actual Units)

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	1,145.7	849.6	149.2	41,535	22.9%	26.3%	14.3%	32.7%
Digital	631.0	542.3	1.5	3,334	12.6%	16.8%	.1%	2.6%
Computervision	419.1	122.6	148.6	2,673	8.4%	3.8%	14.3%	2.1%
Intergraph	179.9	111.0	32.0	1,576	3.6%	3.4%	3.1%	1.2%
McDonnell Douglas	163.8	79.6	51.8	2,508	3.3%	2.5%	5.0%	2.0%
Control Data	162.3	104.8	20.6	1,066	3.3%	3.2%	2.0%	.8%
Prime	160.7	97.6	25.1	1,744	3.2%	3.0%	2.4%	1.4%
Applicon	125.5	58.4	36.3	2,757	2.5%	1.8%	3.5%	2.2%
Hitachi	98.5	64.1	24.8	1,554	2.0%	2.0%	2.4%	1.2%
Hewlett-Packard	82.4	49.2	26.2	3,699	1.7%	1.5%	2.5%	2.9%
Fujitsu	71.1	46.6	17.4	1,252	1.4%	1.4%	1.7%	1.0%
NEC	66.5	39.5	20.3	1,318	1.3%	1.2%	1.9%	1.0%
Siemens	62.0	42.4	13.4	583	1.2%	1.3%	1.3%	.5%
Mitsubishi Electric	59.5	37.1	16.5	674	1.2%	1.1%	1.6%	.5%
Matra Datavision	55.0	43.1	6.4	600	1.1%	1.3%	.6%	.5%
Apollo	53.0	47.5	.0	2,010	1.1%	1.5%	.0%	1.6%
Hitachi Zosen	51.7	24.5	23.4	522	1.0%	.8%	2.2%	.4%
Auto-Trol	49.8	27.6	16.1	584	1.0%	.9%	1.5%	.5%
Apple Computer	46.6	46.6	.0	16,744	.9%	1.4%	.0%	13.2%
Calma	45.4	23.1	12.7	491	.9%	.7%	1.2%	.4%
Mutoh Industries (No OEM)	38.9	22.7	12.4	1,241	.8%	.7%	1.2%	1.0%
Cimlinc	35.2	16.7	13.2	917	.7%	.5%	1.3%	.7%
Silicon Graphics	35.0	31.0	.5	1,000	.7%	1.0%	.0%	.8%
Toshiba (No OEM)	34.4	20.4	10.6	422	.7%	.6%	1.0%	.3%
MacNeal-Schwendler	34.1	.0	34.1	0	.7%	.0%	3.3%	.0%
Sun	33.5	29.7	.0	1,370	.7%	.9%	.0%	1.1%
Graftek	33.3	13.7	14.8	512	.7%	.4%	1.4%	.4%
Ferranti	32.3	18.7	8.3	275	.6%	.6%	.8%	.2%
Dassault	31.4	.0	25.1	0	.6%	.0%	2.4%	.0%
Autodesk	31.0	.0	31.0	0	.6%	.0%	3.0%	.0%
Norsk	30.0	7.0	14.3	313	.6%	.2%	1.4%	.2%
Zenith	29.7	26.7	.0	9,000	.6%	.8%	.0%	7.1%
SDRC	24.5	.0	24.5	0	.5%	.0%	2.3%	.0%
CISI	24.0	10.6	10.5	850	.5%	.3%	1.0%	.7%

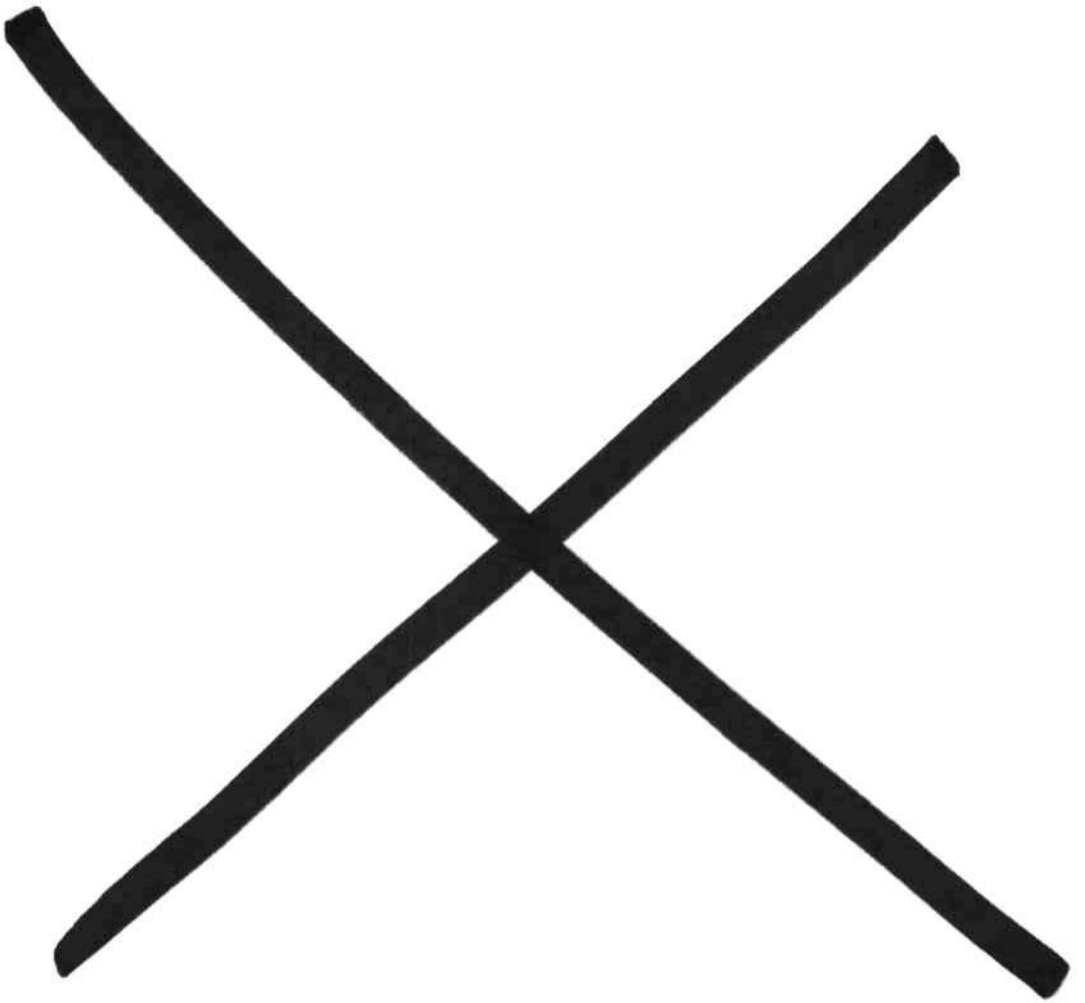
(Continued)

Table 1.5-1 (Continued)

Mechanical CAD/CAM 1987 Worldwide Market Share
(Millions of Dollars, Actual Units)

Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Market Share: Total Revenue	Market Share: Hardware Revenue	Market Share: Software Revenue	Market Share: Wkstns Shipped
Gerber Systems	21.0	12.0	4.6	320	.4%	.4%	.4%	.3%
Swanson Analysis	15.5	.0	15.5	0	.3%	.0%	1.5%	.0%
PDA Engineering	15.2	.0	15.2	0	.3%	.0%	1.5%	.0%
Info. Services Int'l. Dentsu	15.0	2.5	11.2	50	.3%	.1%	1.1%	.0%
PAFEC	15.0	.0	15.0	0	.3%	.0%	1.4%	.0%
Tokyo Electron (No OEM)	13.4	7.8	3.4	55	.3%	.2%	.3%	.0%
ItalCad	9.9	6.4	2.5	98	.2%	.2%	.2%	.1%
Sharp System Products	8.8	5.1	2.8	65	.2%	.2%	.3%	.1%
CADAM	8.7	3.9	3.9	66	.2%	.1%	.4%	.1%
ICL	7.9	5.9	1.5	181	.2%	.2%	.1%	.1%
Compaq	6.8	6.8	.0	1,910	.1%	.2%	.0%	1.5%
ISICAD	6.8	3.4	2.1	61	.1%	.1%	.2%	.0%
Seiko Instruments (No OEM)	3.5	.0	3.2	0	.1%	.0%	.3%	.0%
Syscan	3.4	2.3	.6	24	.1%	.1%	.1%	.0%
Zuken	1.3	.0	1.1	0	.0%	.0%	.1%	.0%
Other Companies	664.0	522.6	117.1	21,200	13.3%	16.2%	11.2%	16.7%
All Companies	4,992.6	3,233.2	1,041.1	127,152	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	4,017.9	2,681.6	717.0	112,713	80.5%	82.9%	68.9%	88.6%
All Asian-Based Companies	644.4	387.6	202.0	9,750	12.9%	12.0%	19.4%	7.7%
All European-Based Companies	330.4	164.0	122.2	4,690	6.6%	5.1%	11.7%	3.7%
All Hardware Companies	1,386.1	1,262.5	1.3	76,368	27.8%	39.0%	.1%	60.1%
All Turnkey & SW Companies	3,606.6	1,970.7	1,039.9	50,785	72.2%	61.0%	99.9%	39.9%

Source: Dataquest
July 1988



2 MCAE—Mechanical Computer-Aided Engineering

MCAE—Key to Higher Corporate Profitability

INTRODUCTION

Mechanical computer-aided engineering (MCAE) is moving into center stage as a primary contributor in the evolution of CAD/CAM. Esoteric analysis and mediocre modeling methods are evolving toward highly functional engineering tools, using the latest in high-performance graphics display and computation. Because MCAE technology is changing the way that the world designs its products, it must be considered by every major manufacturing corporation. The ability of a company to remain profitable will depend more and more on its ability to effectively use MCAE technology. MCAE is a major key to higher corporate profitability.

The purpose of this service section is to provide a background of information describing the history and expected evolution of this important and growing segment of the mechanical CAD/CAM application. The market forecast is given with the supporting significant trends and assumptions. A perspective on driving issues is presented with analysis. Highlights from the section with an overall analysis are found in the concluding Dataquest analysis. Please review the following definitions to confirm the scope of this analysis.

DEFINITION

Mechanical computer-aided engineering (MCAE) has a broad range of definitions, depending on the mechanical application and type of user. A full understanding of the MCAE process should consider all software packages that an engineer or designer would likely incorporate in the everyday use of his workstation. Spreadsheets, word processors, and electronic mail are a few of the major applications outside of engineering graphics that are commonly required to improve the productivity of the designer or engineer.

In general, the largest MCAE effort is directed toward product design, but an important and growing application group includes use of MCAE tools for manufacturing support in the form of design and analysis for tooling, molds and dies, fixtures, material handling equipment, or packaging. The MCAE application in this analysis is limited to the computer graphics tools that have been developed to aid the product design and analysis process, separate from documentation or manufacturing tasks. Software for supporting administration or management tasks is not included.

The design and analysis activities supporting the product design and analysis process exist in two major areas: conceptual design and detail product design, more commonly referred to as computer-aided design (CAD). The functional requirements of conceptual design and detail product design are becoming increasingly similar. The need to share information back and forth between these operations is pushing the requirements even closer. This trend in evolution of common interface, sharing of data, and functional commonality is the basis for combining the products and markets of conceptual design and CAD, calling the result mechanical computer-aided engineering.

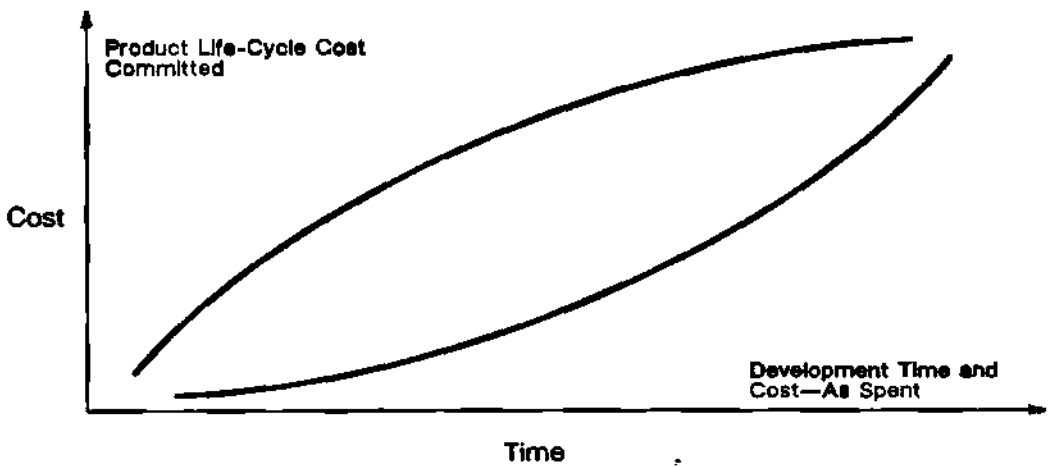
DRIVING FACTORS

Early Design Optimization

The design engineer is the primary individual affecting the design process from early conceptual proposal throughout production of detailed plans ready for transfer to manufacturing. This process of design evolves through many stages, depending on product complexity. A common thread is evident across many industries. As the first 5 percent of time and dollars are spent in the product development process, the direction is set, committing more than 85 percent of the total life-cycle costs. In other words, the most critical product design decisions are made during the earliest stage of design effort. This data was reported from British Aerospace and has been echoed as typical from many manufacturing operations. Figure 2-1 illustrates this trend in cost commitment in the product development process.

Figure 2-1

Cost Profile of Development Process



Source: British Aerospace
Dataquest
July 1988

The two biggest problems with this traditional approach to product development are the following:

- The greatest opportunity to affect the design is given up after expending only 5 percent of design effort.
- Because of the analysis and test activities that take place later in the process, major design problems often do not show up until later; by then it may be too late to implement an optimal design change.

Cost of Engineering Change

Another way of visualizing this commitment to cost over time is to consider the estimated cost of a design change at different stages in the product life cycle. The following breakdown illustrates approximate costs for engineering changes at each stage:

- In drawing board stage—$1
- In design checking—$10
- In process planning—$100
- In manufacturing engineering—$1,000

- In final production—$10,000
- After field failure—$100,000 or more

The real objective of MCAE was succinctly given by Brad Morley, Vice President of Product Development at SDRC, during the 1986 Dataquest Industry Conference. "The real objective of MCAE," said Mr. Morley, "is in providing technology to the design engineer up front in the product development process when there is the greatest opportunity to affect the product design, while at the same time, providing tools which allow for the effective evaluation of many different design concepts during the early stages of product development when the cost per change is least expensive."

Implementation Cost

The above driving factors of early design optimization and cost of engineering change have always existed. Another limiting factor in the expansion of MCAE is directly related to high cost of implementation. Low-cost systems are fueling the growth of MCAE because the largest market is comprised of casual users with less sophisticated requirements. Higher-performance systems will also lower the effective cost, putting more powerful systems in the hands of the experienced user.

Access

The issue of access is critical to the future of MCAE and CAD/CAM in general. Every time an interface is created between manual methods and automation, an inefficiency is introduced. Hopefully, the productivity of islands of automation more than compensate for the overhead of a partially automated process. The complete benefit of design and manufacturing automation cannot be realized until everyone with a need has ready *access* to a workstation. MCAE can be seen as an enabling technology automating a large and important segment of the overall manufacturing process.

Super Graphics Workstation (SGW)

A new breed of ultrahigh-performance workstations is emerging in the market. Apollo, Ardent, Silicon Graphics, Sun, and others have made recent offerings that leapfrog over previous workstations in providing the fastest display or analytical resources. To some degree, this can be seen as a normal extension of the lower-cost/faster trend in engineering computing. The more significant issue concerns the impact of these machines on software development. Dataquest believes that new software product development will proceed on the following two fronts:

- Very sophisticated analytical software, now available only on supercomputers, will be offered on SGWs. Typical applications will include computational fluid dynamics, very large scale finite element analysis (CFD) and crash simulation.

- A more exciting expectation will see the growth of second-generation mechanical computer-aided engineering (MCAE II) that allows the user to manipulate and view the design process with realistic imaging and smooth motion, with a user interface based on subsecond response and a range of analytical tool modules to support any feasible design iteration. These modules would include mass property calculation, stress analysis, mechanism analysis, subsystem and full system simulation.

HISTORICAL PERSPECTIVE

The design and analysis activities associated with MCAE have evolved from two distinct approaches with very different software functionality and different typical users. The common company requirements of design verification and analysis are driving the development of both approaches toward a similar functionality and a larger target market. A third development path has surfaced with a viable success opportunity.

Evolution of MCAE from Turnkey Vendors

The first step in MCAE development came as an outgrowth of computer-aided design and drafting, or CAD. In this context, MCAE is design and analysis primarily by 3-D wireframe modeling techniques but includes 2-D modeling and 3-D surfacing modeling for design and analysis. The early market share leaders in CAD/CAM—such as Applicon, Auto-Trol, CADAM, Calma, Computervision, and McDonnell Douglas—are good examples of vendors with wireframe-based MCAE tools. A Dataquest end-user survey indicates that a majority of current design and analysis activities are accomplished with these tools.

In general, the CAD approach has evolved from early drafting applications to a detail design focus. The strengths of this focus provide robust component design and analysis with an emphasis on proper fit of mating surfaces in assemblies. Typically, analysis ranges from simple clearance measurement between two parts in an assembly to kinematic evaluations of assemblies.

The modeling function to support CAD design and analysis activity is evolving toward solid modeling implemented as a core system function. The effects of this more complete modeling tool will enhance the performance, ease of use, and range of effective applications as solid modeling product developments are turned into effective tools.

Evolution of MCAE from Advanced Analytical Software Vendors

The second path of MCAE development started in component design analysis with strong dependence on finite-element techniques. MacNeal-Schwendler, PDA Engineering, SDRC, and Swanson Analysis are good examples of the early leaders in

finite-element modeling and analysis (FEM/FEA). Part analysis after failure in the field was the most typical use of early FEM/FEA software. As batch mode processing and tedious digitizing input processing gave way to more automated operation, the design analysis tools gained wider acceptance. An increasing volume of analysis was performed before the actual part or assembly was constructed. The time saved in finding a major problem at this early stage of product development was found to contribute sizable savings in time and expenses. As conceptual design improved in performance and price, it became a proven, useful analytical tool.

The need to improve the modeling function to support the analysis operation has promoted the use of 3-D modeling techniques, with solid modeling becoming the preferred modeling method. Solid modeling includes the opportunity to automate the finite-element meshing operation, optimizing the design with recursive analysis/ modification. As with the turnkey vendors, solid modeling is becoming the modeling technique of choice.

The Latest Approach—MCAE as the Engineer's Tool Box

Most recent MCAE developments have taken a new path. The target market is focused on the casual user as engineer or designer. Electronic reference handbooks, sketch-mode data entry, solid modeling, design analysis, and project management tools are mixed together in a variety of cost/performance packages. Several companies have released products or will release products in the near future using these features combined with established modeling and analysis functions.

Artificial intelligence and computational and data base servers are playing an important role in improving the usability and performance of the part-time MCAE resource. The vendor move to capture the engineer's desktop will proceed along the price/performance battle line well into the 1990s.

VENDOR PERSPECTIVE

MCAE Vendors—Who Are They?

Depending on a vendor's marketing focus, it may or may not be considered to be involved in the MCAE market. Definitions are everything in sizing the market and measuring the major players. The Dataquest definition states, "If a system can perform design and/or analysis of mechanical components, it can qualify as having an MCAE functionality." With this definition in mind, an evaluation can be made of the more than 500 worldwide CAD/CAM vendors to determine the population of MCAE vendors. The list developed from the Dataquest *CAD/CAM Industry Directory* is shown in Table 2-1. More than 150 MCAE vendors are listed with an indication of product features.

The top 10 MCAE vendors have been evaluated with the results presented in the market share analysis section. The mechanical turnkey CAD/CAM vendors dominated the list, taking 6 of the top 10 positions. Software-only vendors focusing on design and analysis applications comprised the remaining 4 positions. The "Other" group that makes up 26 percent of the MCAE market comprises a long list of vendors.

Table 2-1

Worldwide MCAE Vendor and Feature Matrix

Vendor Name	3-D Data Representation	Design and Analysis	FEM/ FEA	Kinematics	Imaging
4-D Graphics, Inc.	X	X	X		
Abel Image Research	X	X			X
Accugraph Corporation	X				
AD-Tech, Inc.		X			
Adra Systems, Inc.		X			
Advanced Computer Graphics, Inc.			X		
Algor Interactive Systems, Inc.			X		
Alias Research Inc.	X	X		X	
American Computers & Engineers, Inc.			X		
ANA Tech Corp.					X
Applicon	X	X	X	X	
Aries Technology	X	X	X	X	
Artronics, Inc.	X				
Asahi Optical Co., Ltd.	X		X	X	
Auto-Trol Technology Corp.	X	X	X	X	
Autodesk, Inc.	X	X	X		
Automation Technology Products	X	X	X		
Boeing Computer Services	X	X	X		
Brooks Scientific			X		
C. Itoh Technosciences, Ltd.	X	X	X	X	
CADAM, Inc.	X	X	X	X	
Cadcentre, Inc.	X				
Cadsi	X	X		X	
Calma Co.	X	X	X	X	
Camax Systems, Inc.	X	X			
Cambridge Interactive Systems	X	X		X	
Carnegie Group Inc.		X			
CASA/Gifts Inc.	X	X	X		
Catronix Corp.	X	X	X		
CDC Japan, Ltd.	X	X	X	X	

(Continued)

Table 2-1 (Continued)

Worldwide MCAE Vendor and Feature Matrix

Vendor Name	3-D Data Representation	Design and Analysis	FEM/ FEA	Kinematics	Imaging
Celestial Software, Inc.	X		X		
Chromatics	X				
CIMLINC, Inc.	X				
CIS Ltd.	X			X	
Cisigraph	X		X	X	
Coade			X		
Cognition, Inc.		X	X	X	
Computerized Drafting and Design	X				
Computervision Corp.	X	X	X	X	X
Computervision Japan, Ltd.	X	X	X	X	X
Control Automation, Inc.	X				
Control Data Corp.	X	X	X	X	
Counting House Computer Systems Ltd.	X				
Cubicomp Corp.	X				X
Cymbol Cybernetics Corp.	x				
Dassault Systems	X	X	X	X	X
Daveg Datentechnik	X				
Deltacam Systems Ltd.	X				
DFI Systems		X			
DIS/ADLPIPE, Inc.			X		
ECOM Associates, Inc.			X		
Eikonix Corp.					X
Enertronics Research, Inc.	X				
Engineering Computer Services ECS	X		X	X	
Engineering Mechanics Research			X		
Engineering Methods, Inc.			X		
Engineering Systems Corp.	X				
Entek Scientific Corp.		X			
Evans & Sutherland Computer Corp.	X	X		X	
Evolution Computing	X				
Ferranti Infographics Ltd.	X	X	X	X	
Fujitsu, Ltd.	X		X	X	
Georgia Institute of Technology			X		
Gerber Systems Technology, Inc.	X		X		
GMW Computers, Inc.	X				

(Continued)

Table 2-1 (Continued)

Worldwide MCAE Vendor and Feature Matrix

Vendor Name	3-D Data Representation	Design and Analysis	FEM/ FEA	Kinematics	Imaging
GMWC Ltd.	X				
Graftek	X	X	X	X	
H.G. Engineering Ltd.			X		
Hakuto Co., Ltd.	X				
Harris Corp.	X	X	X		
Hewlett-Packard Co.	X	X	X		
Hibbitt, Karlsson & Sorensen			X		
Hitachi Zosen Info. Systems Co.	X	X	X	X	
Hitachi, Ltd.	X	X	X	X	
HOK Computer Services Corp.	X				
Holguin Corporation	X				
Honeywell Information Systems	X		X		
IBM	X	X	X	X	X
IBM Japan, Ltd.	X	X	X	X	X
ICAD Inc.	X	X			
ICAT	X				
Iconnex Corp.		X			
Impell Computer Systems	X	X			X
Innovative Computer-Aided Tech, Inc.	X				
Interactive Computer Modelling, Inc.	X	X			
Intergraph Corp.	X	X	X	X	X
International Computers Ltd.	X		X		
ISTEL	X	X	X	X	X
Isykon Software GmbH	X				
Kanematsu Electronics, Ltd.	X		X	X	
Kintech, Inc.				X	
Kongsberg	X				
MacNeal-Schwendler Corp.			X		
Manufacturing & Consulting Services	X	X	X	X	
MARC Analysis Research Corp.			X		
Marubeni Hytech Co., Ltd.	X		X	X	
Masscomp Computer Corp.	X	X	X	X	X
Mathsoft		X			
Matra Datavision, Inc.	X	X	X	X	
MC2 Engineering Software	X	X	X		

(Continued)

Table 2-1 (Continued)

Worldwide MCAE Vendor and Feature Matrix

Vendor Name	3-D Data Representation	Design and Analysis	FEM/ FEA	Kinematics	Imaging
McDonnell Douglas Mfg. & Engrg Sys.	X	X	X	X	
Measurement Masters, Inc.	X				
Mechanical Dynamics	X	X		X	
MEGA CADD, Inc.	X				
Megatek Corp.	X		X	X	X
Merlin Technologies, Inc.		X			
Micro Control Systems	X	X			
Micro Engineering Solutions	X				
Mitchell & Gauthier Associates Inc.	X	X	X	X	
Mitsubishi Electric Corp.	X				
Mitsui Engineering & Shipping Corp.	X				
Mohango, Inc.		X			
Moldflow Pty., Ltd.	X	X	X		
Mutoh Industries, Ltd.	X		X	X	
NEC Corp.	X		X	X	
Nihon Digital Equipment Corp.	X	X	X	X	X
Nippon Univac Kaisha, Ltd.	X		X	X	
Norsk Technovision (Dietz)	X				
Number Crunching Microsystems, Inc.			X		
Numerical Control Computer Sciences	X				
P & H Computer Graphics	X	X	X		
Packaged Communications Technology	X	X	X		
Pafec Ltd.	X		X	X	
Panatec Software Inc.			X		
Pathtrace Chicago, Inc.	X				
PDA Engineering	X	X	X	X	
Peng Engineering			X		
Pisces International Co.			X		
Prime Computer Japan, Ltd.	X	X	X	X	
Prime Computer, Inc.	X	X	X	X	
PSI Systems Corp.	X				
PTI Industries/Koala					X
Research Engineers, Inc.			X		
Rikei Corp.	X		X	X	
Robo Systems	X				

(Continued)

Table 2-1 (Continued)

Worldwide MCAE Vendor and Feature Matrix

Vendor Name	3-D Data Representation	Design and Analysis	FEM/ FEA	Kinematics	Imaging
Seiko Instruments & Elec., Ltd.	X				
Shape Data Ltd.	X	X	X	X	
Siemens Data Systems A.G.	X	X	X	X	X
Siemens Factory Automation Systems	X		X		X
SKOK Systems	X				
Stress Analysis Associates, Inc.			X		
Structural Dynamics Research Corp.	X	X	X	X	
Sumisho Electronics Co.	X		X		
Summit CAD Corp.	X				
Supercads	X	X			
Swanson Analysis Systems, Inc.	X	X	X	X	
Synthesis, Inc.	X				
Tektronix, Inc.	X				
Telemecanique	X				
Toshiba Corp.	X	X	X	X	
Toyo Information Systems, Ltd.	X		X	X	
Unicad, Inc.	X				
Uniras, Inc.	X	X		X	
Unisys	X	X	X		
United Information Services, Inc.			X		
Universal Intergraphix Corp.	X	X	X		
VG Systems, Inc.	X	X	X		
Visual Information, Inc.	X		X		
Weber Systems, Inc.	X				
Westinghouse Electric Corp.	X	X	X		X
Yokogawa Hewlett-Packard, Ltd.	X		X	X	
Zuken, Inc.	X		X	X	

Source: Dataquest July 1988

The Development Path

Conceptual design and detail product design are evolving into a cohesive evolutionary direction for MCAE. Specifically, Dataquest expects MCAE to form the backbone of manufacturing corporate data bases by developing the primary CAD/CAM tool to create and update engineering information. Within this framework, a great variety of vendor offerings will be derived from the combination of target markets as

defined by industry and user, with hardware and software products in several price/ performance packages. A prevailing hypothesis in the industry expects every engineer, designer, and technician to have an engineering workstation installed on his or her desk. Vendors are trying to develop the right combination of tools to gain maximum acceptance on the desktop.

Integration—Now or Later?

If a group of users is asked to list the top five areas of concern, the first or second issue listed is usually integration. A reasonable second question is: "What do you mean by integration?" If there are 50 people in the group, you will most likely get 50 different answers. A typical response will include phrases like common data base, uniform user interface, and upgradability. A pragmatic respondent would ask, "Can I get my job done?" The next question would be: "What is the effort required?" This ease-of-use and functionality resolution determines the suitability of all MCAE tools to be used by the target market. Integration can and should be evaluated at the user, group, and corporate levels. For each member of a well-integrated system, the questions are the same: "Can I do the job, and is it worth the effort?"

MCAE has focused on the design and analysis task, bringing a closely integrated tool to a wide variety of potential users. The type of user in each target market is driving MCAE development as much as any other single factor. The esoteric specialty MCAE tools developed for Ph.D.s in crucial tasks differ significantly from the part-time design aid for the designer or technician.

Looking beyond MCAE, integration of MCAE tools must be closely allied with the other major CAD/CAM functions of documentation and manufacturing. The full benefit of CAD/CAM will not be realized until a fully integrated solution can be implemented with complete access by all involved. The implication here predicts CAD/CAM access to become as common as talking on the telephone. In this context, MCAE will meet the total design and analysis requirements of the user, group, and corporation.

TECHNOLOGIES

Virtually all technologies important to the CAD/CAM industry are having an impact on MCAE. Hardware improvements are raising performance and lowering price on the full range of processor types. Display technology is resulting in fixed-configuration price reductions in the range of 30 percent per year. High-performance display of realistic images is finding widespread application with increasing simulation activity. Software enhancements are opening up new applications with easier-to-use interfaces. Overall, the systems resulting from the rapid advances in each of the above enabling technologies can potentially change the way the world designs its products.

Modeling

The first step in any design and analysis task requires the construction of some kind of computer graphics model. There are three basic forms using 2-D, 3-D wireframe/surfacing, and solid modeling construction techniques. Each has inherent advantages in ease of use and speed. Since the vast majority of the world's products have been designed on pieces of paper, it is easy to believe that today's high-performance 2-D drawing systems can be effective design tools. The 3-D design systems developed since the mid-1970s have proven the concept and value of design in a simulated 3-D space. Solid modeling is emerging as the modeling technique of choice if 3-D modeling is required. As the dropping price/performance curve brings high-performance systems within the price range of the average buyer, there will be more systems based on solid modeling. Every major CAD/CAM and MCAE vendor has solid-modeling-based products in a current product offering.

Any limitation in modeling will directly limit the range or class of products that can be effectively designed or analyzed with that tool. Many 2-D systems have reached functional equivalence with manual drafting methods, meeting all engineering drawing standards. The remaining limitations are inherent to the 2-D representation, which is primarily one of interpretation. Considering 3-D modeling, it is interesting to observe that not a single vendor has made the claim of having a solid modeler that can precisely model *all* parts and assemblies commonly found in industry.

Analysis

The status of design evaluation may be illustrated by considering that the largest drawing has been made in a graphics system, but the largest design or analysis problem is still far from realization. This premise indicates a strong appetite for systems able to handle much larger problems with faster response times. As these sytems become available, they will handle more detail in the analysis, potentially improving the quality of the design and reducing the skill level required of the operator to set up the problem due to an enhanced user interface. In general, the analysis function is becoming easier to use with an application interface that more closely speaks the language of the end-user application. Presenting a menu of material choices rather than just prompting for a material density value illustrates the trend in improving ease of use. Automatically preparing a design model for stress analysis using material and boundary condition information derived from the model is a more beneficial illustration.

The MCAE evolution can be viewed from several vantage points. The novice or casual-user approach is being addressed by the blending of engineering sketching, engineering handbook reference, and product design procedures into an easy-to-use package. The result is aimed at the engineer or designer with unpretentious design and analysis requirements who has a small amount of time to learn or relearn the use of the system. It is essential to have direct access to a drafting function in this environment.

The midrange user is typically concerned with complete product design from concept to component detail. A common requirement is verification of the fit and function of the assembly that includes mass property and kinematic studies. This mainstream application segment has been addressed by the 3-D wireframe CAD/CAM systems with reasonable success.

At the high end, the experts are willing to put up with just about any convoluted interface or procedure as long as it gets the job done. Casual or part-time users with less-than optimal experience and training can easily get bogged down trying to solve some of the more complex problems with little probability of reaching a correct result. Finite-element modeling and analysis (FEM/FEA) programs are prime examples of this analytical approach. Fortunately, all of the major FEM/FEA vendors are hard at work improving the user interface, adding error detection, and enhancing analytical applications to reduce the operational overhead.

New Development Areas

Nearly every advancement in computing hardware can be utilized in MCAE. From application-specific integrated circuits (ASICs) to plug-in boards to super computers, almost every hardware technology and packaging scheme is being used to improve performance and lower price.

Processors

Engineering workstations are evolving quickly from a marginal computing resource to a greater than 5-mips processor with very attractive pricing. The supercomputer is evolving, increasing the practical limits of problem solving for aerodynamic, fluid flow, and weather simulations. Processors used as network servers are improving the performance levels of groups of workstations requiring nominal investments.

Display

The expectation of real-time simulation with realistic rendering is driving display technology. An interesting observation finds that the pressure to develop an ultrafast display operation is difficult to justify from the standpoint of just a quicker picture maker. It must be integrated as part of the total system. Dataquest believes that a strong opportunity exists for an MCAE product optimized for a highly interactive environment. Once users have access to a fully operational system with a user interface optimized for fast interaction, they will never go back to the old way of doing business.

Optimization

The closer integration of design and analysis techniques is opening the door for optimization processing. This implies a computer-controlled modification of the design model based on a set of rules and results of each iteration of the analysis. Full implementation of this process is years away, but the potential benefit is enormous, affecting every aspect of product design.

New Algorithms

More efficient algorithms that should speed up processing are now in development. The "P-version" of the finite-element method is an example that constructs the model for analysis out of larger elements that more closely follow the shape of the model. This can result in more accurate and faster analysis. Although this approach lends itself toward further automation in model generation and significant analysis performance improvement, further development is needed for more than the 3-D elastostatic analysis.

Explicit methods using cell iteration techniques are promising alternatives to the current popular implicit methods. The computational requirements are more rigorous, but potential reduction in solution time on complex problems can be significant.

New Applications

Design constraints for higher strength and lower weight are forcing new design and analysis efforts in applications that have not historically required robust evaluation. The development of new engineering materials in the form of plastics, composite materials, metal alloys, and ceramics is compounding the complexity by combining new product design with new engineering materials. Precise modeling and analysis of these materials with simulation of the design in the as-used environment are leading the way to new development areas for MCAE.

Artificial intelligence, rule-based programming, and data base enhancements are being used to enhance MCAE development. The resulting systems promise to be more valuable with efficient user interfaces.

END USERS

MCAE System Utilization by the Industry

The users of MCAE are found in all manufacturing industries. Every industry has CAD/CAM installations involved with design and analysis of the manufactured products. A recent Dataquest survey determined the percentage of system utilization for the four primary application areas in mechanical CAD/CAM. The applications measured were design, analysis, drafting, and manufacturing. Combining the design and analysis percentages on an industry-by-industry basis provides the data shown in Table 2-2.

Table 2-2

System Utilization for MCAE/Design and Analysis

Industries	Number of Sites	Percent with Mechanical Applications	MCAE Utilization	Design Percent	Analysis Percent
Computer	38	68%	46%	39%	7%
Automotive	40	78%	45%	38%	7%
Communications	16	63%	43%	34%	9%
Aerospace	68	68%	41%	31%	10%
Other	94	71%	39%	29%	10%
Mechanical Machinery	54	91%	38%	32%	6%
Electrical Machinery	106	76%	35%	30%	5%
Transportation	18	83%	32%	22%	10%
Fab Metal	56	78%	28%	23%	5%

Source: Dataquest
July 1988

user interface to drive the display must by definition be easy to use in order to provide flexible control of the orientation and scale of the display in a truly interactive environment. As system performance continues to improve, dynamic manipulation ofgeometry will require new interface techniques. Dynamic stretching and scaling of geometry could become the most frequently used commands in this new system. Another jump in computational performance will be required to allow real-time analysis. Imagine the user turning a dial that increases the pressure of a hydraulic cylinder in a mechanism! Dataquest expects many coffee wagers to be made between engineers and designers predicting the possible result of type of failure. "Will something bend or will the cylinder explode?" "If we increase a wall thickness by 1/16 inch, then what?" When this level of interactivity has been reached in the design and analysis process, the corresponding MCAE tool will be indispensable to all manufacturing industries.

Networking

Networking must provide communications between systems and accommodate computational and data base servers. The transfer of engineering data is essential both inside and outside a company. Transfer of IGES files are common now in the automotive industry between the major manufacturers and first-line suppliers. Networking is an integral necessity in completing the communications path of design and manufacturing automation.

Data Base Management

Data base management with associativity between part geometry and nongraphic engineering data is necessary to maintain reliable design control and management.

Complete Part Modeling Functions

The I-can-model-anything modeler is not required to set up FEM/FEA analysis problems. Simplifications are made to speed up the process, hopefully, not distorting the results of the analysis. Advancements in computational resources and automated analysis techniques will make the approximations that are common today, obsolete in the long term, as fully detailed parts and assemblies are optimized under program control.

Data Base Evolution toward Corporate Definition

In order for the MCAE process to feed the downstream detail design and manufacturing operations, there must be provided a complete geometric modeling function. This does not imply that the conceptual designer will build the final detail model, but it does imply that the functionality must be in the system for everyone to work to the level of detail required for his or her job. The result would then be passed along to the next person in the product design and manufacturing process. A common data base will allow the ready application of analysis tools to new design as well as

production enhancements with a minimum of overhead. This unified approach is necessary to form the core of a corporate resource creating the development and production data base.

FEM/FEA

The extensive use of finite-element modeling and analysis will assure the continued use of this technology. The confidence of working with a time-proven analysis code is strong incentive to continue business as usual. Evolution will occur primarily in the user interface and new application areas. New analysis codes are expected to make inroads slowly, requiring substantial verification. Acceptance will be accelerated if significant improvements are made in reducing time for problem setup, if accuracy is improved, and if there are significant cost savings. New users will be more open to new analytical techniques, but reliable correlation to physical test must be proven.

Kinematics

Kinematic analysis is essential for development of mechanisms in product design. Eventually the assembly process is all that would be required to constrain the motion of the mechanism with full 3-D simulation of part assembly with slop in the joints and just-touching contact. Full analysis with post processing of results is required. Analysis of the dynamic properties of the mechanism is required in many applications.

MARKET FORECASTS

This section presents detailed analysis of the 1987 MCAE market, with a forecast through 1992. It is analyzed by product type and region, indicating the hardware and software content of each classification. The hardware and software analysis allows an apples-to-apples comparison in looking at market share ranking of third-party software vendors and turnkey system suppliers. Market share analysis for 1987 is included for the leading MCAE suppliers.

Overview

The MCAE workstation unit CAGR of 29 percent is significantly higher than the expected 16 percent CAGR of the total mechanical market through 1992. The 1987 to 1988 revenue growth in software for MCAE is expected to be more than 25 percent. More than 35 percent of the mechanical workstations sold were used primarily as MCAE workstations. This application is expected to experience significant growth throughout 1992, when more than 80 percent of the MCAD workstations will have MCAE functionality.

Table 2-2 is based on the 1985 Dataquest end-user survey. Number of sites indicate total number of sites responding to the survey, sorted by industry. Percentages represent the percentage of sites with mechanical applications and the percentage of system operations utilized for MCAE applications. The MCAE percentage is comprised of the sum of the design percentage and the analysis percentage.

Manufacturers in the computer, automotive, communication, and aerospace industries are the largest users of MCAE, based on the percentage of system use. The mechanical machinery industry is also large as a result of extensive use of mechanical CAD/CAM applications.

PENETRATION

The level of penetration in mechanical CAD/CAM is defined to be the ratio of installed workstations to the population of potential users. In the long term, Dataquest expects this ratio to approach 100 percent as workstation access becomes common. Since MCAE is viewed by Dataquest as a keystone in mechanical CAD/CAM development, the trend toward full implementation of MCAE is expected to continue with high probability.

The current penetration levels for MCAE can be estimated by using data gathered in the Dataquest 1987 Mechanical CAD/CAM System Manager Survey. (See Research Newsletter Number 1987-25 for a complete discussion of this survey.) We asked a series of questions to determine the total number of man-hours of work suitable for automation using CAE/CAD/CAM technology. This was defined by work type and then compared with the actual level of work being performed using CAE/CAD/CAM systems. Highlights of the survey include the following:

- Of the total work suitable to CAE/CAD/CAM tools, 27 percent was defined as design related, with one-third of that mechanical design activity related to products with a significant electrical or electronics content. The penetration measured in man-hours was 31 percent.
- An additional 11 percent of the total was defined as analysis; the penetration measured in man-hours was 11 percent.
- The composite penetration rate for all design and analysis work was 25 percent.
- A comparison with an earlier Dataquest survey is revealing. The 1985 System Manager Survey indicated that an average of 2.9 users had been trained for every workstation installed. In 1987, this number had dropped to 1.7.

- A similar comparison made for workstation hours of use per day indicates a significant drop. The average in 1985 was 12 hours per day. While in 1987, there was a reported 7 hours per day.
- All of the above is relevant to the sites surveyed, which were selected as current users of CAE/CAD/CAM technology. Sites that had not implemented any CAE/CAD/CAM systems were not surveyed.

USER ISSUES

Performance Requirements for Display and Computation

The appetite for computer horsepower and display performance for design and analysis activities is insatiable. A reasonable means of visualizing this situation is to suggest that the largest drawing has been constructed in a CAD/CAM system. The largest design or analysis problem is still orders of magnitude away from realization. Display and manipulation operations must support the growing problem complexity and provide subsecond response time to reach the next plateau of user productivity.

Cost per Seat

The cost of system purchase and/or lease, including operation costs, must be low enough to allow widespread implementation on a corporate level. The magic number for wholesale installation is expected to be in the $10,000 to $20,000 range. PC-based products in that range have experienced phenomenal growth.

An average price per seat of $49,400 for a turnkey workstation in 1987 is expected to drop to $35,300 in 1992. The average price per seat of MCAE workstations is expected to follow a similar price reduction.

Ease of Use

Ease of use is something that every vendor claims but few demonstrate with any unique capability. The full-time user needs an improved interface to drive the higher-performance systems being developed. At the low end, the standard fare of menus, icons, mice, and prompting will have to suffice. Since the lower-cost systems are generally used by the casual users, it is very important to provide an easy-to-learn and relearn interface. Users are suggested that on-line tutorial and help functions are beneficial.

At the high end, an opportunity exists for a balanced combination of hardware and software to provide a real-time user interface during design and analysis simulation. A subtle implication is made here relative to the ease of use issue. Improvements in display performance are bringing real-time motion to the designer. The corresponding

Market Forecast by Product Type

The forecast shown in Table 2-3 represents worldwide hardware and software revenue by product type. Table 2-4 indicates the percentage distribution of the same data. The 1987 market estimate, product distribution, and forecast to 1992 are based on reported 1987 company revenue and survey data. Revenue for both bundled and unbundled software products has been considered in the forecast. The units specified are estimated to be the corresponding systems and workstations required to support the expected software revenue. A growing percent of software revenue can be expected from unbundled software sold and used on existing hardware. The following should be noted about the market forecast by product type:

- More than 55 percent of the MCAE workstations sold in 1987 were configured with host-based computers. This number is expected to drop to less than 17 percent in 1992.
- Technical workstations are the fastest growing product type, expected to grow from a 27 percent share in 1987 to more than 70 percent in 1992.
- Software revenue for technical workstations is expected to increase by more than a factor of 7 from 1987 through 1992.
- Personal computers are expected to provide an important hardware platform for MCAE, representing a peak of 17.3 percent share in 1987. The level of PC-based MCAE products is expected to fall off after 1987 as the standalone product becomes dominant.
- More than 6 out of 10 *software* dollars were spent on host-based products in 1987. This expenditure is expected to drop dramatically to a 15 percent level in 1992.
- Hardware revenue for host-based products follows the same pattern, dropping from 80 percent in 1987 to less than 38 percent in 1992.

Table 2-3

Worldwide MCAE Market Forecast by Product Type
Hardware and Software Only
(Millions of Dollars, Actual Units)

	1987	1988	1989	1990	1991	1992	CAGR
Worldwide							
Total Revenue	1,973	2,456	2,914	3,295	3,309	3,184	10.0%
Software	391	548	745	965	1,099	1,195	25.0%
Hardware	1,583	1,908	2,170	2,331	2,210	1,989	4.7%
Systems	20,057	34,686	55,786	79,012	96,928	112,722	41.2%
Workstations	34,938	55,354	75,971	98,439	114,518	126,319	29.3%
Technical Workstation							
Total Revenue	391	731	1,181	1,624	1,924	2,089	39.8%
Software	123	240	414	622	791	927	49.8%
Hardware	267	491	768	1,002	1,133	1,162	34.1%
Workstations	9,634	19,987	36,325	56,088	73,550	88,631	55.9%
Host-Dependent							
Total Revenue	1,506	1,602	1,565	1,483	1,207	924	-9.3%
Software	242	263	266	263	225	184	-5.4%
Hardware	1,265	1,339	1,299	1,219	982	741	-10.1%
Systems	4,395	6,889	7,764	8,446	7,995	7,157	10.2%
Workstations	19,276	27,558	27,949	27,873	25,585	20,754	1.5%
Personal Computer							
Total Revenue	76	123	168	189	178	171	17.4%
Software	26	45	65	80	83	84	26.4%
Hardware	50	78	103	109	95	87	11.5%
Workstations	6,028	7,809	11,697	14,478	15,382	16,934	22.9%

Source: Dataquest
July 1988

Table 2-4

Worldwide MCAE Market Forecast by Product Type
Hardware and Software Only
(Percentage of Total)

	1987	1988	1989	1990	1991	1992
Technical Workstation						
Total Revenue	19.8%	29.8%	40.5%	49.3%	58.1%	65.6%
Software	31.5%	43.8%	55.5%	64.4%	72.0%	77.6%
Hardware	16.9%	25.7%	35.4%	43.0%	51.3%	58.4%
Workstations	27.6%	36.1%	47.8%	57.0%	64.2%	70.2%
Host-Dependent						
Total Revenue	76.3%	65.2%	53.7%	45.0%	36.5%	29.0%
Software	61.8%	48.0%	35.7%	27.3%	20.5%	15.4%
Hardware	79.9%	70.2%	59.9%	52.3%	44.4%	37.2%
Systems	21.9%	19.9%	13.9%	10.7%	8.2%	6.3%
Workstations	55.2%	49.8%	36.8%	28.3%	22.3%	16.4%
Personal Computer						
Total Revenue	3.9%	5.0%	5.8%	5.7%	5.4%	5.4%
Software	6.7%	8.3%	8.7%	8.3%	7.5%	7.1%
Hardware	3.2%	4.1%	4.8%	4.7%	4.3%	4.4%
Workstations	17.3%	14.1%	15.4%	14.7%	13.4%	13.4%

Source: Dataquest
July 1988

Market Forecast by Region

The forecast shown in Table 2-5 represents worldwide hardware and software revenue by region. Table 2-6 indicates the percent distribution of the same data. The 1987 market estimate, product distribution, and forecast to 1992 are based on reported 1987 company revenue and survey data. Revenue for both bundled and unbundled software products has been considered in the forecast. The units specified are estimated to be the corresponding systems and workstations required to support the expected software revenue. The following should be noted about the market forecast by region:

- The majority of MCAE product was sold in North America in 1987, representing more than 49 percent of the product revenue, corresponding to a 44 percent revenue share for the total mechanical market.
  - The MCAE market revenue is expected to drop slightly to 41 percent in 1992.
  - Roughly half of the MCAE workstations sold in 1987 were sold in North America.
- The European region is growing slightly as a percentage of revenue and workstation units installed. Revenue and unit share of the world market are expected to stay in the 31 percent range.
- The Far East was responsible for approximately 19 percent of product revenue in 1987, corresponding to a lower unit percentage of roughly 15 percent. The more prevalent high-cost product causes the lower unit percentage.
- The remaining worldwide market has a small 1.5 percent of revenue and 3.5 percent of unit shipments. This market is keeping up with the growth of MCAE in general, maintaining modest growth to 4.5 percent revenue in 1992.

Table 2-5

Worldwide MCAE Market Forecast by Region
Hardware and Software Only
(Millions of Dollars, Actual Units)

	1987	1988	1989	1990	1991	1992	CAGR
Worldwide							
Total Revenue	1,973	2,456	2,914	3,295	3,309	3,184	10.0%
Software	391	548	745	965	1,099	1,195	25.0%
Hardware	1,583	1,908	2,170	2,331	2,210	1,989	4.7%
Systems	20,057	34,686	55,786	79,012	96,928	112,722	41.2%
Workstations	34,938	55,354	75,971	98,439	114,518	126,319	29.3%
North America							
Total Revenue	966	1,128	1,277	1,401	1,384	1,321	6.5%
Software	191	252	326	410	460	496	21.0%
Hardware	774	876	951	991	924	825	1.3%
Systems	9,846	15,930	24,448	33,601	40,541	46,752	36.6%
Workstations	18,126	27,057	35,539	44,770	51,281	56,123	25.4%
Europe							
Total Revenue	605	767	919	1,043	1,050	1,014	10.9%
Software	120	171	235	305	349	381	26.0%
Hardware	485	596	684	737	702	633	5.5%
Systems	6,065	10,836	17,594	24,999	30,764	35,890	42.7%
Workstations	10,343	16,719	23,174	30,126	35,161	38,911	30.3%
Far East							
Total Revenue	373	514	653	772	792	768	15.5%
Software	74	115	167	226	263	288	31.3%
Hardware	299	399	487	546	529	480	9.9%
Systems	3,547	7,257	12,508	18,507	23,187	27,191	50.3%
Workstations	5,255	9,434	14,087	19,237	22,952	25,570	37.2%
Rest of World							
Total Revenue	30	47	64	79	83	82	22.3%
Software	6	10	16	23	28	31	39.0%
Hardware	24	36	48	56	56	51	16.3%
Systems	599	663	1,234	1,906	2,435	2,888	37.0%
Workstations	1,214	2,144	3,171	4,306	5,124	5,715	36.3%

Source: Dataquest
July 1988

Table 2-6

Worldwide MCAE Market Forecast by Region
Hardware and Software Only
(Percentage of Total)

	1987	1988	1989	1990	1991	1992
North America						
Total Revenue	48.9%	45.9%	43.8%	42.5%	41.8%	41.5%
Software	48.9%	45.9%	43.8%	42.5%	41.8%	41.5%
Hardware	48.9%	45.9%	43.8%	42.5%	41.8%	41.5%
Systems	49.1%	45.9%	43.8%	42.5%	41.8%	41.5%
Workstations	51.9%	48.9%	46.8%	45.5%	44.8%	44.4%
Europe						
Total Revenue	30.6%	31.2%	31.5%	31.6%	31.7%	31.8%
Software	30.6%	31.2%	31.5%	31.6%	31.7%	31.8%
Hardware	30.6%	31.2%	31.5%	31.6%	31.7%	31.8%
Systems	30.2%	31.2%	31.5%	31.6%	31.7%	31.8%
Workstations	29.6%	30.2%	30.5%	30.6%	30.7%	30.8%
Far East						
Total Revenue	18.9%	20.9%	22.4%	23.4%	23.9%	24.1%
Software	18.9%	20.9%	22.4%	23.4%	23.9%	24.1%
Hardware	18.9%	20.9%	22.4%	23.4%	23.9%	24.1%
Systems	17.7%	20.9%	22.4%	23.4%	23.9%	24.1%
Workstations	15.0%	17.0%	18.5%	19.5%	20.0%	20.2%
Rest of World						
Total Revenue	1.5%	1.9%	2.2%	2.4%	2.5%	2.6%
Software	1.5%	1.9%	2.2%	2.4%	2.5%	2.6%
Hardware	1.5%	1.9%	2.2%	2.4%	2.5%	2.6%
Systems	3.0%	1.9%	2.2%	2.4%	2.5%	2.6%
Workstations	3.5%	3.9%	4.2%	4.4%	4.5%	4.5%

Source: Dataquest
July 1988

MARKET SHARE ANALYSIS

The estimated mechanical computer-aided engineering market analysis for 1987 is shown in Table 2-7 and Figure 2-2. Software-only revenue is used to indicate market share for both 1986 and 1987. Only company revenue from direct end-user sales is represented, except as noted.

Table 2-7

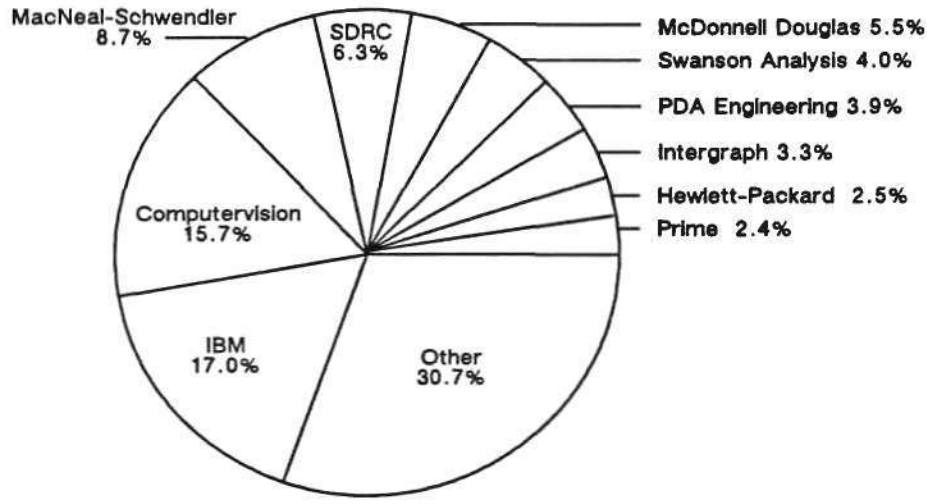
Estimated 1986 and 1987 MCAE Market Share
(Millions of Dollars)

	1986 Software Revenue	1986 Market Share	1987 Software Revenue	1987 Market Share	AGR	1987 Rank
Computervision	34.3	11.5%	61.2	15.7%	78.5%	2
Control Data	8.4	2.8%	7.7	2.0%	-8.3%	
Hewlett-Packard	5.5	1.8%	9.8	2.5%	78.2%	9
IBM	52.8	17.7%	66.3	17.0%	25.5%	1
Intergraph	11.1	3.7%	12.9	3.3%	16.5%	8
McDonnell Douglas	16.0	5.3%	21.7	5.5%	35.3%	5
MacNeal-Schwendler	26.2	8.8%	34.1	8.7%	30.2%	3
PDA Engineering	13.3	4.4%	15.2	3.9%	14.3%	7
Prime	7.2	2.4%	9.4	2.4%	30.4%	10
Schlumberger	10.6	3.5%	9.0	2.3%	-14.7%	
SDRC *	22.8	7.6%	24.5	6.3%	7.5%	4
Swanson Analysis	12.1	4.0%	15.5	4.0%	28.1%	6
Other	78.8	26.3%	103.7	26.5%	31.5%	
Total	299.1	100.0%	391.0	100.0%	30.7%	
* SDRC Combined End-User and OEM Revenue	27.5	9.0%	35.8	9.0%	30.2%	3

Source: Dataquest
July 1988

Figure 2-2

Estimated 1987 MCAE Market Share



Source: Dataquest July 1988

DATAQUEST ANALYSIS

Market

MCAE is a key element in the evolution of CAD/CAM. MCAE is growing, upgrading the complete design and analysis process including conceptual design and detailed product design. Users at all levels will benefit by having access to efficient tools for the dedicated or casual user.

In the short term, the benefits of MCAE are derived from the close integration of design and analysis applications. Full integration of MCAE into the mainstream of corporate decision making is a long-term issue essential in gaining the full benefit of design automation technology.

Product

The total range of process and display advancements, from personal computers to supercomputers, are being utilized. Aall types of display hardware are being used, from monocolor low-resolution to high-resolution, full color, real-time dynamic display. Dataquest strongly believes that the basic requirement to solve more complex mechanical design and analysis problems will continue to drive product offerings toward higher-performance packages.

Solid modeling is emerging as the primary modeling tool in MCAE, with 2-D and 3-D wireframe supporting the effort. Finite-element modeling and analysis is expected to remain an important technology in MCAE throughout the foreseeable future. New algorithms development may accelerate user acceptance of MCAE technology by improving cost/performance ratio and usability. Analytical tools are being applied to a growing list of applications, increasing the value and utility for a larger audience.

Vendor

The 57 percent MCAE market growth estimate in workstation units in 1988 is significantly greater than the expected 27 percent growth of the mechanical market in general. All major CAD/CAM vendors are contributing with current product offerings. The 1986 and 1987 market share analysis shows the turnkey vendors nearly splitting the market with software-only vendors. The top ten mechanical CAD/CAM vendors must offer highly functional MCAE products to remain in the club of market leaders.

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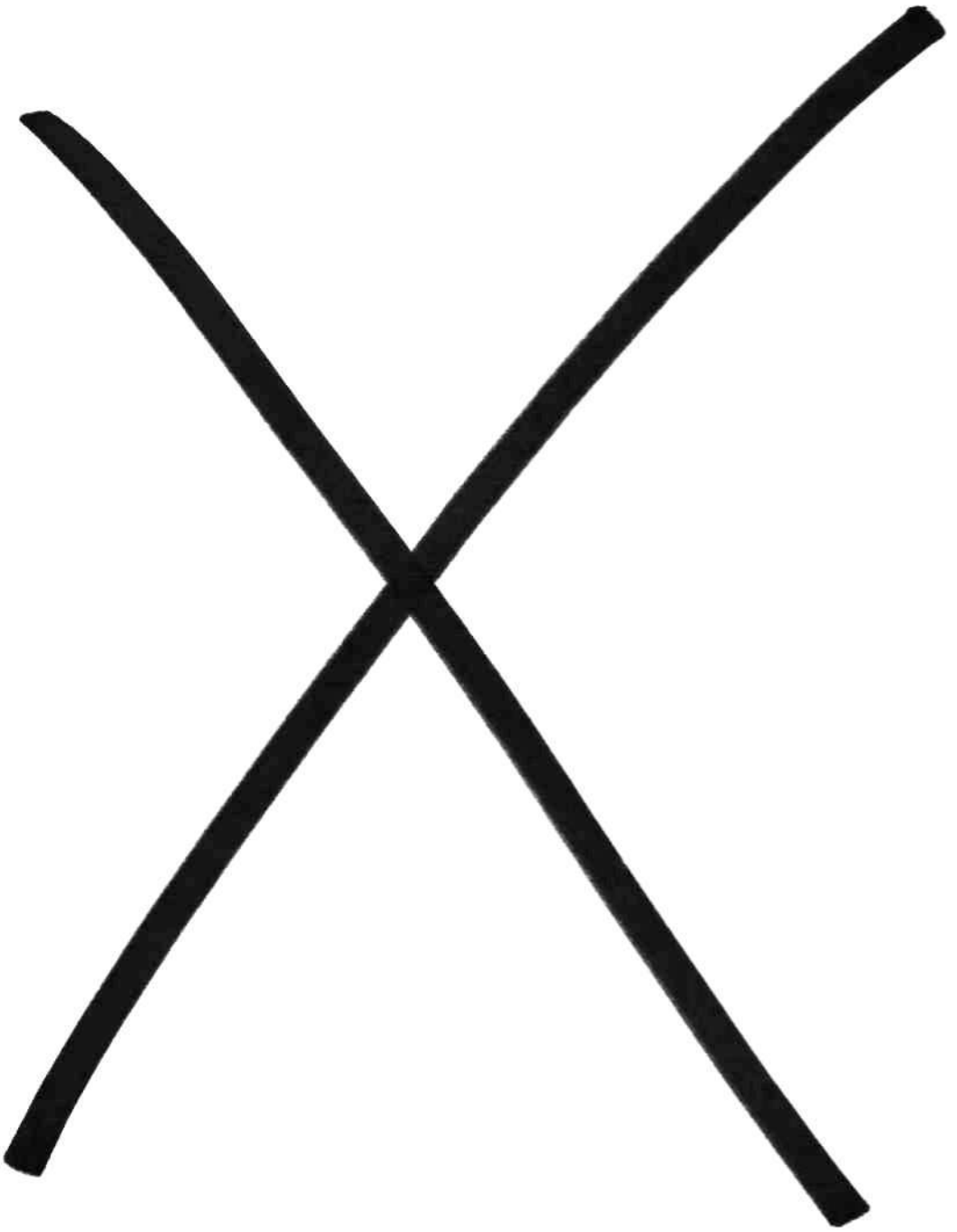


3 Numerical Control

INTRODUCTION

Numerical control (NC) is the language of automation. It is a written language that humans use to communicate with automated machines. The machines that most commonly use numerical control are metal-cutting machines, but the full range includes metal forming, material handling, and inspection devices. A closer look at the NC process highlights its major difficulty: There is no common language understood by each component of the process. From a human perspective, the languages are cryptic and difficult to verify for accuracy. However, recent advances in computing technology are improving the productivity, control, and accuracy in the generation of NC programming information. Using the latest computing technology provides a much smoother flow of accurate, up-to-date engineering data from product engineering to manufacturing to the shop floor.

This service section explores the current status of NC technology, relates the evolution to user industry needs, and defines the market in terms of the CAD/CAM industry.

DEFINITION

Numerical control is a general label given to a process that provides automated alternatives to manually operated machine tools. Virtually every type of machine tool has been automated with NC. Lathes, mills, flame cutters, and drills are a few common examples. The automation methods vary from basic computer controls that remember several machining steps to computer systems that simulate complex machining processes, optimizing the results, which are then downloaded to shop floors and machine tools.

The NC Operation

An NC operation can be generalized, as shown in the illustration at the beginning of this section. Every machining or manufacturing process starts with a plan.

Plan

A plan can be as simple as a sketch of a finished part with notes for tool path location and direction. A more complex plan can contain a detailed set of documents, including a detailed part drawing, a process plan laying out the sequence of machining operations, and operation sheets describing the specifics of each step. Many supporting tasks must be considered to get a job done. Fixtures need to be designed and built to hold a part or parts during machining. Special tools may be required to speed up a process or to produce a desired shape.

Input

An NC part programmer must input some form of numerical data to define the path a tool must follow during the machining process. The methods of programming NC machine tools vary, depending primarily on the complexity of the machining process and the difficulty of defining the correct path for the tool or cutter. The simplest operation requires little more than a digital readout on a machine tool showing the cutter location. For more ambitious operations, an off-line simulation is required. A detail drawing is used to define the shape of the part and edge boundaries. The NC programmer then codes a cutter path that will guide the cutter to remove material from the unfinished part so that the desired size and surface finish results. A CAD/CAM system can be used to generate a three-dimensional model of a part and a cutting tool. A simulation of the machining operation is used to walk through a procedure, defining the numerical data required by different machining operations.

Processing

Processing the input data involves one or more steps to generate numerical data that are fed into a machine control unit (MCU). Processing takes the man-readable information and converts it into a series of commands that operate a machine tool. Step by step, each hole is drilled, and each surface is milled and profile turned in the process.

Machining

It is important to realize that NC is not a machining method. It is a concept of machine control. Typical machining methods are drilling, milling, boring, tapping, and so on. NC has not changed or altered the basic concept of chip cutting by a twist drill or a milling cutter. It will, however, affect the ability of the cutter to be driven efficiently and to be used much more closely to its theoretical maximum capacity. Machine utilization of 20 percent is typical and quite respectable for moderately complex manual operation. Utilization to 70 percent and beyond is typical for a well-programmed NC operation. This is accomplished by reducing or eliminating the wasted, redundant, nonproductive motions and waiting times characteristic of manual operation.

NC has also been able to generate complex machine motions to a high degree of precision. This is particularly true with airfoil contours and complex forming die or mold surfaces. NC can control the machining of any surface that can be mathematically defined.

HISTORICAL PERSPECTIVE

The root of NC can be traced back to 1947, in Traverse City, Michigan, where the Parsons Corporation developed a technique of using punched-card tabulating equipment to check airfoil curve profiles for helicopter blades. Using this more precise numerical data, standard accuracy for templates improved from plus or minus 0.007 inch to plus or minus 0.0015 inch.

In April 1948, John Parsons saw plans for an integrally stiffened aircraft wing section. The demanding requirement to machine three-axis airfoil curves provided the impetus to combine numerical calculation of tool location with controls to manipulate the actual machining. The marriage of servomechanism controls for the machine tool with machine-readable numerical data for control resulted in the first working NC machine. The idea received mixed reactions when it was presented to the manufacturing technology group of Wright Patterson Air Force Base. It was almost a year later that it placed a contract with Parsons to build the first NC machine. Snyder Corporation was awarded a subcontract to design and build the basic machine tool. In October 1949, the Massachusetts Institute of Technology Servomechanisms Laboratory was given a subcontract to design servomechanisms for the machine tool.

In 1952, the first NC machine, a vertical spindle Cincinnati Hydrotel, executed simultaneous three-axis cutting movements. More development followed with the November 1954 formal announcement of the birth of NC.

The first and still the most common NC language in aerospace and industrial manufacturing is the Automated Programming Tool (APT) processor. Development of the basic APT language/processor began during the first project. Following this was a massive influx of capital from the U.S. government, which fueled NC machine tool development at the Massachusetts Institute of Technology, along with the sponsorship of the Aerospace Industries Association (AIA), until APT III was released in 1961.

This process has evolved with greater dependence on higher-level languages that allow the programmer to work in more easily understood terms. This has been a two-step process in which the program is written in a high-level language, then post-processed into usable form for each controller/machine combination. A variety of mostly incompatible languages has been developed, including APT, Compact, Split, and Autoplot. APT has evolved as the leading choice for all programming tasks, particularly when precise multiaxis control is required on complex surfaces. Many of the other languages were developed to make programming easier for less complex machining operations.

In the last few years, pressure to make NC tools easier to use has caused development in several areas. Efforts in one area have resulted in the addition of more intelligence in the machine tool controller. Computer numerical control (CNC) has improved machine tool functionality by giving the operator more control at the machine tool for direct local programming, for the use of canned procedures such as drilling a bolt-hole pattern, or for reading in program information from tape or directly from a direct numerical control (DNC) network. Some machines allow an operator to monitor a current machining operation while editing another stored program. Several CNC controllers can now read a binary cutter location (BCL) input format that has been adopted as an Electronic Industries Association (EIA) standard for this purpose.

Significant development work has been directed toward interactive systems that enhance the writing of high-level part programming code. These systems have evolved with a user interface that is oriented toward NC language- or graphics-based programming. Both types of interactive systems have been implemented on the full range of computing resources. The recent availability of personal computers has caused a wave of low-cost, easy-to-use NC programming stations well suited to a variety of programming tasks. Higher-performance interactive workstations using APT-based languages are increasing the programmer productivity and allowing optimized tool path generation. This results in higher-quality machined parts produced with less machining time.

NC PROGRAMMING METHODS

A current evaluation of the NC process finds that the most common NC programming methods fall into one of four major categories. A general overview of these methods is shown in Table 3-1.

Table 3-1

Major NC Programming Methods

Programming Method	Input	Processing
Manual	Operation Codes	Little if any processing is required. Programmer writes tool control commands in a format that is understood by the particular machine tool and controller combination.
CNC Local	Canned Routines	The machine operator programs the machine by selecting predefined operations or procedures.
Language-Based	Tool Movements	The program must be compiled or post-processed to develop machine-readable commands that actually control the machine.
Graphics-Based	Part Geometry/ Tool Movements	The interactive process builds the part model, which is then referenced as the tool path is simulated. The resulting graphical representation of the tool path is processed to generate a language description of the operation with additional post-processing for the specific controller/machine tool.

Source: Dataquest July 1988

Manual Programming

Manual programming is suitable for less complex programming tasks, typically two-axis positioning or profiling operations. An estimated 25 to 30 percent of all part programming is currently done manually. Programming by manual methods forces the programmer to plan and calculate every movement of the machine tool. In addition, the programmer must keep in mind the basic capabilities of the specific machine tool to be used. Each combination of machine tool and NC controller requires subtle changes in programming technique. Each tool must be called out. Every feed rate, spindle speed, and tool change must be defined as part of the process. This method of NC program preparation is time consuming. Its high probability of error requires careful testing of the program. Furthermore, the test period ties up machine and operator time for multiple test runs until the programmer gets it right.

Computer Numerical Control

CNC is now a common feature of most NC machine tools. The basic features of CNC are required to support the communication between the MCU and any remote programming system. This local computer resource has been used to build in some canned machining procedures for direct use by the machine operator. Using the direct manual input mode, the operator becomes the NC programmer. The programmer works interactively with the controls and the predefined machining operations to control the machining operation. Continued development of local functions is resulting in a variety of programming options. Many two-dimensional point-to-point movements or tool movements around circles or arcs, such as a bolt-hole pattern, are now available. Some systems provide for direct input of traced or digitized information. Since most NC machine tools now have CNC-type controllers, operators have several options. They can control machines manually with computer assist using canned functions for specific operations or load an NC program and put machines on auto pilot. The CNC can plug into a DNC network and allow a machine to be controlled remotely from a master program.

Language-Based NC

Language-based computer assist processors were originally developed to run in a batch environment. Many second- and third-generation language-based processors have extended an original design to include an interactive graphic front end to the language processor while retaining the original batch-processing capability. Many language-based systems now build part geometry to aid in tool path generation. Usually just enough part surface or edge information is defined to allow the programming task. The front-end processor captures the user input and reformats it into individual language statements that are saved as a source program. The program structure and data association are maintained with the same level of intelligence as if they had been coded off-line. Language-based NC is dominated by the industry-proven standards, APT and Compact II.

Graphics-Based NC

Graphics-based NC typically uses a complete part model as a starting point, then interactively defines the tool path simulation. The part model is typically generated as part of the detail design process and is used as is in the NC part programming task. If the part geometry is not available from the product engineering data base, the manufacturing engineer will generate a graphics model of the part features to be machined and specify the tool motion by choosing options from a menu or data tablet. The precise position of the cutter is calculated from the geometry of the part. The user systematically works around the part, simulating the machining operation with various cutters until the part is fully machined. A turning operation is a good example of a machining operation where a high level of automation is possible. The programmer indicates the profile of the rough stock and the desired finished shape. The multiple-pass rough cut and finish cut tool path can be automatically generated. The association common between the graphics part model and tool path enhance the editing process so that a change in the part will automatically cause a change in the tool path. Other semiautomatic routines are available for profile or pocketing operations. These operations specialize in area clearance applications that require only 2-, 2 1/2-, or 3-axis machining.

VENDOR PERSPECTIVE

Three primary vendor groups supply NC programming tools. Table 3-2 is a partial list illustrating several examples of each group. A complete list of all known vendors with NC programming software is included in the table at the end of this section.

Table 3-2

NC Vendor Types

Vendors	Primary Products
Machine Tool Vendors (Partial List) Bridgeport Machines Cincinnati Milacron Kerney & Trecker	Manual programming workstations and CNC products with machine tool hardware
Language-Based NC Vendors (Partial List) ELCAM Leonard N/C Systems MDSI (now Applicon) Numeridex Weber NC Systems, Inc.	Computer systems independent of machine tools used exclusively for NC programming
Graphics-Based Vendors (Partial List) Applicon (now Schlumberger) Auto-Trol Calma Computervision IBM Intergraph McDonnell Douglas	NC capability as an add-on application to a CAD/CAM system

Source: Dataquest July 1988

Machine Tool Vendors

The advantages of using machine tool systems are:

- An extremely close association with machine tool users provides the opportunity to develop effective and possibly unique solutions.
- These vendors have a high level of credibility with their current customers.
- The systems give operators local control for quick response to unavoidable situations such as tool substitution, speed change, or setup change.

The disadvantages of using machine tool systems are:

- The vendors have little knowledge of the CAD/CAM business or benefits, thereby limiting the potential for synergism.
- These computer-aided tools are very rudimentary in comparison with language- or graphics-based products.
- There is no standardization among machine tool vendors for controller programming.
- Each machine tool/controller is unique, with little if any commonality with other machines for user interface or programming technique.

Language-Based Vendors

The advantages of using language-based systems are:

- APT or a subset of APT has been implemented on everything from a PC to a mainframe.
- Post-processors for languages have been debugged over time and are becoming reliable production aids. (Post-processors built into process controllers or developed for new languages will require significant debugging to become usable.)
- Many NC programmers are trained and familiar with APT and Compact II programming languages.

The disadvantages of using language-based systems are:

- The arithmetic element (ARELEM) for APT was, for the most part, developed more than 20 years ago and has been pushed to the limits of its capability. Deficiencies in calculation of surface-to-surface intersection and part/tool gouging detection are typical of this situation. Few if any enhancements are being made to APT at this time.
- They have weak integration with CAD systems to share part geometry and application software.
- Visual feedback mechanisms are weak or nonexistent.

Graphics-Based Vendors

The advantages of using graphics-based systems are:

- The systems allow integration of CAD-generated part model and tool path simulation.
- Surface creation and editing functions are often better than with other types of programming systems.
- The systems can bypass the use of an intermediate language.
- The part model generated as part of the detail design process can be used as the starting point in the NC part programming task.
- The general approach can be applied across a wide range of machine tools and methods.
- A fully integrated CAD/CAM system can offer part-configuration management tracking from production part release throughout the revision cycle.
- The user interface can be custom-tailored to speak the user's language.
- The systems are much easier to use.

The disadvantages of using graphics-based systems are:

- A software vendor typically does not understand machining problems as well as machine tool vendors.
- Software vendors usually treat NC as one application of many, but NC requires significant development resources to keep up with advances in the machine tool industry.
- In most cases, the machining options are in the form of system-defined, canned routines that cannot be modified easily by the end user.
- Insufficient user control often prevents optimal tool motion and/or multiaxis tool orientation for complex machining operations.

TECHNOLOGY OVERVIEW

Development is occurring in every step of the NC process, from the basic computing resource used in programming to advances in tooling used in the actual cutting process. It is important to recognize, however, that NC must fit into large organizations that need more than tool paths and cutting fluid to operate effectively. The following are key technology issues affecting the evolution of NC and its use in industry.

Computer-Dependent Technology

Computer-Integrated Manufacturing

If the language of automation is numerical control, then CAD/CAM is the word processor for the script describing the factory operation. A present-day CAD/CAM status report would indicate proficiency at the bit-part level, but corporate management of manufacturing operations is done outside the CAD/CAM system. In the future, CAD/CAM simulation and programming tasks will be expanded to include virtually every manufacturing process, control, and management function. This overall simulation, management, and control process is often called computer-integrated manufacturing (CIM).

Both analyzing proposed manufacturing operations and controlling existing systems will be common. The primary benefit of simulation will come from the optimization of the process. Evaluating what-if situations before committing to large equipment purchases will result in significant savings when matching equipment to the process. This exciting realization now combines the belief that today's success stories indicate a very high level of confidence that full automation with CIM will occur in the future.

Manufacturing-Automation Protocol

Translators are used at each interface to move NC data from programming station to machine controller to machine tool. The same translate and transport problem exists for virtually all shop floor equipment. Robots, material handling equipment, material storage systems, and NC machine tools all suffer from the lack of standards for physical connection in a network and a common communication language to control the operation. A recent step forward in improving this situation is a proposed manufacturing-automation protocol (MAP). The purpose of MAP protocol is to define a network communications structure for multivendor factory automation systems. Dataquest believes the MAP approach has reached critical mass and is providing the unifying effect required. General Motors has been the chief proponent of MAP and has dictated its use throughout its organization. The time has come for cooperation between vendors of automation equipment. The manufacturing community is demanding the benefits of standards. MAP has allowed machines to be physically connected, but the issue of what language or languages are spoken over the network is still open for discussion.

Knowledge-Based Systems

The combination of the common sense of an experienced manufacturing technician with next-generation computer hardware captures the essence of knowledge-based systems. This task, though easily described, has eluded developers for the last decade. Progress has been made, but the full benefit of knowledge processing and control is a long way in the future. The primary short-term benefit will come not from a fully operational system but from the definition of a structure to capture knowledge. The added insight gained by analysis and what-if scenarios will allow better management and planning.

Modeling and NC Tool Path Generation

Part modeling in CAD/CAM systems has progressed to the point of being able to model virtually any level of complexity in form or shape. Solid-modeling techniques are being used to aid the NC part-programming process by supplying complete part models. A complete model description will allow automatic tool path generation, since the computer knows where every surface resides and how the surfaces are connected. Simulation of the cutter and the part as solid objects can determine material removal rates and collision situations, and can automatically verify the correspondence between the machining process and the design model.

Feature-Based Modeling

One of the latest part-modeling techniques uses the concept of features to speed up the modeling process and quickly capture fine-level graphic detail and related nongraphic data. As an example, the user might select a feature that specifies a drilled, tapped, and countersunk hole. This is as easy as picking a few options from a feature menu. The resulting geometric data will have precise volume and shape definition for every minor surface and edge of the hole, thread, and chamfer. The complete geometry definition can be used in most of the later design analyses and certainly in the NC manufacturing operations. The fine detail can be turned off if desired in some systems to speed up the interactive process. The graphic and nongraphic data can provide hooks to ensure that proper tooling is available or that the cost of a project will not exceed certain limits.

Adaptive Control

Adaptive control implies a measuring operation simultaneous with the machining operation. This feedback allows the machine to accurately control the operation and compensate for variable material conditions or tool wear. Error conditions or near error conditions can be detected. Appropriate action can be taken under program control or the system can signal an operator.

Noncomputer-Dependent Technology

Automation technology does not depend solely on computer-related developments, however. The noncomputer-oriented developments are just as dramatic. In fact, they may provide larger, more easily quantified short-term benefits. The following are a few of the significant trends and major development areas for noncomputer-related technology.

Near Net Shape

The logic of the near net shape approach is as simple as it is effective. What better way to improve the machining operation than to refine the shape of the raw material so the machining process is reduced to minor cleanup or in some cases eliminated

altogether. Preprocessing blank stock to near net shape is more expensive than using standard bar or plate stock, but the lower machining cost can easily make up the difference. This certainly has the potential of reducing the need for NC programming.

Tooling

A drill is a drill is a drill? Not so. The shop environment is rapidly accepting titanium nitride-coated, carbide-tipped cutting edges on drills, boring tools, and milling cutters as superior tooling. Tests have proven that their use provides an incredible sevenfold improvement in productivity. Feed rate, surface finish, and cutting speed are all enhanced. Tool development using hot-pressed silicon nitride is indicating even higher performance levels. Cycle times 20 times shorter than with high-speed steel tools are being measured. The effect of this dramatic performance increase, when combined with NC operation, is profound. More parts can be machined on the same machine tool. More NC programs can be generated for a wider variety of parts without requiring capital spending for more equipment.

Acoustic Emission Monitoring

A present-day metal cutting machine can easily remove 300 cubic inches of steel per minute. Considering that this mass of metal is often peeled off in thin strips or chips, the question of chip control is critical. If the chips break up, they can be easily removed and will not interfere with the machining process. If, however, the cut material forms a long, stringlike mass, a problem is imminent. Sensor technology using acoustic emission listens to the machining process and monitors its status. Excessive tool wear, cracked tools, or other problem situations can all be detected with this technology, leading to reliable, unattended operations.

END USERS

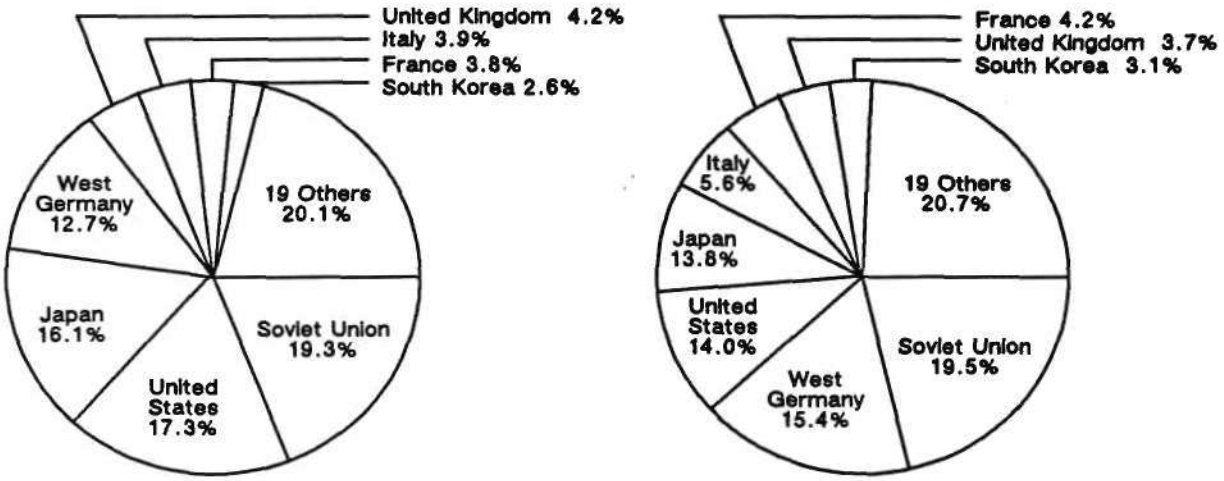
Since their introduction in 1952, numerically controlled machine tools have extended across virtually all national boundaries and into every manufacturing industry. Seen in the global view, NC machine tools represent only about 5 percent of the total population of machine tools. This percentage is growing steadly, since most new machine tools purchased depend on NC technology.

The Worldwide NC Market

The offshore consumption of machine tools is massive. More than 85 percent of the total machine tool consumption was purchased offshore in 1987. More than 40 percent of this revenue is estimated to be NC related. Figure 3-1 illustrates the percentage of machine tool consumption by country. The 1986-to-1987 variation is also shown.

Figure 3-1

Leading Machine Tool Consumers



Source: American Machinist and Automated Manufacturing
Dataquest
July 1988

The U.S. NC Market

It is difficult to define precisely where each NC machine tool is being used and for what application. However, a significant source of data is available from the U.S. Census Bureau and the 13th American Machinist Inventory. The population of NC machine tools has been analyzed by industry and type.

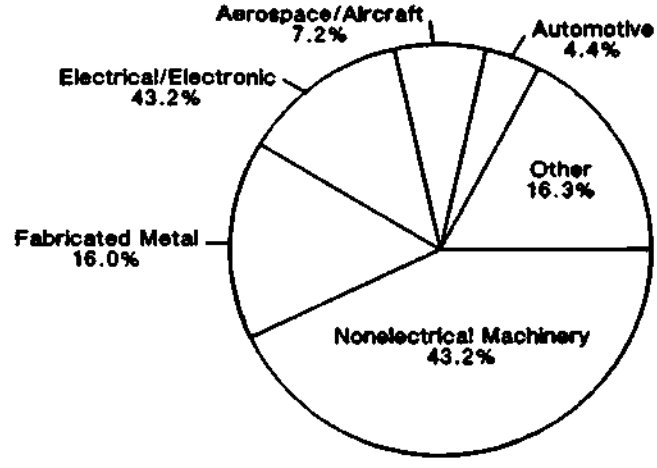
Dataquest uses the U.S. Department of Commerce's Standard Industrial Classification (SIC) codes to define the major industries. The largest user of NC is the nonelectric machinery group. This includes everything from internal combustion engines to farm, construction, and oil field machinery. Conveyers, hoists, and machine tools are also included. The fabricated metal group is the next largest user of NC. This group includes hand tools, nuts, bolts, springs, metal doors, and valve and pipe fittings. The electrical and electronic machinery group includes switches, motors, lights, household appliances, radios, televisions, telephones, semiconductors, and medical apparatus. The aircraft/aerospace group consists of aircraft, parts, and engines. The automotive group includes cars, trucks, and trailers. Any "Other" group includes the remaining manufacturing SIC codes, from 20 through 39. These cover the food and food processing, apparel, lumber and wood products, furniture, paper, printing, chemical, petroleum, rubber, leather, stone, glass, concrete, primary metal, instrument, photographic, clock, jewelry, toy, and other manufacturing industries. Figure 3-2 gives the estimated 1986 NC machine tool distribution, and Table 3-3 shows the distribution for 1983, with estimates

of the 1986 and 1991 figures. The 14th American Machinist Inventory is in progress, with results scheduled for release late in 1988. This data, when available, will be used to update these tables.

NC has had the largest impact on metal-cutting machine tools. More than 78 percent of all NC machines belong to this group. The distribution of all NC machine tool types is shown in Figure 3-3 and Table 3-4.

Figure 3-2

Estimated Distribution of NC Equipment by Industry SIC in 1986



Programmable Machine Tool Installed Base
in United States = 166,600

Source: 13th American Machinist Inventory
U.S. Census Bureau
Dataquest
July 1988

Table 3-3

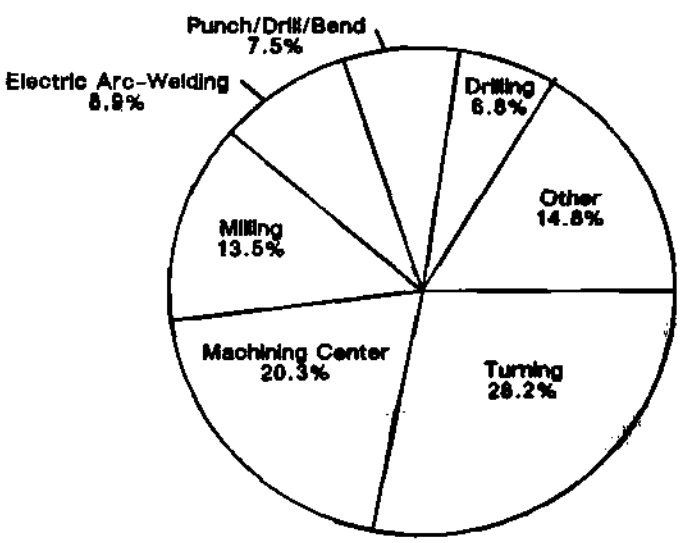
Estimated Distribution of NC Equipment by Industry SIC

Manufacturing Industry		1983	1986	1991
SIC 35	Nonelectrical Machinery	45.0%	43.2%	37.3%
SIC 34	Fabricated Metal	13.3%	16.0%	21.0%
SIC 36	Electrical/Electronic	10.2%	12.9%	15.8%
SIC 372	Aerospace/Aircraft	7.4%	7.2%	7.2%
SIC 371	Automotive	3.7%	4.4%	5.9%
SIC xx	Other	20.4%	16.3%	12.8%
Programmable Machine Tool Installed Base in U.S.		118,200	166,600	263,500

Source: 13th American Machinist Inventory
U.S. Census Bureau
Dataquest
July 1988

Figure 3-3

Estimated Distribution of NC Machines by Type in 1986



Source: Dataquest
July 1988

Table 3-4

Distribution of NC Machines by Type in 1986

Type	Percentage	Annual Unit Shipments CAGR*
Turning	28.2%	14%
Machining Center	20.3%	19%
Milling	13.5%	4%
Electric Arc-Welding	8.9%	N/A
Punch/Shear/Bend	7.5%	(11%)
Drilling	6.8%	11%
Boring	4.3%	(19%)
Automatic Assembly Machine	2.5%	N/A
Grinding	1.9%	0
Thermal Cut	0.9%	N/A
Other	5.2%	N/A

N/A = Not Available
*Compound annual growth rate

Source: 13th American Machinist Inventory
Dataquest
July 1988

By far the largest user of NC metal-cutting machines is the machinery building industry, which accounts for 45 percent of the total use of NC equipment. Table 3-5 indicates the distribution of NC machine tools by type and by major SIC code. Each industry has its unique manufacturing requirements that are reflected in the tools it uses. Fabricated metal is the largest user of thermal cutting equipment and metal-forming machines. Electrical and electronic industries have a high usage of NC drilling and milling tools. Automobile manufacturers use more turning and grinding equipment and are the largest users of specialized cutting equipment. The aircraft industry has focused on machining center, milling, and grinding tools.

Table 3-5

Distribution of NC Machines by SIC Code

SIC	34 Fab Metal	35 Machinery	36 Electrical	371 Auto	372 Aircraft	Other
NC Metal Cutting Machines						
Turning	13.0%	55.7%	8.0%	4.5%	8.4%	10.3%
Boring	9.9%	58.0%	3.6%	2.0%	8.4%	18.2%
Drilling	14.0%	52.6%	14.4%	3.1%	4.2%	11.7%
Machining Center	6.9%	58.0%	11.0%	2.4%	11.7%	10.0%
Milling	10.5%	49.4%	12.4%	2.0%	10.6%	15.0%
Grinding	16.6%	41.6%	7.5%	4.7%	11.2%	18.4%
Thermal Cut	38.5%	38.1%	5.9%	0.8%	4.3%	12.5%
Other	16.5%	37.8%	12.3%	26.6%	0.9%	5.8%
Total	11.4%	53.9%	10.0%	4.0%	9.0%	11.7%
NC Metal Forming Machines						
Punch/Shear/Bend	39.0%	19.8%	14.6%	4.6%	3.6%	18.4%
Joining and Assembly Equipment						
Auto Assy. Machine	29.4%	24.1%	36.4%	5.5%	0.1%	4.5%
Electric Arc Welding	34.8%	27.6%	6.1%	19.0%	0.7%	11.7%
Grand Total	13.3%	45.0%	10.2%	3.7%	7.4%	20.3%

Source: 13th American Machinist Inventory
Dataquest
July 1988

NC Programming Demographics

The market penetration for NC programming is effectively 100 percent. Nobody would purchase an NC machine tool without a means of programming it. The opportunity for growth in NC as a CAD/CAM application is dependent upon these several interrelated factors:

- Continued steady growth of the NC machine tool business (From 1983 to 1987, this growth has averaged more than 12 percent per year.)
- Transition from manual to computer-aided techniques because of complexity requirements and lower-cost programming tools

- Increasing demand for more productive programming techniques as more NC equipment is installed
- A potential shortage of experienced manual programmers
- Continued price erosion of NC programming tools

Further insight into NC programming demographics can be gained by reviewing key findings of a survey that was performed by the National Machine Tool Builder Association, as shown below:

- Nearly two-thirds of all the NC part programming done by the respondents uses some form of computer assistance. Approximately one-third of the NC programming is done manually.
- The larger the size of the installation, the more likely it is that at least some computer-assisted NC programming is used.
- Slightly less than half of the typical programmer's time is spent specifically on part program coding. The balance of the time is spent on such associated tasks as process planning, tape prove-out, media preparation, and tool selection.
- The typical NC installation has a nearly equal number of lathes, mills, and drills, with about half that number of machining centers. The percentage of drills appears to increase as the size of the installation increases. This indicates that most programming techniques are needed at each location (point-to-point, continuous motion, 2-D, and perhaps multiaxis).
- Also according to the survey, approximately one-third of the NC programs used in a given time period are either new or revised, thus requiring part programmer effort. The remaining two-thirds were previously prepared and are being reused.
- Approximately two to seven programmer hours are required per new or revised tape. More time is required as the programming complexity of the machine increases. Increased programmer time is required as the task progresses from drills to lathes to mills to machining centers.
- On the average, approximately 30 to 60 programmer hours per month are being used to support each installed NC machine. Again, the time increases as machine programming complexity increases.

MARKET FORECAST

The U.S. NC market measured by units has grown an average of 13,700 units per year since 1982. The year 1986 was a record-breaking year with an estimated 18,000 units sold. Imported NC machine tools have contributed to a large and growing percentage of the total U.S. consumption. The percentage of units imported has steadily grown from 53 percent in 1982 to 78 percent in 1986. The total machine tool industry is expected to experience minor to flat growth in the next few years. The unit consumption of NC-based machine tools is expected to grow at an average of 9.6 percent from 1986 to 1991. Table 3-6 shows the historic annual consumption growth of the U.S. NC machine tool market in revenue, units, and percentage of units imported. Table 3-7 estimates the revenue and unit growth during the next five years.

Table 3-6

Consumption of NC Machine Tools in the United States
(Analysis by Revenue and Actual Units)

Year	Revenue (Millions of Dollars)	Units	Percentage of Units Imported
1982	$1,702.4	11,018	52.9%
1983	$1,100.0	9,237	54.3%
1984	$1,512.8	13,830	64.8%
1985	$1,808.0	16,499	72.8%
1986	$2,010.9	18,027	78.0%

Source: U.S. Department of Commerce
Dataquest
July 1988

Table 3-7

Estimated Consumption of
NC Machine Tools in the United States
(Analysis by Revenue and Actual Units)

Year	Revenue (Millions of Dollars)	Units
1987	$2,203	19,500
1988	$2,300	20,000
1989	$2,262	19,500
1990	$2,242	19,000
1991	$2,280	19,000

Source: Dataquest
July 1988

The drop in the number of machine tools programmed manually is dramatic. Language-based programming is expected to continue at the current rate with a minor reduction during 1988 and 1989. Virtually all NC controllers now have some CNC functionality. The growth in local programming is due primarily to this trend of making simple, canned machine operations available. Language- and graphics-based programming tools are expected to lead the growth forecast, with new practitioners and converts from manual methods. Table 3-8 indicates the estimated distribution of the installed U.S. base of NC machine tools from 1983 through 1989.

Table 3-8

Estimated Distribution of U.S. NC Machine Tool Installed Base by Programming Method (Number of Units and Percentage of Total)

Programming Method	1983		1986		1989	
Manual	33,100	28%	28,900	17%	18,800	8%
CNC Local	5,500	5	9,900	6	14,000	7
Language-Based	65,000	55	93,100	56	91,000	40
Graphics-Based	14,600	12	34,700	21	100,800	45
Total	118,200	100%	166,600	100%	225,600	100%

Source: Dataquest July 1988

No change in manual programming productivity is expected, which is reflected in the constant figure of two machines per programmer. Advances in CNC are causing a modest growth in the number of CNC machine tools used with the local programming option. A modest increase in productivity is expected as well. Language-based programming is shown to have a productivity benefit over manual programming. This benefit would be greater except that language-based programming is typically used for more complex tasks. System enhancements are expected to increase the number of machine tools a language-based programmer can support in the future. Graphics-based programming is expected to follow the same productivity improvement trend. Table 3-9 shows the estimated average number of NC machines that can be supported by different programming methods.

Table 3-9

Estimated Average Number of
NC Machines Supported by Programmer

Programming Method	1983	1986	1989
Manual	2.0	2.0	2.0
CNC Local	1.8	2.2	2.7
Language-Based	5.0	6.5	7.0
Graphics-Based	6.0	7.5	10.0

Source: Dataquest
July 1988

The general decline in manual programming is being picked up by the interactive programming techniques. The peak of manual NC programming was probably in 1983. As PC-based programming tools came on-stream in 1984, and as remote time-share programming lost favor, language- and graphics-based products accelerated their development and popularity. Table 3-10 shows the rapid growth of graphics-based and CNC local programming techniques.

Table 3-10

U.S. Population of Programmers by Method
(Number of Programmers and Percentage of Total)

Programming Method	1983		1986		1989	
Manual	11,000	38%	9,300	27%	6,800	18%
CNC Local	3,200	11	5,800	17	8,500	23
Language-Based	10,600	36	11,400	33	10,200	27
Graphics-Based	4,300	15	7,900	23	12,100	32
Total	29,100	100%	34,400	100%	37,600	100%

Source: Dataquest
July 1988

A large percentage of installed language- and graphics-based CAD/CAM systems have NC programming software available. The number of bug reports and training requests indicate that a significant percentage of systems with NC programming software are not used for NC programming. This is not intended to reflect on the software's suitability for the job. Rather, it seems to be a fallout of a typical sales transaction. To

wit, when an evaluation committee was going through a purchasing cycle, there is a good chance that the salesperson demonstrated the system's NC functionality. Then, in the closing throes of the selling process, the salesperson sweetened the deal by throwing in a few software packages that had been reviewed with some interest. This often happens in response to pressure to lower the system selling price.

The number of workstations shown in Table 3-11 is an estimate of the actual number of workstations used on a regular basis for NC programming. As stated above, the number of CAD/CAM workstations or systems with access to NC software that goes unused is estimated to be much higher, perhaps by a factor of two or three.

Table 3-11

Installed Base of U.S. NC Programming Workstations

	1983	1986	1989
Installed Base	9,300	13,800	18,600
CAGR	—	14%	10%

Source: Dataquest July 1988

DATAQUEST ANALYSIS

Dataquest believes that the industrial world is on the threshold of a new era destined to revolutionize every manufacturing industry. Manufacturing technology is evolving quickly under intense competitive pressure, with emphasis on higher and more consistent quality. Numerical control is playing a key role in providing the means of definition, communication, and control in the process.

The message to the vendors of NC tools is clearly one of challenge to make the technology work in a changing environment. The rewards will be great to those who can improve the quality and performance of the traditional manufacturing industries. New manufacturing industries built on emerging technologies such as fiber optics will require higher quality, closer tolerances, and more sophisticated manufacturing processes. This will provide more challenges and opportunities for NC suppliers.

The majority of new NC programmers is expected to use graphics-oriented programming systems. Language-based systems will continue to be popular, but little growth is expected in the number of NC machines programmed by language-based tools. As the language-based systems improve, their increased productivity should result in a gradual reduction of the number of language-oriented programmers.

From a CAD/CAM applications viewpoint, opportunities exist in the steady growth of the NC machine tool business. From 1983 to 1987, this growth has averaged more than 12 percent per year. The use of computer-aided NC will increase as the cost of systems continues to drop and the shortage of manual programmers becomes more widespread. Demand for more productive programming techniques will increase as more NC equipment is installed at each location.

Software vendors must keep up with developments in manufacturing technology to maintain the ability to program the latest NC tools effectively. Flexibility is needed in dealing with new materials, new tooling, and tool handling. Developing close working relationships with foreign NC machine tool builders may increase software market opportunities. Developing special-purpose NC software in high-growth applications such as ultraminiature machining and custom tooling production are other growth opportunities.

NC SOFTWARE VENDORS

Table 3-12 is a complete list of all known vendors that offer NC programming software. All product-specified data are based on published information and are subject to change.

Table 3-12

Vendors Offering NC Software

Company Name	Product Name	Computer Used	Function	Cost*
4-D Graphics	N/A	N/A	N/A	N/A
Accugraph	Multidraw	IBM PC, HP 1000, VAX, Sun, Host	Punch	$15K
Adra Systems, Inc.	N/A	N/A	N/A	N/A
Advanced Computer Graphics	N/A	Wrkstn.	N/A	N/A
Aida Engineering	N/A	PC		
Alden Computer Systems	N/A	N/A	N/A	N/A
American Channels	AC/GNC AC/POST	Digital, Apollo Digital, Apollo Wrkstn., Host	N/A Generic post	N/A $12K-$18K
Applicon (Schulumberger)	Bravo-NC	VAX, Wrkstn., Host	2-, 2-1/2-axis, Compact II, APT, APT-CL	N/A
Autodesk	N/A	N/A	N/A	N/A
Auto-graph Technology	N/A	N/A	N/A	N/A
Auto-Trol	N/A	PC, Apollo, Host, Wrkstn.	N/A	N/A
Autographic Digitrol	CAD/NC	IBM PC XT, Host	CNC, 2-axis	$20K +PC
Automation Intelligence	N/A	PC, Wrkstn., Host	2-, 2-1/2-, 3-, 5-axis	N/A
Automation Technology Products	Cimplex-Manufacturing	Host		
Bridgeport Machines	EZ-CAM II	N/A	2-, 3-axis, mill, turn, EDM	N/A
C. Itoh TechnoSciences	N/A	PC, Wrkstn.	N/A	N/A
Cadam	Cadamac	IBM Wrkstn., Host	2-, 3-, multiaxis APT Interface APT Source Geo Compact II Interface Split Interface	$17.5K $18.0K $10.0K $15.4K $11.5K
Cadcentre, Inc.	GNC	Apollo, ICL Perq, VAX	2-, 3-, 5-axis	N/A

(Continued)

Table 3-12 (Continued)

Vendors Offering NC Software

Company Name	Product Name	Computer Used	Function	Cost*
Cadkey	XL/NC CAM	IBM PC	Mill, lathe, grind, laser, EDM	N/A
Calma	NC/PROgrammer	VAX, Apollo Wrkstn., Host	Point-to-point	N/A
	NC Lathe-PRO		2-axis, lathe	N/A
	NC Surface-PRO		2- to 5-axis	N/A
	NC Mill-PRO		2- to 5-axis	N/A
Camax Systems	800 Series—NC Output	IBM PC AT, UNIX, Wrkstn., Host	2- to 5-axis, DNC, CNC	N/A
Carr Lane Manufacturing Co.	N/A	N/A	N/A	N/A
CDC Japan	N/A	PC, Wrkstn.	N/A	N/A
CGX	N/A	PC, Wrkstn.	N/A	N/A
Cimline	CIM CAM	CIM Station	2- to 5-axis, APT-CL	N/A
	CIM POST	Wrkstn.	Individual post	$4K-$8K
Cincinnati Milacron	N/A	IBM PC	Off-line CNC	N/A
CIS	N/A	PC, Wrkstn.	N/A	N/A
Cisigraph	N/A	PC	N/A	N/A
Computer Graphics Technology	Vericut	N/A	N/A	N/A
Computervision	CVNC	CDS 3000, 4000, 5000, Host	2-1/2-axis, turning	$15K
			2-1/2-axis, milling	$15K
			2-1/2-axis, both	$25K
	Personal Machinist	IBM PC AT	2-1/2-axis, universal post	$11.8K
Control Data	ICEM-NC	Cyber 17x, 800, 700 Wrkstn., Host	2- to 5-axis, APT	N/A
Counting House Computer Systems	N/A	PC	N/A	N/A
Dassault Systemes	NC MODULE	IBM 43XX, 30XX	3- to 5-axis, APT, APT-CL, DNC	$2,260/Mo. Lease

(Continued)

Table 3-12 (Continued)

Vendors Offering NC Software

Company Name	Product Name	Computer Used	Function	Cost*
Daveg Datentechnik	N/A	Wrkstn.	N/A	N/A
Deltacam Systems	N/A	PC, Wrkstn.	N/A	N/A
Elcam	N/A	Wrkstn.	2- to multiaxis, APT	N/A
Emco-Maier	N/A	Host	N/A	N/A
Engineering Computer Services	N/A	PC, Wrkstn.	N/A	N/A
Exapt NC	N/A	PC	N/A	N/A
Ferranti Infographics	N/A	PC, Wrkstn.	N/A	N/A
Fujitsu	N/A	PC, Host	N/A	N/A
Gerber Systems Technology	Sabre BNC	HP 9000, MASSCOMP 5500, PC AT, Wrkstn., Host	N/A	$18K
Gibbs & Assoc.	Macintosh for the Machine Shop	PC		
Graftek	NC Module	MASSCOMP, Apollo, VAX, Gould, HP Wrkstn.	2-, 2-1/2-, 3-, 4-, 5-axis, APT, Compact II Generic post Individual post	$15K, 1 to 4 users $12K $2K-$5K
Hakuto Company	N/A	PC	N/A	N/A
Harris	N/A	PC, Wrkstn.	N/A	N/A
Hewlett-Packard	Series 50 NC Tool Path Dev. 2-Axis Post—3750 Point 2-1/2 to 3-Axis Mill Post—6250 4-Axis Machining CTR Post—7500 5-Axis Machining CTR Post-Quote 2-Axis Lathe—5000 4-Axis Lathe—6250	HP 9000 Wrkstn., Host	N/A APT III/IV CC APT Source N/A N/A N/A N/A N/A	$16.5K, includes 4 days training N/A N/A N/A N/A N/A N/A N/A
Hitachi Zosen Info. Systems	N/A	PC, Host	N/A	N/A
Hitachi	N/A	PC	N/A	N/A
Honeywell Information Systems	N/A		N/A	N/A

(Continued)

Table 3-12 (Continued)

Vendors Offering NC Software

Company Name	Product Name	Computer Used	Function	Cost*
PAFEC	N/A	Wrkstn.	N/A	N/A
Pathtrace Chicago	N/A	Host	N/A	N/A
PMX	N/A	Host	N/A	N/A
Prime Computer	Medusa PDGS/NC GNC—Medusa	Prime 2000-9000 Wrkstn.	Flat pattern 3-axis 2-, 2-1/2-, 3-axis, ISO, CL	$6K-$10K $20K N/A
Process & Instrumentation Design	N/A	PC, Wrkstn., Host	N/A	N/A
PSI Systems	N/A	PC	N/A	N/A
Radan Computational	N/A	Wrkstn., Host	N/A	N/A
Remex Cam Operations	N/A	PC, Host	N/A	N/A
RHV	N/A	Host	N/A	N/A
Seiko Instruments & Elec.	N/A	PC, Wrkstn.	N/A	N/A
Shape Data	N/A	PC, Wrkstn.	N/A	N/A
Shipping Research Services A/S	N/A	PC, Wrkstn.	N/A	N/A
Siemens AG	N/A	PC, Wrkstn., Host	N/A	N/A
Sperry	UNIS #CAD	Sperry 1100	2-1/2-axis, APT	N/A
Sumisho Electronics	N/A	PC	N/A	N/A
SuperCADS	N/A	Wrkstn., PC	N/A	N/A
SuperDraft	N/A	Host	N/A	N/A
Techmaco Pathtrace Int'l	N/A	Host	N/A	N/A
Toshiba Corporation	N/A	PC	N/A	N/A
Toyo Electric Mgf.	N/A	PC	N/A	N/A
Toyo Information Systems	N/A	PC	N/A	N/A
Tri-Digital Systems	N/A	Host	N/A	N/A

(Continued)

Table 3-12 (Continued)

Vendors Offering NC Software

Company Name	Product Name	Computer Used	Function	Cost*
Trumpf America	N/A	Digital, Host	2-, 2-1/2-axis, APT, DNC	N/A
Upgrade Technologies	Micro Graphic Mfg. Station	PC		
Unicad	Romulus	Wrkstn.	N/A	N/A
Unisys	N/A	PC, Wrkstn.	N/A	N/A
Universal Intergraphix	N/A	Host	N/A	N/A
VG Systems	N/A	PC, Wrkstn.	N/A	N/A
Visual Inspection Products	NC Tool Master	Radio Shack Model 4, Host	2-axis	$5.5K
Weber NC Systems	Prompt NC	HP	2-, 2-1/2-, 3-axis	N/A
Yokogawa Hewlett-Packard	N/A	PC, Wrkstn.	N/A	N/A
Zuken	N/A	PC	N/A	N/A

N/A = Not Available
*Package prices, lease rates, and optional pricing are based on published data and subject to change.

Source: Dataquest July 1988

Table 3-12 (Continued)

Vendors Offering NC Software

Company Name	Product Name	Computer Used	Function	Cost*
IBH Automation	IBH CAM Workstation	PC		
IBM	See Dassault and Cadam			
ICAM	CAM-Post	N/A	N/A	N/A
	CAM-FAMS	N/A	N/A	N/A
	CAM-APT-SURF	N/A	N/A	N/A
	CAM-PAC	N/A	N/A	N/A
	AUTO-CAM	N/A	N/A	N/A
Infinite Graphics	IGI-BNC	IBM PC XT/AT, Host	2- to 3-axis	$4K
			Universal post	N/A
			Tape reformatting	N/A
Innovative Computer-Aided Tech	N/A	Wrkstn.	N/A	N/A
Intergraph	NC	VAX, Wrkstn., Host	2- to 5-axis, APT, APT-CL	N/A
International Computers	N/A	PC, Wrkstn.	N/A	N/A
Isykon Software GmbH	N/A	PC	N/A	N/A
Kanematsu Electronics	N/A	PC	N/A	N/A
Kongsberg	N/A	PC	N/A	N/A
Leonard N/C Systems	Ultra Path II	Victor 9000, Host	2- to 3-axis, DNC	$10K, includes CPU
			CNC, universal post, lathe mill options	$6K
MAHO	N/A	N/A	Multiaxis, mill	N/A
Manufacturing & Consulting Services	ANVIL 4000	HP 9000, VAX, IBM, Prime, Harris, DataGen, Perkin-Elmer Wrkstn., Host	2-, 2-1/2-axis, includes drafting	$35K-150K
	NC Combo		APT-CL, APT Source	$20K
	Nest/Fab/Path		Compact II	N/A
	Extended NC		3- to 5-axis	N/A
Manufacturing Data Systems (See Applicon)	N/A	Wrkstn.	N/A	N/A

(Continued)

Table 3-12 (Continued)

Vendors Offering NC Software

Company Name	Product Name	Computer Used	Function	Cost*
Marubeni Hytech Co.	N/A	PC, Wrkstn., Host	N/A	N/A
Matra Datavision	Module 1 Module 2 Module 3	VAX	2-, 2-1/2-axis, APT, Compact II 3-axis, CL 5-axis	$4K-$30K N/A N/A
McDonnell Douglas Info. Systems	Unigraphics II GLM—Lathe GMM—Mill pocketing GMAX—3- to 5-axis Nesting—Flat pattern	DataGen, VAX, Wrkstn., Host	N/A Custom post	N/A $7.5K $9.5K $10K $2.5K
Measurement Masters	N/A	Host	N/A	N/A
Micro Aided Engineering	N/A	Host	N/A	N/A
Micro Engineering Solutions	Solution 3000			
Mitsubishi Electric	N/A	PC, Host	N/A	N/A
Mitsui Engineering & Ship.	N/A	PC	N/A	N/A
Mutoh Industries	N/A	PC, Wrkstn.	N/A	N/A
NEC	N/A	PC, Host	N/A	N/A
Nihon Digital Equipment	N/A	PC, Wrkstn.	N/A	N/A
Nippon Univac Kaisha	N/A	PC	N/A	N/A
Norsk Technovision (Dietz)	N/A	PC	N/A	N/A
Numeridex	NICAM	IBM PC	2- to 3-axis, CNC	$20K, includes HW
Numerical Control Computer Sciences	N/A	Wrkstn.	Multiaxis, mill	N/A
Olivetti	N/A	PC, Host	N/A	N/A
P & H Computer Graphics P & H	N/A	N/A	N/A	N/A
Packaged Communications Technology	PCIM/NC	N/A	N/A	N/A
PAFEC Engineering Consultants	DOGS—NC	Prime, Perkin-Elmer, VAX, Wrkstn.		$20K

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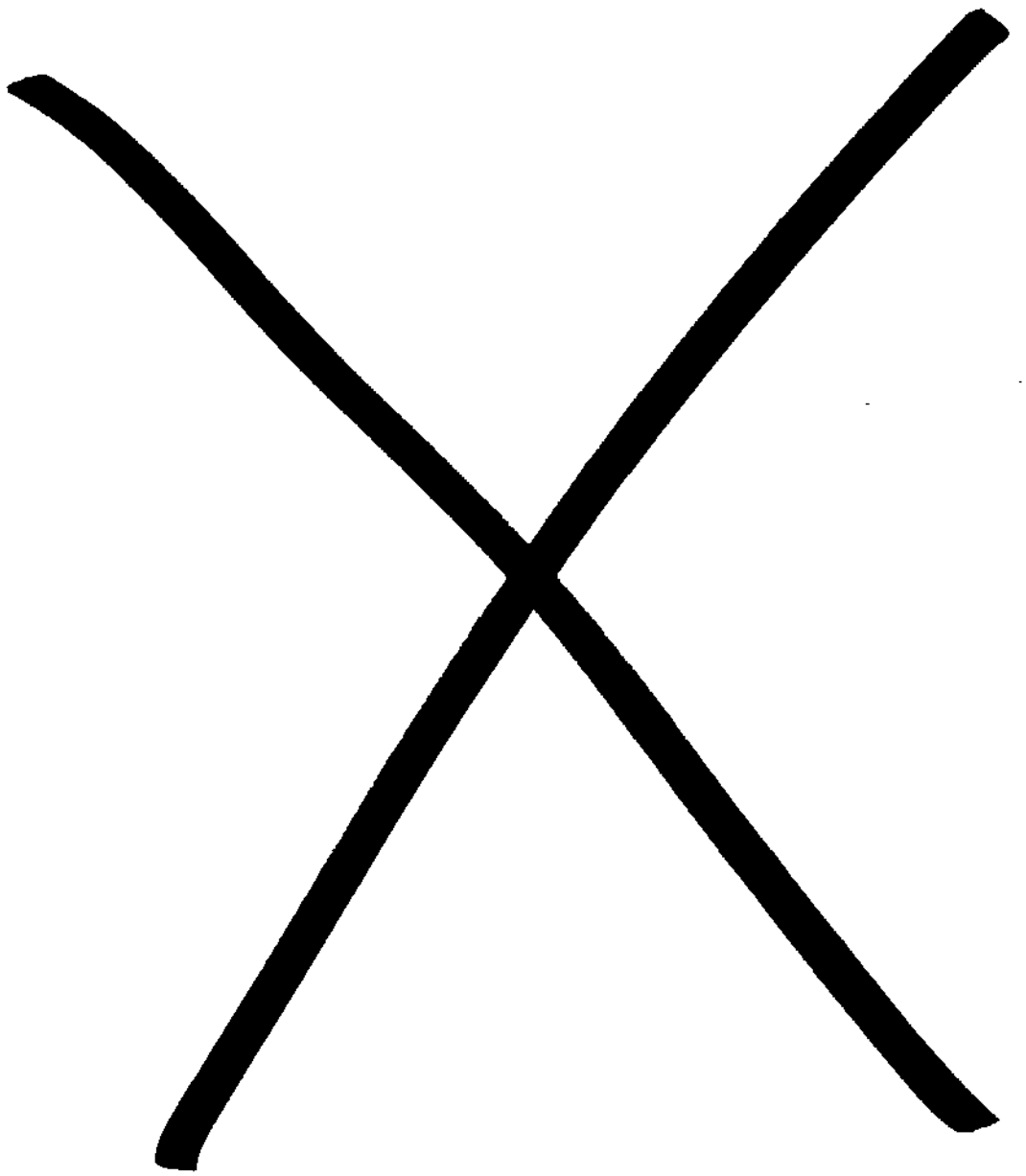


4 Solid Modeling

Solid Modeling—
More Than a Pretty Face

Source: Robot from "Brilliance," Robert Abel & Associates

Looking at realistic images is the first significant benefit derived from solid modeling. The images can represent an automobile, an airplane, or, in this case, a robot model used in a commercial. But, the value of pretty pictures is quickly overshadowed by the full potential of solid modeling in the manufacturing sector. Solid modeling is used to build computer models of existing parts for analysis and redesign, resulting in improved products. New design concepts can be tested in a fraction of the time that is required using manual methods. Solid modeling represents the next generation of modeling technology. It has proven to be effective in several application areas, but the full measure of its benefit will evolve over the coming decade.

The future of solid modeling depends on its ability to meet the total product description requirements of the manufacturing industries. The modeling needs vary by industry but the core issues are the same.

Can solid modeling provide a complete part description in a computerized data base that supports all the applications needed to operate the business? This service section answers this question by discussing the vendor and user viewpoints, and it provides insight into the current status of solid modeling. Our detailed forecast and analysis measures the expected progress of this exciting new technology.

DEFINITION

The first serious question to resolve is: What is solid modeling? Everybody believes a scale model carved from wood or plastic is in fact a solid model. The resulting model of the car, boat, building, or structure is a valuable conceptual design and visualization tool. Unfortunately, the physical model provides little support for the detail design, documentation, or manufacturing process. Dataquest believes that solid modeling technology can solve these problems by building a model that is geometrically complete

and provides the foundation to support a full array of CAD/CAM applications used throughout the design and manufacturing process. These two issues, completeness and the ability to support CAD/CAM applications, form the basis for comparison of all solid modelers. Limitations in either will restrict the utility of the system and the markets that can profitably use the system.

The next question of definition concerns the content of the electronic data base. It is physically impossible to store a solid object on a magnetic disk spinning at 3,600 rpm. What is stored obviously is a digital representation of the object or group of objects. The question then is: What information is required? The answer varies with the needs of the user and the application. For some, just seeing a color-shaded image of the new object provides a significant benefit. For others, a complete part description accurately describing every bump, hole, surface, and feature is required. This complete geometric part description can be combined with other pertinent data to fully describe the manufacturing tolerances, material, processing, and cost parameters of the object. This implies a further ability to extract this data for all design, analysis, simulation, manufacturing, documentation, testing, and verification operations. The key benefit of solid modeling is derived from sharing a single part representation throughout the design and manufacturing process. Solid modeling is the first data base format that conceptually can provide this required level of functionality.

Providing all this in a package that is easy to use, fast, and reliable is the challenge being addressed by dozens of solid modeling developers. Understanding how to use these tools effectively as they evolve is the challenge facing the users. The competitive pressure to accurately design and build better products in a shorter time frame is driving the user industries toward CAD/CAM technology. Today, solid modeling is widely believed to be the best fundamental tool for the job.

HISTORY

The modeling process in computer graphics is growing through its third phase. The first phase began in the mid-1960s as a few straight lines on a storage tube display. These lines could represent just about anything from the circuit path on a printed circuit board to the object lines of a drawing. As the two-dimensional elements of lines and curves grew into three-dimensional wire-frame models, the mid-1970s saw the evolution of the second phase of computer-aided modeling. The second phase in the modeling process evolved as the design continued to grow in complexity, representing more and more information about the precise shape, size, and surface contour of the parts required.

Solid modeling represents the third step in the evolution of computer-aided modeling. All of the edges, surfaces, and holes of an object are knitted together to form a cohesive whole. The computer can determine the inside of the object from the outside. Perhaps more importantly, it can automatically trace across the object and readily find all intersecting surfaces and edges.

Architects have the highest ratio of current users who plan to use solid modeling. This 4.6 to 1.0 ratio shows a very large sales potential in the short term. Historically, however, architects have looked for functionality in a low-cost package, which may slow solid modeling penetration into this market.

Mappers have the smallest level of interest in solid modeling by current users and those with plans to use it. It is worth noting that this group provides a good example of a vertical niche market. The portion of mapping that works with three-dimensional data obtained for subterranean modeling, mining, or oil exploration could benefit from solid modeling.

PENETRATION

Determining market penetration requires market sizing and setting the level of installed product. As always, definitions are necessary to put the data in proper context. Long term, Dataquest expects the potential solid modeling market to include 100 percent of mechanical and 80 percent of AEC markets. For this potential to be realized, solid modeling will be required to support all CAD/CAM applications better than they are supported today by wire-frame and surfacing technology.

Since today's systems use solid modeling as an add-on application or as a core system function, it is difficult to determine the level of use at the workstation level. The 1985 Dataquest User Survey was used to set the current level of usage on a per-site basis. Roughly 25 percent of the CAD/CAM user sites responding to the 1985 Dataquest User Survey were using solid modeling. This corresponds to more than 17,400 workstations installed worldwide with full- or part-time access to solid modeling in 1984. Dataquest believes that market penetration by site will increase from approximately 25 percent in 1984 to 53 percent in 1989. An estimated 47 percent unit growth rate in 1988, forecast to increase to 55 percent in 1990, is responsible for the expected doubling of market penetration on a per-site basis.

A 1987 Dataquest MCAD user survey asked what percent of the existing data base was stored as a solid model rather than as 3-D surface or 2-D wire frame models. The site managers indicated that 6 percent of the current data base was based on solid modeling, with the number growing to 15 percent by 1989.

USER ISSUES

To live up to its full potential, solid modeling must pass an impressive set of hurdles. Functionality, ease of use, and price are some of the most significant barriers. The following segments discuss these issues from a user perspective, indicating the needs and level of expectation.

Functionality

The basic solid modeling procedure uses a variety of standard objects as primitives, adding or subtracting them from each other to form the desired part. The current flexibility of this process will allow the precise modeling of fully machined parts. Increasing the complexity of parts by including castings, forgings, molded, and formed parts, however, adds a level of difficulty that few solid modelers can address. Adding the constraint of building these complex models in a reasonable time frame is another major hurdle.

After building the model, the immediate question arises, "What can be done with it?" The first useful application is to look at it. The visualization process has virtually been solved from a functional view. The engineer can be his own artist and easily produce full-color rendered images. Technical illustrations can be displayed that include line drawings in perspective, with hidden lines removed. Accurate, detailed sectioned views can be generated for use in design studies or for detail drawings. Still ahead are improved algorithms and special-purpose hardware that will produce images faster, with more realism and more user control, but at a lower cost.

Building two or more parts that fit together adds another dimension of complexity. Evaluating the nominal fit, mass properties, interferences, and relative motion in mechanism are all significant elements of required functionality. Each of these functions is currently available in various forms of utility and ease of use. Building large assemblies with more than a thousand components is difficult if not impossible. Complex products or structures can easily have tens of thousands of parts. Configuration management of these large structures must be available. New techniques to allow the interactive use of these large data bases is essential.

The classic major application areas of CAD/CAM must be supported by solid modeling. These are finite element analysis, numerical control part programming, and documentation. Each area can take advantage of the more complete part model and produce precise results in a more automated, easier-to-use scenario. Rule-based procedures will complement the operation, giving the user more time to think about his problem and less time to worry about the steps he needs to follow to make it happen.

Dimensional tolerancing associated with solid modeling is a long-term functionality with exciting potential. Today, edges, holes, and profiles are stored in computers with one value for each component or feature. Allowing a multiple value or a range of values for each of these dimensions opens the door for more complete design evaluation, for manufacturing process optimization, and for automated testing for quality assurance.

Solid modeling will provide an efficient base for geometric part data in corporate data bases. Access, format, control, and definition are a few of the major issues involved in using such a data base. By definition, a corporate data base must be accessible to anyone with a legitimate need for business information. Controlling the level of access to each of the functional groups or individuals is a nontrivial task, but it

Table 4-2 (Continued)

University Research and Development Activity in Solid Modeling

University	Project Name*	Modeling
Tech. Univ. Berlin	ASP-GM	Modeling
	Compac	Modeling, interfaces, AI
	Baustein Geometrie	
Tech. Univ. Delft	Raymo	Ray tracing
Tech. Univ. Denmark	SEDA	Modeling
	Technovision (Compac)	Modeling
Univ. of Bath	Vole, Dora	Raycasting, NC, modeling
Univ. of Cambridge	Build II	GKS graphics, autofeature recognition, auto NC, robotics
Univ. of East Anglia	-	Solids/sculptured surfaces
Univ. of Edinburgh	Robmod	Robotics
Univ. of Karlsruhe	Dicad	Modeling, AI
	Proren	
Univ. of Michigan	Architectural System	Architectural modeling
	ASV	Feature extraction
Univ. of Rochester	PADL II	Object modeling
		Process modeling and planning
Univ. of Tokyo	Geomap	Free-form shapes, NC

*Project or product names shown in parentheses indicate affiliations between universities or commercial products.

Source: Dataquest
July 1988

END USERS

The users of solid modeling technology come from virtually all industrial sectors. Table 4-3 indicates the major industrial sectors and the corresponding primary area of use.

Earlier in 1985, Dataquest conducted a user survey of more than 600 user sites. This survey was designed to define the current status of the use of solid modeling and the future expectation of use by industry. Based on the total response, 24 percent of the site managers said they were using solid modeling on their systems. This does not mean that 24 percent of all system hours are spent on solid modeling, but it does mean that 24 percent of the users have access to solid modeling if they need it. An additional 39 percent said they plan to use solid modeling in the future, 21 percent have no plans, and 16 percent do not know. This sets the ratio of believers to nonbelievers in the current CAD/CAM user base at 2 to 1. The challenge will be to make the systems good enough to attract the nonbelievers of the current user base and to become the preferred choice of new CAD/CAM purchasers.

Table 4-3

Primary Solid Modeling Applications by Industry

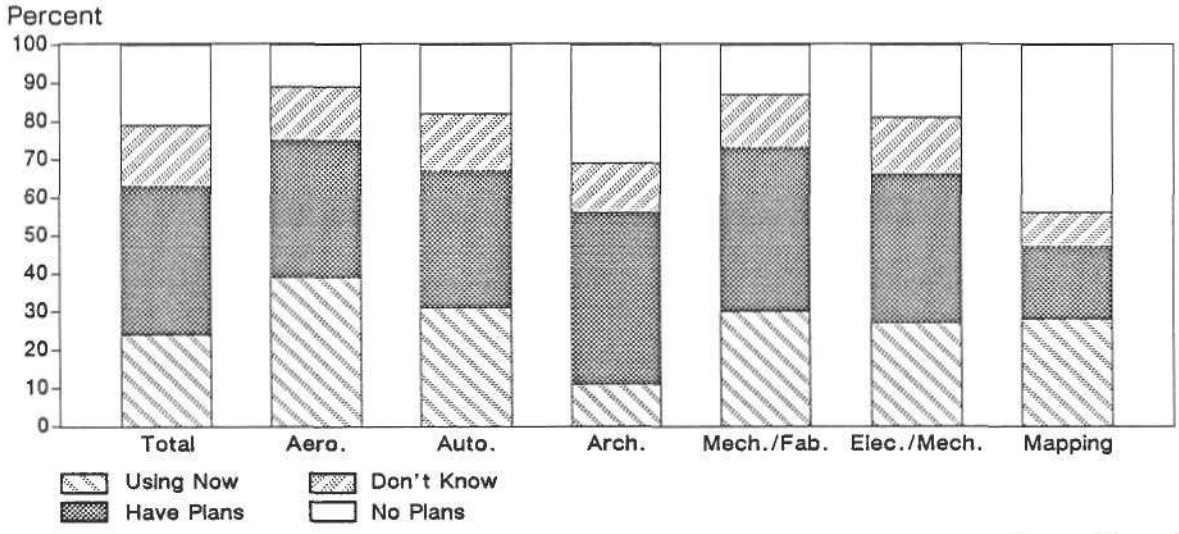
Industry	Application
Aerospace	Conceptual design—visualization
Automotive	Design verification—packaging—visualization
Architectural	Visualization
Mechanical/Fabrication	Packaging—early design—analysis
Electro/Mechanical	Packaging
Mapping	Subterranean modeling

Source: Dataquest
July 1988

As Figure 4-1 indicates, aerospace has the highest level of installations by site (39 percent). The high degree of complex new design work and a need for quality make the solid modeling systems attractive in the aerospace industry.

Figure 4-1

Analysis of User Survey
Solid Modeling Use by Industries



Source: Dataquest
July 1988

shaded images in isometric, perspective, single, or multiple views. Application-specific ICs and displays designed for this task are solving the problem. Display performance is improving by a factor of approximately two each year. In other words, a 10,000-polygon shaded image could be rotated and redisplayed in one second a year ago. Now, 20,000 polygons can be processed in the same time, or 10,000 in half the time. Products released in 1988 are expected to handle 150,000 polygons in a second or less.

Realism in display is available with shadows, multiple colored light sources, and textures. Longer term, both image quality and speed of generation will improve, approaching movie film for imaging dynamics and quality. Apollo, Ardent, Phoenix Data Systems, Raster Technologies, Silicon Graphics, and Sun Microsystems are leaders in the technology development of solid modeling display.

User Interfaces

Enhanced user interface options include pop-up menus, icons, command strings, and programmable options for repeatable operations. The issue here is not so much how the interface is presented as it is whether or not the interface is easy to use, self-teaching, predictable, reliable, and flexible enough to allow the construction of the necessary detail to accurately define the object for the follow-on operations. Combining the functional need with the diversity of potential users and with the possibility of building in some rule-based logic to speed up the process will keep the system designers busy for years. User interfaces that are programmable and custom tailored for the user are rapidly becoming the common expectation.

Data Base

The full potential of solid modeling will not be realized until all applications can work from the same data base. The data base will include many different types of information, but there will be one representation for the part description with other data related to it. This process will accurately capture the engineering data base, defining the legal part description and archival record. Where-used and made-from questions can be answered directly. The volume of information associated with this data base is directly related to the level of design and manufacturing automation installed at that time.

Application Interfaces

For solid modeling to become fully accepted, it must support all the major application areas. The primary issue involves taking advantage of the more complete data base. Solid modeling cannot be treated as an add-on application. It must be built in to the core system where the application code can depend on the information being available for use. Virtually any application can be improved and, in some cases, fully automated if the solid modeling techniques are available.

CURRENT UNIVERSITY RESEARCH AND DEVELOPMENT ACTIVITY IN SOLID MODELING

Universities around the world have been working on solid modeling-related issues for the last 15 years. Several commercial products have evolved from university development, with ongoing development in progress at dozens of sites. Table 4-2 lists the names of universities performing solid modeling research and development activities.

Table 4-2

University Research and Development Activity in Solid Modeling

University	Project Name*	Modeling
Carnegie-Mellon	Glide, BDS	Modeling
Computer & Automation Inst. Budapest	Built+	Double quadratic surfaces
	Modbuild	Robotics
	Mosy	Motion synthesizer with movie interface
Cornell University	TIPS	Auto generation and verification of NC
Cranfield Inst. of Tech.	Test Bed Modeler	AI, process planning CAM-I AIS, form features
Czech Tech. Univ. Prague	JOE/GSFEL	Modeling
Federal Inst. of Tech. Zurich	Euklid	Modeling
Helsinki Univ. Technology	GWB	Modeling, kinematics, and FEM generation
Hokkaido Univ., Japan	TIP/GSP	Geometric simulator
IBM U.K. Scientific Centre	Winsom	Organic molecule modeling
Kernforschungszentrum Karlsruhe	Gipsy	Application interfaces
Royal Inst. of Tech., Sweden	GPM	Modeling
Leeds University	Noname (Boxer)	Auto NC and FEM generation
Loughborough Univ. of Tech.	SWANS (Leeds)	CAM applications
Newcastle Polytechnic	-	Form-feature data base
Norwegian Inst. of Tech./Sinteff	Assembled Plate	Assembler welding
	Genus	Modeling, kinematics, NC turning
Politecnico di Milano	Cadme	CAD/CAM national project
Polytechnic of Central London	-	Modeling, tolerancing, NC
Purdue University	-	Modeling,
RPI	Octree	Modeling, ray tracing
Royal Inst. of Tech. Stockholm	GPM	Modeling, sheet metal, robotics, welding, AI
Ruhr Univ.-Boehm	Proren-2	Modeling
Tech. Research Centre Finland	Uniblock	Modeling, AI, FEM generation, kinematics

(Continued)

Making It Real

Some of the early product successes such as Geomod from SDRC/GE CAE-I, Euclid from Matra Datavision, and PADL from the University of Rochester proved the practical application of solid modeling. Conceptual design with improved visualization and accurate part properties for weight and mass have been the most successful application areas. Vendors are hard at work expanding the scope of solid modeling from a design tool to the basis for a corporate data base. The systems now in development will be used for everything from early conceptual design to final production and inspection. A serious effort to understand the scope of this task elicits respect for the system designers and programmers that are trying to make it happen.

The current stage in the evolution of systems used for conceptual design is mechanical computer-aided engineering (MCAE). The MCAE products combine enhanced modeling with improved analysis functions. On-line engineering reference documents and a user interface for the engineer are also getting development attention.

Niche Integration Versus Data Base Integration

Today, each of the top 10 mechanical CAD/CAM vendors has a solid modeling product. Dozens of others have, or are in the process of developing, their own products. The approach is different from vendor to vendor, but they fall into two general groups. The niche-vendor approach capitalizes on an opportunity to focus on a vertical market and provide a high level of integration in a specific application area. The hope is to attract the user with special requirements, leading to higher-performance packages that are easier to use.

The system-integrator approach is as broad as possible. By providing a complete package or a solid foundation for the total corporate graphics needs of a company, the vendor hopes to become the standard graphics tool supplier for the entire operation. As standards for communication improve, the opportunity for the system integrators and the niche suppliers to work together will improve as well. The combined synergy and competitive pressure in this environment will push product development to high levels in all application areas.

Dataquest believes that the niche developers will lead in developing innovative solutions in each of their application areas, but that the system integrators will be close behind taking advantage of any significant development. The major development areas have been identified as finite element modeling, analysis and optimization, numerically controlled part programming, drafting/documentation, and design verification. As market leaders emerge, strategic alliances will be formed to move the niche solutions toward integration as complete systems. This process would be aided considerably if standards were in place to define the format of data to share between unlike systems.

TECHNOLOGIES

Millions of dollars are being spent to improve performance, functionality, and user-interface operations. The following sections discuss the key technology development areas and identify their major features and current trends.

Modeling

The primary function of solid modeling is to give the user the ability to model completely any realizable object. Modeling development is being directed toward solving the deficiencies that limit the classes of parts that can be modeled. Castings, forgings, and sculptured pieces such as automotive body parts are the most common problem areas. Making the part model more complete by more accurately capturing all relevant information in an easily maintained form is the key issue.

A current trend in making the systems easier to use is based on a modeling process that uses more complex primitive shapes called feature-based modeling. Rather than using blocks, cones, or cylinders to form the part, standard part features are used as part construction operations. Asking for a drilled, countersunk, and tapped hole in a single operation is an example of this process. An extension of this process generates complete standard parts. By filling in questions to a parametric program, standard gears, pulleys, or brackets can be modeled. Any of these procedures can be custom tailored for the user company to reflect established company practices or manufacturing constraints. The rapid construction of standard part features or standard parts can improve the productivity of the system. Feature-based modeling is a useful tool in moving solid modeling from a conceptual design to the mainstream of production design and manufacturing.

Adding tolerance data to the data structure is currently under study. Longer-term developments center on modeling manufacturing processes and functional test environments. Accurately modeling processes such as painting, plating, or heat treatment may or may not be necessary; however, the information describing the operation must be captured and maintained with the part data base. The complete part data base will support top-down part planning and bottom-up operation planning.

Display

Fast image generation has been an Achilles heel for solid modeling. Rapid rotation and translation of view and part orientation is essential for interactive design tasks. Application-specific VLSI and display packaging designed for this market are just becoming available to speed up this process.

Fortunately, one of the most successful development areas associated with solid modeling has been display. Image generation has progressed from hours and days worth of computing time to fractions of a minute. Images include wire-frame, hidden-line, and

In the mid-1970s, various universities and industrial developers began to develop elements of this new modeling process. The PADL project from the University of Rochester is typical of some of these early systems. The essence of the approach uses well-defined, three-dimensional objects as building blocks. Various sizes of blocks and cylinders are added and subtracted from each other to form the desired part. This procedure is known as Constructive Solid Geometry (CSG). The set of primitive objects now includes cones, wedges, and several other regular-shaped objects. Boolean operators (union, difference, and intersection) and other operators are used to combine the objects. The advantage of this process is the fast description of the shape of the part and the ease of modification. Unfortunately, modeling the full range of part shapes is difficult if not impossible. Cast and forged parts with tapered sides and rounded corners are good examples of parts extremely difficult to model with the CSG approach.

Another form of solid modeler has evolved, called the Boundary Representation (B-Rep). In this process, every vertex, edge, and face is explicitly defined. The connectivity (topology) showing the relationship between each of these elements provides the glue to turn the list of elements into a geometrically solid object. This process is inherently more flexible but requires rigorous algorithms to guarantee the construction of a valid object. However, the easy access to individual surfaces for sampling or display is an advantage of B-Rep solid modelers. Other conceptual approaches have been developed, such as Octree, but have not made significant impact as commercial systems.

The common expectation of today's solid modelers includes a variety of primitive objects with construction operations to form any free-form swept or sculptured shape. Most vendors are meeting this expectation by providing a hybrid or combination of B-Rep and CSG features. Users require Boolean operators to quickly join and shape the object, and easy part modification to support design iteration and revision.

VENDOR PERSPECTIVE

The Check-Off Box

A flurry of solid modeling products were introduced a few years ago that allowed the vendors to reply affirmatively to the question: Do you have solid modeling? Heightened media attention suggested the need to ask, even though the prospect probably did not understand why it was important. Today, a "yes" response to the question is not enough. The expectations of the potential users have progressed, looking for a wide range of capabilities. The vendors have risen to the challenge and are in the process of developing next-generation products that meet the real needs of the user. Table 4-1 lists the solid modeling vendors and products that Dataquest currently tracks.

Table 4-1

Major Solid Modeling Vendors and Products

Company Name	Product Name
Applicon	Solids Modeling II
Aries Technology	Concept Station
Autodesk	Auto Solid
Auto-trol Technology Corp.	SERIES 7000 SOLIDS MODELING
Automation Technology Products	CIMPLEX
British Technology Group	VOLE
CADAM Inc.	Solids Modeler (MAGI)
Cadetron	Cadrasolids
CADCentre	PDMS
CAEtec Software Inc.	PRO-SOLID
Calma Co.	GEOMOD
Catronix Corp.	CATSOLID
Cimlink Inc.	COMPONENT GEOMETRY MODELER
Computervision Corp.	MEDUSA (CIS); SOLIDESIGN
Control Data Corp.	ICEM
CSA	Solid Modeler
Cubicomp Corp.	CS-5 PolyCAD 10
Daisy	Gemsmith
Dassault Systems USA	CATIA
Evans & Sutherland Computer Co.	ROMULUS
Ferranti Infographics	CAM-X ROMULUS
GE-CAE International/SDRC	GEOMOD
Gerber Systems Technology Inc.	GST-Solid
GMWC	RUCAPS
Gould	Gemsmith
Graftek	Solid Modeling System
Harris Corp.	HarrisCAD
IBM	CADAM, CAEDS, CATIA
Interactive Computer Modelling Inc.	GMS
Intergraph Corp.	Solid Modeler
Isykon	PROREN
Manufacturing & Consulting Services	OMNISOLIDS
Matra Datavision Inc.	EUCLID
McDonnell Douglas Mfg. Info. Systems	UNISOLIDS
Norsk Data	TECHNOVISION
Pafec Inc.	Boxer
PDA Engineering	PATRAN II
Perspective Design Ltd.	MicroSolid
Phoenix Data Systems	Insight
Prime Computer Inc.	PRIME MEDUSA
Sperry Corp.	CIM/ME SOLID MODELER
Swanson Analysis Systems Inc.	ANSYS
Tektronix Inc.	PATRAN II
Unicad	M/P/E (Romulus)

Source: Dataquest July 1988

is essential in order to support the full level of communication requirements in industrial automation. Today's CAD/CAM products address the issues of local data bases and local area networks. The tools are just beginning to be available to put together large corporate data bases.

Standards are an essential ingredient in this scheme. Creating a format to capture the essence of product design and manufacturing information is the formidable task of several standards organizations. ISO/TC184-SC4, CAM-I/AIS, ANSI/Y14.26, DIN/TAP/VDA, AFNOR-SET, and EEC-ESPRIT are leaders in this worldwide effort.

Users are asking for complete application integration as one of the most important components of a solids-based system. Unfortunately, asking 10 users for a functional definition of a well-integrated system gets at least 10 answers. From Dataquest's current point of view, the most important solid modeling applications are:

- Finite element mesh generation and analysis
- Numerical control part programming
- Drafting and documentation
- Dimension tolerancing and analysis
- Design verification by interference detection
- Visualization
- Mass properties

As the quality and quantity of part geometry and associated information improves, defining a fully operational data base, the emphasis will focus on the flow of information and where it is used. Information integration is the primary goal tying organizations into a single business unit.

Performance

The essential element of performance is to retain the interactive nature of the system, independent of the complexity involved. Every system operation, user interface, functionality, or output process has a performance element. Consider two highly functional systems, one interactive and responsive, the other batch-oriented and ponderous. The first is a powerful design tool; the second is a laboratory curiosity. Blinding speed has been the dream of solid modeling practitioners since the first Boolean operation. The current rapid progress in computing horsepower and display processing are having a positive effect. But the general problem is far from being solved.

A close look at a realistic design problem illustrates the true need. Routing a hose through the engine compartment of an automobile and designing the necessary clamps and fittings can take weeks, working from engineering drawings. Considering the effect of a simple modification to one of the parts or the diversity of engine options increases the complexity by an order of magnitude. Using a solid representation of the assembly with interactive performance would shorten the job to a few hours. Simulating the design process allowing fly-around display performance with models having thousands of parts is a real expectation of automotive, aerospace, and heavy industrial designers around the world.

In the example cited above, moving to a new location to see a fresh vantage point can require minutes or even hours with today's systems. The user needs less than one-second image redisplay time.

Subtracting one shape from another is a powerful modeling operation. Waiting more than a few seconds to see the result is frustrating and counterproductive.

Productivity

Productivity can be measured in many ways. Completing a measured task in half the time or less is understood to be productivity improvement. Completing a task that has never been done or never been possible to do is difficult to quantify for productivity improvement. If the task is important, productivity is infinitely improved. Solid modeling opens the door for both types of productivity improvement.

The major ease-of-use issue relates directly to productivity. What percentage of the user's time is spent thinking about how to make the system do what he wants versus the time spent working directly on the problem? Dataquest believes that this ratio needs to be greater than 90 percent.

Assisting design or manufacturing applications is a primary function of solid modeling. What is the level of application integration? How much time is required to set up each operation? If the task requires a drawing to be generated, what convolutions are required to get the correct views on the paper? What happens to the drawing when the design is updated? Who is notified when engineering makes a change? A system approach to the above will profoundly improve the communication and productivity of the user's organization.

Ease of Use

Casual users who spend less than two hours per day on a system are the target for the designers of user interfaces. These users need to have a little hand-holding on each excursion into the land of computer-aided design and manufacturing. They do not want to be slowed down by menu structures or lengthy procedures of small, "easily understood" command steps in the name of ease of use. On the other hand, they do need assistance in knowing what to do next. This is fertile ground for real innovation in system design.

A key element of ease of use is providing a self-teach mode of operation. Ideally, the system could monitor the progress of the user and make suggestions for independent study or present tutorial sessions for the learning of new or revised functions.

Price

The performance and display requirements for most solid modeling applications force the use of high-end hardware packaging. Typically, the cost per terminal hour is between $15 and $35. Each potential user will need to evaluate the current level of functionality for proper application to the problem. For some users, the potential benefit could be a bargain at $100 per hour. For the rest, a wait of a year or two will make the difference.

Trends

Exaggerated vendor claims with high-level media coverage have produced overly optimistic expectations. This situation will continue as a result of the extremely competitive nature of this business and misunderstandings in dealing with the complex issues.

Conceptual design using solid modeling technology has proven to be effective. Most short-term enhancements will evolve from this foundation.

The availability of the low-cost, high-performance drafting solution is good and bad for solid modeling developers. The good news is that an expensive system does not need to be tied up doing drafting. Developing a complete interface between the solid modeling design system and the high-performance, low-cost drafting system will solve the drafting application need. The bad news is that the users now have the choice: Do they buy three or four drafting systems, or do they buy one solids-based design system? Dataquest estimates that more than half of the total available mechanical CAD/CAM system hours are used for drafting. The current users of three-dimensional design systems can off-load their drafting tasks to the new low-cost systems and free up already-purchased design stations. Considering the availability of terminal hours, trained users, and established procedures, this could slow short-term demand for new design systems.

MARKET FORECASTS

Dataquest's worldwide solid modeling market forecast is shown in Table 4-4. Table 4-5 indicates the percentage distribution of the same data. The revenue total represents software-only revenue for solid modeling packages and application software that depends on the solid modeling process. This represents a larger market than the modeling-only market but more accurately presents the true impact of this technology on the CAD/CAM industry. Revenue from both bundled and unbundled suppliers is included in the 1987 analysis, and both sources are considered in the forecast. The actual units specified represent the number of systems and workstations required to

operate the new software. The expected drop in average system selling prices and the transition of solid modeling from an add-on application to a core system function have been considered in this forecast.

The solid modeling market forecast by region is shown in Table 4-6. Table 4-7 indicates the percentage distribution of the same data.

Table 4-4

Solid Modeling Market Forecast by Platform
(Millions of Dollars and Actual Units)

	1987	1988	1989	1990	1991	1992	CAGR
Worldwide							
Total Revenue	811	1,085	1,421	1,937	2,472	2,935	29.3%
Software	178	268	403	604	857	1,126	44.7%
Hardware	633	816	1,017	1,333	1,615	1,809	23.4%
Systems	5,979	10,961	18,943	32,760	50,758	70,391	63.7%
Workstations	10,501	17,692	27,177	43,195	63,124	84,341	51.7%
Technical Workstation							
Total Revenue	157	278	496	844	1,263	1,658	60.3%
Software	54	97	182	321	512	723	67.8%
Hardware	103	181	315	523	751	936	55.6%
Workstations	3,602	7,320	14,110	26,081	42,368	60,603	75.9%
Host-Dependent							
Total Revenue	650	800	912	1,072	1,182	1,245	13.9%
Software	122	169	216	272	330	385	25.9%
Hardware	528	631	696	800	852	860	10.3%
Systems	2,136	3,241	4,043	5,226	6,320	7,278	27.8%
Workstations	6,659	9,972	12,277	15,660	18,686	21,228	26.1%
Personal Computer							
Total Revenue	4	7	12	21	28	31	49.6%
Software	1	3	6	11	15	18	67.3%
Hardware	3	4	7	10	13	13	36.4%
Workstations	241	400	790	1,454	2,070	2,510	59.7%

Source: Dataquest
July 1988

Table 4-5

Solid Modeling Market Forecast by Platform
(Percentage of Total)

	1987	1988	1989	1990	1991	1992
Technical Workstation						
Revenue Total	19.4%	25.6%	34.9%	43.6%	51.1%	56.5%
Software	30.6%	36.0%	45.0%	53.2%	59.7%	64.2%
Hardware	16.2%	22.2%	30.9%	39.2%	46.5%	51.7%
Workstations	34.3%	41.4%	51.9%	60.4%	67.1%	71.9%
Host-Dependent						
Revenue Total	80.1%	73.8%	64.2%	55.3%	47.8%	42.4%
Software	68.6%	62.9%	53.5%	45.0%	38.5%	34.2%
Hardware	83.4%	77.3%	68.4%	60.0%	52.7%	47.5%
Systems	35.7%	29.6%	21.3%	16.0%	12.5%	10.3%
Workstations	63.4%	56.4%	45.2%	36.3%	29.6%	25.2%
Personal Computer						
Revenue Total	.5%	.6%	.9%	1.1%	1.1%	1.1%
Software	.8%	1.1%	1.4%	1.8%	1.8%	1.6%
Hardware	.4%	.5%	.6%	.8%	.8%	.7%
Workstations	2.3%	2.3%	2.9%	3.4%	3.3%	3.0%

Source: Dataquest
July 1988

Table 4-6

Solid Modeling Market Forecast by Region
(Millions of Dollars and Actual Units)

	1987	1988	1989	1990	1991	1992	CAGR
Worldwide							
Total Revenue	811	1,085	1,421	1,937	2,472	2,935	29.3%
Software	178	268	403	604	857	1,126	44.7%
Hardware	633	816	1,017	1,333	1,615	1,809	23.4%
Systems	5,979	10,961	18,943	32,760	50,758	70,391	63.7%
Workstations	10,501	17,692	27,177	43,195	63,124	84,341	51.7%
North America							
Total Revenue	413	510	631	836	1,047	1,234	24.5%
Software	90	126	179	261	363	473	39.2%
Hardware	322	384	452	575	684	761	18.7%
Systems	3,179	5,401	8,841	14,865	22,625	31,165	57.9%
Workstations	5,381	8,375	12,158	18,763	26,915	35,709	46.0%
Europe							
Total Revenue	253	353	471	642	817	961	30.6%
Software	56	87	134	200	283	369	46.0%
Hardware	198	266	337	442	534	593	24.5%
Systems	1,808	3,457	6,087	10,528	16,261	22,339	65.3%
Workstations	3,344	5,863	9,169	14,574	21,235	28,119	53.1%
Far East							
Total Revenue	131	206	297	424	553	660	38.1%
Software	29	51	84	132	192	253	54.5%
Hardware	102	155	212	292	361	407	31.8%
Systems	893	1,944	3,719	6,759	10,727	14,946	75.7%
Workstations	1,615	3,217	5,458	9,106	13,623	18,286	62.5%
Rest of World							
Total Revenue	13	15	22	35	55	80	43.5%
Software	3	4	6	11	19	31	60.5%
Hardware	10	12	15	24	36	49	36.8%
Systems	99	160	295	609	1,146	1,941	81.3%
Workstations	162	237	392	752	1,351	2,227	69.0%

Source: Dataquest
July 1988

Table 4-7

Solid Modeling Market Forecast by Platform
(Percentage of Total)

	1987	1988	1989	1990	1991	1992
North America						
Total Revenue	50.9%	47.0%	44.4%	43.1%	42.3%	42.0%
Software	50.9%	47.0%	44.4%	43.1%	42.3%	42.0%
Hardware	50.9%	47.0%	44.4%	43.1%	42.3%	42.0%
Systems	53.2%	49.3%	46.7%	45.4%	44.6%	44.3%
Workstations	51.2%	47.3%	44.7%	43.4%	42.6%	42.3%
Europe						
Total Revenue	31.3%	32.6%	33.2%	33.2%	33.1%	32.8%
Software	31.3%	32.6%	33.2%	33.2%	33.1%	32.8%
Hardware	31.3%	32.6%	33.2%	33.2%	33.1%	32.8%
Systems	30.2%	31.5%	32.1%	32.1%	32.0%	31.7%
Workstations	31.8%	33.1%	33.7%	33.7%	33.6%	33.3%
Far East						
Total Revenue	16.2%	19.0%	20.9%	21.9%	22.4%	22.5%
Software	16.2%	19.0%	20.9%	21.9%	22.4%	22.5%
Hardware	16.2%	19.0%	20.9%	21.9%	22.4%	22.5%
Systems	14.9%	17.7%	19.6%	20.6%	21.1%	21.2%
Workstations	15.4%	18.2%	20.1%	21.1%	21.6%	21.7%
Rest of World						
Total Revenue	1.6%	1.4%	1.5%	1.8%	2.2%	2.7%
Software	1.6%	1.4%	1.5%	1.8%	2.2%	2.7%
Hardware	1.6%	1.4%	1.5%	1.8%	2.2%	2.7%
Systems	1.7%	1.5%	1.6%	1.9%	2.3%	2.8%
Workstations	1.5%	1.3%	1.4%	1.7%	2.1%	2.6%

Source: Dataquest
July 1988

MARKET SHARE ANALYSIS

The three groups of companies profiled in Table 4-8 indicate market share analysis by vendor and number of installed workstations with access to the named product. The level of utilization of the solid modeling product or module is expected to range from often to full-time. Group A represents vendors with established solid modeling products in production in many user organizations. Group B includes emerging products by well-known vendors or second sources for third-party software products. Group C includes the newest entries with just-announced products or products in beta test. Some of the latest technology can be found in these products.

Table 4-8

Solid Modeling Market Share Analysis

Company	Product
Group A	
Applicon	Solids Modeling II
CADCentre	PDMS
Computervision Corp.	MEDUSA (CIS), SOLIDESIGN
Control Data Corp.	ICEM
IBM	CATIA, CAEDS
Matra Datavision Inc.	EUCLID
McDonnell Douglas Mfg. Info. Systems	UNISOLIDS
Prime Computer	PRIME MEDUSA
Structural Dynamics Research Corporation	IDEAS
Group B	
Auto-trol Technology Corp.	Series 7000 Solids Modeling
CADAM Inc.	Solids Modeler (MAGI)
Calma Co.	GEOMOD, Prism DDM
Evans & Sutherland Computer Co.	ROMULUS
Ferranti Infographics	CAM-X ROMULUS
GMWC	RUCAPS
IBM	CADAM
Intergraph Corp.	Solid Modeler
Manufacturing & Consulting Services	OMNISOLIDS
Group C	
Aries Technology	Concept Station
Autodesk	Auto Solid
Automation Technology Products	CIMPLEX
British Technology Group	VOLE
Cimlink Inc.	Component Geometry Modeller
CAEtec Software Inc.	PRO-SOLID
Catronix Corp.	CATSOLID
Cubicomp Corp.	CS-5 PolyCAD 10
CSA	Solid Modeler
Gerber Systems Technology Inc.	GST-Solid
Graftek	Solid Modeling System
Gould	Gemsmith
Harris Corp.	HarrisCAD
Hewlett-Packard	SMD-Solid Modeling Design
Interactive Computer Modeling Inc.	GMS
Isykon	PROREN
Norsk Data	TECHNOVISION
Pafec Inc.	Boxer
Parametric Technology	N/A

(Continued)

Table 4-8 (Continued)

Solid Modeling Market Share Analysis

Company	Product
Group C (Continued)	
PDA Engineering	PATRAN II
Perspective Design Ltd.	MicroSolid
Phoenix Data Systems	Insight
Sperry Corp.	CIM/ME Solid Modeler
Swanson Analysis Systems Inc.	ANSYS
Tektronix Inc.	PATRAN II

N/A = Not Available
Notes: Group A contains companies with products installed on more than 750 workstations
Group B contains companies with products installed on more than 200 and less than 751 workstations
Group C contains companies with products in development, in beta test, or recently released with up to 200 workstations installed

Source: Dataquest
July 1988

DATAQUEST ANALYSIS

The Promise

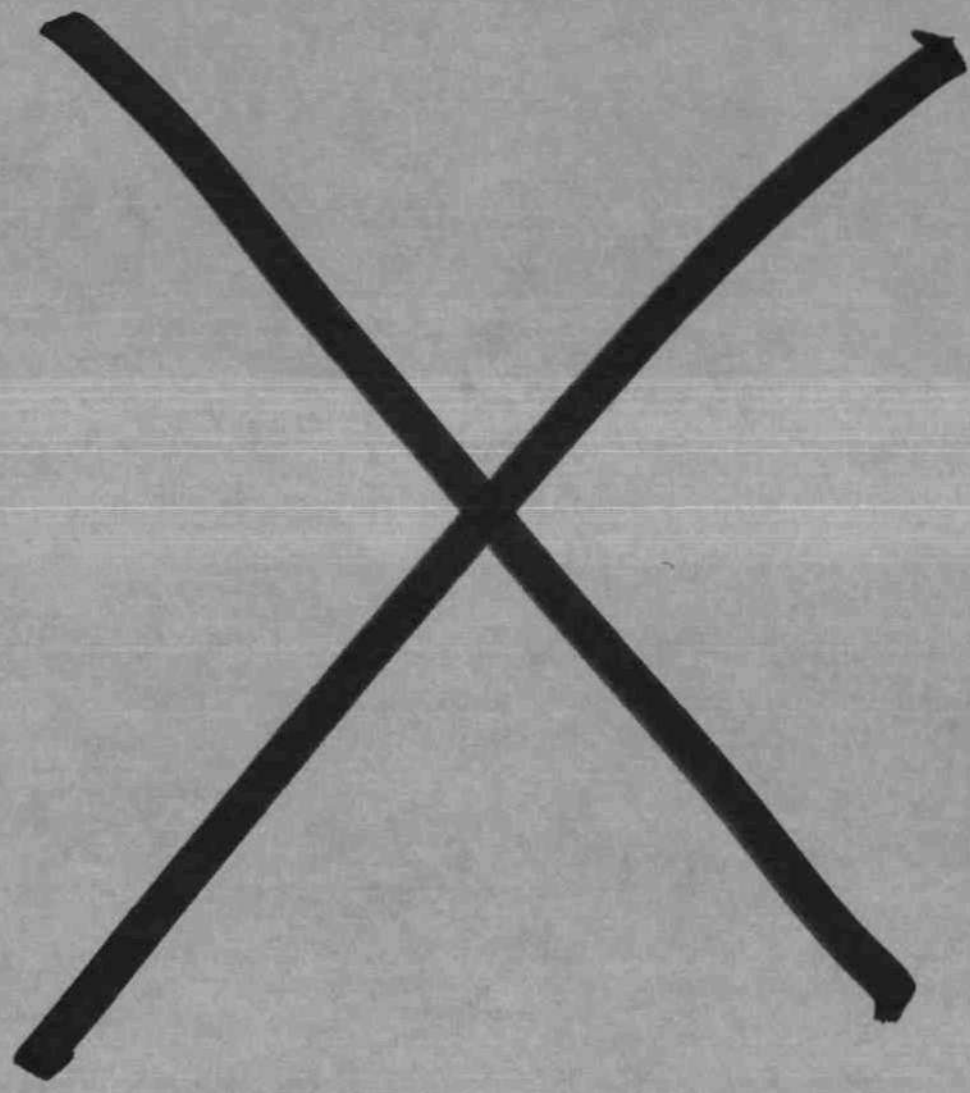
The promise of real-world simulation in a computer system conjures visions of electronic sculpting and forming with the ease of hands on clay. The designer's eye gazes upon the full-color shaded images and sees a new product evolve from an idea to a tested concept in an afternoon. The promise of products optimized for performance and quality will result in improved profitability for the company. The full realization of this promise will revolutionize the industrial sector.

The Wait

Remarkable progress has been made in turning promise into reality. Niche markets have demonstrated many of the concepts, proving their feasibility. Conceptual design has been the most successful niche market, proving the effective combination of solid modeling and analysis. Close integration with other design and manufacturing applications is in development. The future of solid modeling is directly dependent upon the successful implementation of the fully integrated system; the add-on approach will not serve the real needs of the user. The application packages must be able to depend on the availability of solid modeling information to reach the next plateau of system performance and functionality.

The Winners

The person, group, department, division, and/or company that understands the effective use of solids-based CAD/CAM will have a basic competitive advantage over the nonusers. Products that are produced from CAD/CAM systems based on solid modeling and on the application packages that take full advantage of the technology will be more competitive, more reliable, less costly, and more profitable. Solid modeling is making the mechanical CAD/CAM business exciting again.



Forecast Data Base Introduction

STRUCTURE OF THE FORECAST DATA BASE

For these research notebooks, the forecast data base is structured in three parts. Each part is found in one of the following appendices:

- History and Forecast—Five years each of history and forecasts, segmented by application, region, and platform
- Market Share—Data for all companies with total company CAD/CAM revenue of $15 million or more, segmented by application, region, and platform
- Company History—Five years of history for all companies with CAD/CAM revenue of $15 million or more, segmented by application

Each applications binder contains its own Appendix A and Appendix B. Appendix C, for all companies and all applications, is found only in the *Industry Overview* notebook.

Information in the forecast data base appendices is presented in table format only. These data are intended to cover all possible market segmentation. Please refer to the applications modules, *Industry Overview*, and each relevant segment for Dataquest's analysis and interpretation of the data.

Definitions of forecasting terms can be found in the glossary located behind the Glossary tab. A list of companies and countries contained in the data base and a description of forecasting methodology can be found in the section entitled "Introduction to the Service" that appears in each binder.

The forecast data base hierarchy is reflected in each of the reports. The History and Forecast and Market Share appendices are organized as follows:

- Application—All, mechanical, facilities design, mapping, electronic design automation, electronic CAE, IC layout, and PCB layout by
  - Region—Worldwide, North America, Europe, Far East, and Rest of World by
    - Platform—All, technical workstation, host-dependent, and personal computer

DOUBLE COUNTING

Dataquest takes great care to avoid double counting company revenue and shipment data in our estimates for the total market. To avoid this, we collect information on vendors' total CAD/CAM revenue as well as OEM revenue, or revenue derived from sales to another CAD/CAM company for its resale. OEM revenue is then subtracted from total company revenue to count just end-user sales.

We do, however, distinguish between distributors such as those companies that provide a sales service for a CAD/CAM vendor's product and true OEMs. In most cases, the distributors in our data base are Japanese companies that sell, install, and/or service CAD/CAM products for a vendor based outside of Japan. The following guideline and examples illustrate our definitions and how we avoid double counting.

- Computer manufacturers—We collect and count only revenue direct to end users, either turnkey or hardware only. For example, we report $110 million for Sun Microsystems, which is 50 percent of that company's total CAD/CAM revenue. The unreported $110 million is from sales to OEM customers.

- Software vendors—We collect total CAD/CAM sales, then subtract any reported OEM revenue. For example, CADAM reported $53 million in total CAD/CAM revenue, of which $17 million was through OEM channels. To arrive at CADAM's end-user sales of $36 million, the amount we use to calculate market share, we subtracted $17 million from $53 million.

- Distributors—Seiko Instruments, based in Japan, reported $89.5 million in CAD/CAM sales. Seiko is a distributor for Daisy Systems and McDonnell Douglas, as well as a vendor of its own proprietary products. Only the portion of Seiko's revenue that is derived from its own products is included in the total market calculation, even though we show all of Seiko's revenue in the Asian segment market share tables.

REPORTING CHANGES FROM 1986 TO 1987

In order to best serve our clients' needs, we continue to expand the scope of how we report on the CAD/CAM market. For the current reports, dated July 1988, the changes noted in the following subsections have been made.

Integrated Worldwide Data Base

Since 1985, Dataquest has been collecting sales information on seven European regions and Japan. In addition, in 1988, we have collected information on five other Asian regions for the first time. We included all regional data in the CAD/CAM data base, thus achieving a truly integrated, worldwide data base. Data on individual European and Asian countries are available in the respective CCIS segments.

Turnkey and Unbundled Forecasts

Because of the pronounced trend toward users purchasing CAD/CAM products directly from the original suppliers, thus bypassing the turnkey channel, we expanded the level at which we forecast. Dataquest now forecasts the unbundled and turnkey channels individually, giving more clarification and analysis to each.

PC-Based CAD/CAM Software Companies

To best analyze and report on the trends of the personal CAD market, we have expanded our data collection to include revenue information from 35 additional companies participating in this segment. Most of these companies have revenue of significantly less than $15 million; for the CCIS application and regional segments, they are included in the "Other" category. Refer to the personal CAD segment binder for complete information on all of the companies participating in the PC market.

PC Software Units

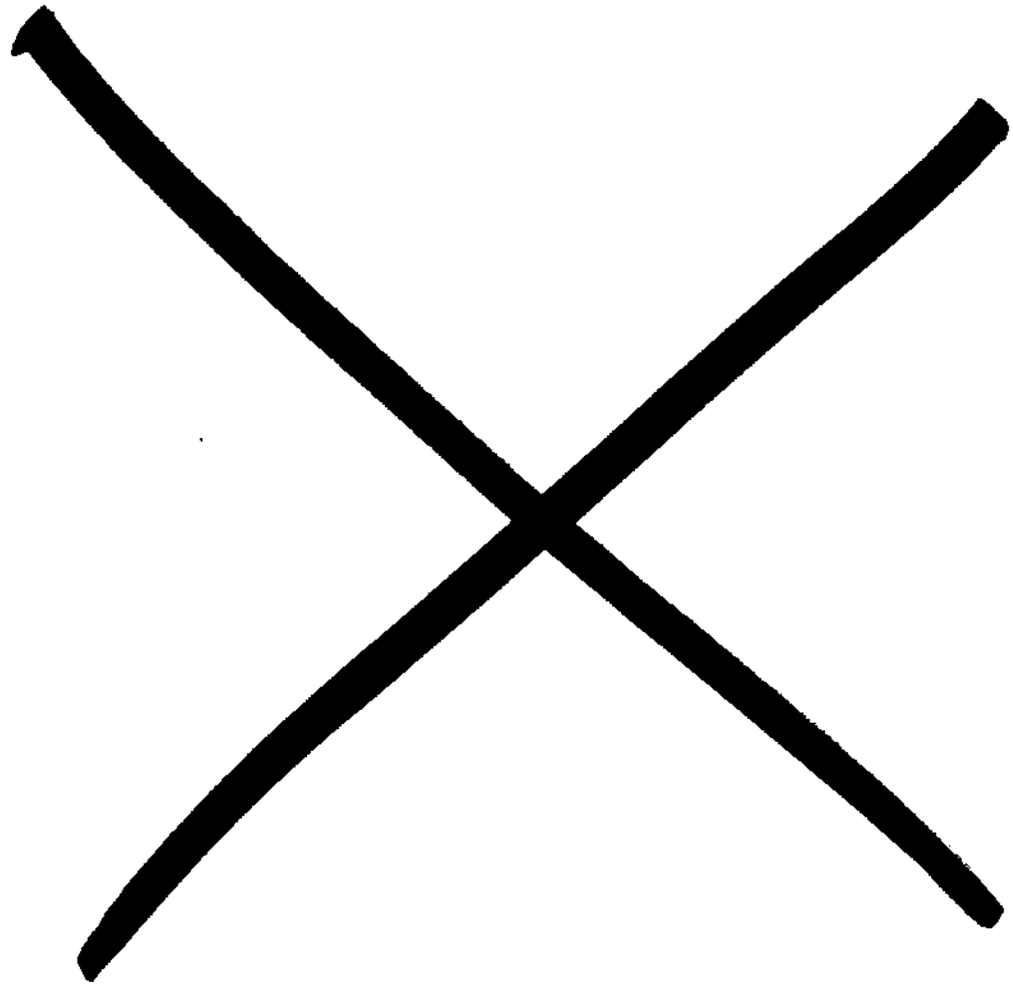
For the first time, Dataquest's CCIS is reporting software units sold; we include this measure in our market share estimates. Because of the high need for unit information in the PC CAD segment, this information is available first and only in our personal CAD segment binder.

Installed Base Versus Workstations Shipped to Date

We have developed a retirement model that takes into account platform and year sold to calculate installed base. The retirement model, in tandem with our forecast by platform, provides clients with product life cycle analysis and data. We differentiate between installed base and workstations shipped to date in such a way that the latter is shown only on a company basis and installed base is calculated only at the aggregate market level.

More Information in the History and Forecast Tables

Three new line items are included in the History and Forecast Appendix: Turnkey versus hardware-only average system price, total hardware revenue, and bundled versus unbundled software revenue. So that clients can better understand the turnkey versus unbundled channels, and because we now forecast at this level, we distinguish system pricing and software revenue based on point of sale. For convenience, the sum of CPU, workstation, and peripheral revenue is shown in the hardware revenue line.



Appendix A—Forecast

INTRODUCTION

The following history and forecast tables present Dataquest's 10-year CAD/CAM market window. The tables contained in this section represent our estimates for the years 1983 through 1987 and our forecasts for 1988 through 1992. Each table is a consolidation of all the companies contained in our data base model for each applicable segment.

Please refer to the section entitled "Introduction to the Service" for a complete list of companies, forecasting methodologies, and caveats. Forecasting terms and definitions can be found behind the Glossary tab.

This chapter is structured as follows:

- Application by
  - Region by
    - Platform

TABLE NUMBER: 1
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Worldwide
PLATFORM: All Platforms

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	1,818	14,904	28,834	65,583	102,287	132,450	164,230	198,860	227,630	248,890	174%	19%
Workstation Shipments	9,337	24,671	45,874	85,676	127,152	160,510	193,950	229,080	256,320	273,900	92%	17%
CPU Installed Base	2,159	12,708	39,889	97,658	199,181	328,100	481,180	654,290	834,090	1,007,820	210%	38%
Workstation Installed Base	9,746	27,030	69,402	143,593	267,896	421,260	598,270	791,990	985,400	1,163,010	129%	34%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	596.9	536.9	192.1	121.9	80.9	69.8	59.9	52.9	47.7	43.1	-39%	-12%
Hardware-Only ASP	471.0	27.8	23.1	22.7	17.9	16.2	14.9	13.9	12.8	11.6	-56%	-8%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	2,010	2,965	3,233	3,620	3,879	4,129	4,174	3,985	NA	4%
CPU Revenue	NA	NA	953	1,318	1,485	1,484	1,613	1,742	1,787	1,729	NA	3%
Workstation Revenue	NA	NA	788	1,232	1,293	1,679	1,803	1,924	1,950	1,866	NA	8%
Peripheral Revenue	NA	NA	269	415	455	457	464	463	437	390	NA	-3%
Software Revenue	NA	NA	539	757	1,041	1,413	1,794	2,145	2,493	2,768	NA	22%
Bundled	NA	NA	445	567	607	759	864	960	1,028	1,040	NA	11%
Unbundled	NA	NA	94	190	434	655	930	1,185	1,465	1,728	NA	32%
Service Revenue	220	270	361	522	718	853	964	1,094	1,198	1,277	34%	12%
Total Revenue	1,266	1,931	2,937	4,268	4,993	5,886	6,637	7,367	7,864	8,030	41%	10%
Increase over Prior Year	NA	52%	52%	45%	17%	18%	13%	11%	7%	2%		

Source: Dataquest
July 1988

TABLE NUMBER: 2
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Worldwide
PLATFORM: Technical Workstation

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	130	1,029	4,552	10,584	22,182	36,560	56,160	81,820	109,430	133,260	262%	43%
Workstation Shipments	130	1,029	4,552	10,584	22,182	36,560	56,160	81,820	109,430	133,260	262%	43%
CPU Installed Base	112	865	5,068	14,541	36,699	73,100	128,590	208,210	312,000	433,160	326%	64%
Workstation Installed Base	112	865	5,068	14,541	36,699	73,100	128,590	208,210	312,000	433,160	326%	64%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	133.6	116.9	63.0	64.6	47.0	45.0	41.7	38.5	35.6	33.0	-23%	-7%
Hardware-Only ASP	40.0	30.6	30.5	26.1	24.6	22.3	20.1	18.4	16.5	14.8	-11%	-10%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	169	388	649	995	1,358	1,758	2,077	2,222	NA	28%
CPU Revenue	NA	NA	65	165	272	444	616	808	963	1,037	NA	31%
Workstation Revenue	NA	NA	65	165	272	444	616	808	963	1,037	NA	31%
Peripheral Revenue	NA	NA	39	57	105	107	125	143	152	149	NA	7%
Software Revenue	NA	NA	87	175	344	531	784	1,080	1,416	1,716	NA	38%
Bundled	NA	NA	68	136	216	301	393	501	605	673	NA	25%
Unbundled	NA	NA	19	39	128	231	392	579	811	1,043	NA	52%
Service Revenue	2	13	34	78	189	284	398	538	679	811	209%	34%
Total Revenue	13	95	295	653	1,182	1,811	2,540	3,375	4,172	4,750	207%	32%
Increase over Prior Year	NA	613%	210%	121%	81%	53%	40%	33%	24%	14%		

Source: Dataquest
July 1988

TABLE NUMBER: 3
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Worldwide
PLATFORM: Host-Dependent

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	1,689	2,349	4,269	6,594	8,550	9,610	10,190	10,570	10,470	9,820	50%	3%
Workstation Shipments	9,207	12,116	21,309	26,687	33,415	37,670	39,910	40,790	39,160	34,830	38%	1%
CPU Installed Base	2,047	3,609	7,388	13,054	21,604	31,220	41,400	51,970	62,440	72,260	80%	27%
Workstation Installed Base	9,634	17,931	36,901	58,989	90,319	124,380	158,490	189,680	213,750	227,440	75%	20%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	617.7	670.2	500.9	508.4	316.7	291.9	266.6	243.0	222.1	203.6	-15%	-8%
Hardware-Only ASP	585.7	428.5	398.5	259.4	253.8	227.5	204.3	186.5	165.8	146.8	-19%	-10%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	1,699	2,275	2,204	2,232	2,125	1,991	1,763	1,478	NA	-8%
CPU Revenue	NA	NA	822	1,022	1,048	862	817	762	672	561	NA	-12%
Workstation Revenue	NA	NA	658	937	856	1,057	1,007	944	835	699	NA	-4%
Peripheral Revenue	NA	NA	219	316	300	313	301	285	256	218	NA	-6%
Software Revenue	NA	NA	397	439	509	597	659	677	683	661	NA	5%
Bundled	NA	NA	342	349	296	327	326	318	299	266	NA	-2%
Unbundled	NA	NA	55	90	213	271	333	359	384	394	NA	13%
Service Revenue	218	256	325	413	489	515	505	493	458	407	22%	-4%
Total Revenue	1,253	1,711	2,441	3,129	3,203	3,345	3,289	3,161	2,904	2,545	26%	-4%
Increase over Prior Year	NA	37%	43%	28%	2%	4%	-2%	-4%	-8%	-12%		

Source: Dataquest
July 1988

TABLE NUMBER: 4
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Worldwide
PLATFORM: Personal Computer

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	0	11,526	20,013	48,405	71,556	86,280	97,880	106,470	107,740	105,810	NA	8%
Workstation Shipments	0	11,526	20,013	48,405	71,556	86,280	97,880	106,470	107,740	105,810	NA	8%
CPU Installed Base	0	8,234	27,434	70,063	140,878	223,780	311,190	394,110	459,650	502,400	NA	29%
Workstation Installed Base	0	8,234	27,434	70,063	140,878	223,780	311,190	394,110	459,650	502,400	NA	29%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	.0	.0	25.4	22.6	19.6	18.2	16.9	15.7	14.6	13.6	NA	-7%
Hardware-Only ASP	.0	10.7	4.7	4.2	3.9	3.6	3.3	3.0	2.7	2.4	NA	-9%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	143	303	380	393	397	379	334	285	NA	-6%
CPU Revenue	NA	NA	66	130	166	178	180	172	152	131	NA	-5%
Workstation Revenue	NA	NA	66	130	165	178	180	172	152	131	NA	-5%
Peripheral Revenue	NA	NA	11	42	50	37	38	35	29	23	NA	-14%
Software Revenue	NA	NA	55	143	188	284	351	388	394	391	NA	16%
Bundled	NA	NA	35	82	95	131	146	142	123	100	NA	1%
Unbundled	NA	NA	20	61	93	153	205	247	271	291	NA	26%
Service Revenue	0	1	3	31	40	53	61	63	61	58	NA	8%
Total Revenue	0	124	201	486	608	730	809	831	788	735	NA	4%
Increase over Prior Year	NA	NA	62%	141%	25%	20%	11%	3%	-5%	-7%		

Source: Dataquest
July 1988

TABLE NUMBER: 5
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: North America
PLATFORM: All Platforms

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	1,133	10,185	14,870	35,101	53,450	67,120	82,250	99,960	115,560	128,210	162%	19%
Workstation Shipments	5,139	16,671	24,819	44,039	63,656	77,760	93,090	110,830	125,980	137,350	88%	17%
CPU Installed Base	1,847	12,032	26,902	62,001	114,712	179,210	253,890	338,250	426,330	513,310	181%	35%
Workstation Installed Base	8,138	24,788	49,447	92,842	154,181	226,410	307,210	395,380	484,500	569,550	109%	30%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	570.5	523.0	235.7	135.6	85.4	74.3	63.0	53.9	47.3	41.8	-38%	-13%
Hardware-Only ASP	394.1	21.6	22.6	18.4	15.3	13.9	13.0	12.3	11.5	10.6	-56%	-7%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	1,005	1,296	1,337	1,460	1,568	1,699	1,764	1,734	NA	5%
CPU Revenue	NA	NA	461	593	600	601	657	723	762	758	NA	5%
Workstation Revenue	NA	NA	418	536	547	689	740	803	834	820	NA	8%
Peripheral Revenue	NA	NA	126	167	190	170	171	173	168	156	NA	-4%
Software Revenue	NA	NA	292	308	379	492	621	741	862	960	NA	20%
Bundled	NA	NA	228	202	199	226	252	280	305	314	NA	9%
Unbundled	NA	NA	64	106	180	266	370	461	557	647	NA	29%
Service Revenue	125	173	245	270	305	351	389	439	480	508	25%	11%
Total Revenue	737	1,206	1,542	1,873	2,022	2,303	2,578	2,879	3,106	3,203	29%	10%
Increase over Prior Year	NA	64%	28%	21%	8%	14%	12%	12%	8%	3%		

Source: Dataquest
July 1988

TABLE NUMBER: 6
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: North America
PLATFORM: Technical Workstation

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	112	714	2,524	5,575	10,197	16,420	25,850	38,470	52,380	65,280	209%	45%
Workstation Shipments	112	714	2,524	5,575	10,197	16,420	25,850	38,470	52,380	65,280	209%	45%
CPU Installed Base	112	826	3,350	8,923	19,098	35,390	60,770	97,900	147,170	206,350	262%	61%
Workstation Installed Base	112	826	3,350	8,923	19,098	35,390	60,770	97,900	147,170	206,350	262%	61%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	123.6	109.9	67.9	56.3	40.7	37.9	35.2	32.7	30.3	28.1	-24%	-7%
Hardware-Only ASP	40.0	30.5	27.8	23.8	23.7	21.6	19.6	18.0	16.2	14.6	-12%	-9%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	98	178	268	389	550	739	898	994	NA	30%
CPU Revenue	NA	NA	38	77	113	175	252	341	418	464	NA	33%
Workstation Revenue	NA	NA	38	77	113	175	252	341	418	464	NA	33%
Peripheral Revenue	NA	NA	21	24	42	38	46	56	63	66	NA	10%
Software Revenue	NA	NA	51	85	115	169	249	342	448	546	NA	37%
Bundled	NA	NA	38	59	74	96	123	156	188	209	NA	23%
Unbundled	NA	NA	13	26	40	74	125	186	260	337	NA	53%
Service Revenue	1	8	21	44	74	107	150	205	258	308	167%	33%
Total Revenue	10	60	170	307	456	665	949	1,285	1,605	1,848	161%	32%
Increase over Prior Year	NA	508%	184%	81%	48%	46%	43%	35%	25%	15%		

Source: Dataquest
July 1988

TABLE NUMBER: 7
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: North America
PLATFORM: Host-Dependent

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	1,021	1,507	2,202	3,235	3,703	4,080	4,250	4,360	4,370	4,150	38%	2%
Workstation Shipments	5,027	7,993	12,152	12,173	13,910	14,720	15,090	15,230	14,790	13,280	29%	-1%
CPU Installed Base	1,736	3,242	5,444	8,679	12,383	16,460	20,710	25,070	29,450	33,600	63%	22%
Workstation Installed Base	8,027	15,998	27,989	39,521	51,851	63,670	74,030	82,200	87,610	89,840	59%	12%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	594.1	649.7	509.2	484.6	317.8	292.4	269.0	247.1	226.7	207.5	-14%	-8%
Hardware-Only ASP	568.5	428.8	342.5	217.8	230.4	207.4	186.6	171.1	152.8	135.9	-20%	-10%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	851	995	909	902	847	791	710	602	NA	-8%
CPU Revenue	NA	NA	396	459	412	347	324	301	270	228	NA	-11%
Workstation Revenue	NA	NA	353	403	359	434	408	381	342	289	NA	-4%
Peripheral Revenue	NA	NA	102	133	137	121	115	108	99	85	NA	-9%
Software Revenue	NA	NA	224	167	198	229	253	261	268	261	NA	6%
Bundled	NA	NA	186	127	109	113	111	108	104	94	NA	-3%
Unbundled	NA	NA	38	39	90	115	142	153	164	167	NA	13%
Service Revenue	124	164	223	216	221	231	222	217	203	181	16%	-4%
Total Revenue	727	1,085	1,297	1,377	1,328	1,362	1,322	1,268	1,181	1,045	16%	-5%
Increase over Prior Year	NA	49%	20%	6%	-4%	3%	-3%	-4%	-7%	-12%		

Source: Dataquest
July 1988

TABLE NUMBER: 8
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: North America
PLATFORM: Personal Computer

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	0	7,964	10,143	26,291	39,550	46,630	52,160	57,130	58,810	58,790	NA	8%
Workstation Shipments	0	7,964	10,143	26,291	39,550	46,630	52,160	57,130	58,810	58,790	NA	8%
CPU Installed Base	0	7,964	18,108	44,399	83,232	127,350	172,410	215,280	249,710	273,360	NA	27%
Workstation Installed Base	0	7,964	18,108	44,399	83,232	127,350	172,410	215,280	249,710	273,360	NA	27%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	.0	.0	20.7	19.5	15.8	14.5	13.4	12.3	11.3	10.3	NA	-8%
Hardware-Only ASP	.0	7.7	4.6	3.8	3.7	3.4	3.1	2.9	2.6	2.3	NA	-9%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	57	123	161	168	171	170	155	138	NA	-3%
CPU Revenue	NA	NA	28	57	75	79	81	81	74	66	NA	-3%
Workstation Revenue	NA	NA	28	57	75	79	81	81	74	66	NA	-3%
Peripheral Revenue	NA	NA	2	10	11	10	9	9	7	6	NA	-12%
Software Revenue	NA	NA	17	56	66	94	119	138	147	154	NA	18%
Bundled	NA	NA	4	16	17	17	17	16	14	11	NA	-8%
Unbundled	NA	NA	13	40	50	77	102	123	133	143	NA	24%
Service Revenue	0	1	1	10	10	14	16	18	18	19	NA	12%
Total Revenue	0	62	75	189	237	276	306	326	320	310	NA	5%
Increase over Prior Year	NA	NA	22%	152%	26%	16%	11%	6%	-2%	-3%		

Source: Dataquest
July 1988

TABLE NUMBER: 9
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Europe
PLATFORM: All Platforms

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	428	2,129	8,606	15,762	24,876	31,260	37,640	44,560	48,820	50,200	176%	15%
Workstation Shipments	2,176	3,704	12,338	21,560	31,704	38,320	44,610	51,360	55,030	55,430	95%	12%
CPU Installed Base	0	0	8,606	24,368	49,244	79,890	115,070	153,250	190,400	223,210	NA	35%
Workstation Installed Base	0	0	12,338	33,898	65,602	103,260	145,070	188,640	228,630	261,030	NA	32%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	564.1	520.1	225.8	133.1	67.8	56.8	48.1	42.2	37.4	33.2	-41%	-13%
Hardware-Only ASP	578.9	50.5	18.4	19.1	19.1	18.0	16.6	15.3	14.2	13.0	-57%	-7%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	539	809	835	908	944	976	943	846	NA	0%
CPU Revenue	NA	NA	252	352	375	372	392	411	402	365	NA	-0%
Workstation Revenue	NA	NA	200	342	344	417	435	451	437	394	NA	3%
Peripheral Revenue	NA	NA	86	115	116	119	117	114	103	87	NA	-6%
Software Revenue	NA	NA	129	233	379	511	677	836	1,001	1,138	NA	25%
Bundled	NA	NA	107	178	176	204	230	256	270	265	NA	9%
Unbundled	NA	NA	22	54	203	308	447	580	731	874	NA	34%
Service Revenue	51	59	69	109	261	303	349	406	458	506	50%	14%
Total Revenue	293	396	730	1,171	1,475	1,723	1,971	2,218	2,401	2,491	50%	11%
Increase over Prior Year	NA	35%	84%	60%	26%	17%	14%	13%	8%	4%		

Source: Dataquest
July 1988

TABLE NUMBER: 10
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Europe
PLATFORM: Technical Workstation

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	18	156	1,248	3,260	7,240	10,850	15,540	21,390	27,090	30,920	348%	34%
Workstation Shipments	18	156	1,248	3,260	7,240	10,850	15,540	21,390	27,090	30,920	348%	34%
CPU Installed Base	0	0	1,248	4,508	11,748	22,580	37,960	58,730	84,070	111,180	NA	57%
Workstation Installed Base	0	0	1,248	4,508	11,748	22,580	37,960	58,730	84,070	111,180	NA	57%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	159.8	119.9	52.3	66.1	41.7	38.1	34.8	31.7	28.8	26.2	-29%	-9%
Hardware-Only ASP	.0	30.9	45.3	37.2	25.9	23.1	20.6	18.5	16.4	14.4	NA	-11%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	45	135	205	274	349	426	472	468	NA	18%
CPU Revenue	NA	NA	16	57	86	121	157	195	218	218	NA	20%
Workstation Revenue	NA	NA	16	57	86	121	157	195	218	218	NA	20%
Peripheral Revenue	NA	NA	13	22	33	32	34	37	36	32	NA	-1%
Software Revenue	NA	NA	22	61	148	230	351	489	646	787	NA	40%
Bundled	NA	NA	19	54	72	94	119	149	174	184	NA	21%
Unbundled	NA	NA	4	7	76	136	231	340	473	603	NA	51%
Service Revenue	1	3	10	17	84	120	167	227	291	356	239%	34%
Total Revenue	4	16	78	225	436	625	867	1,142	1,409	1,610	234%	30%
Increase over Prior Year	NA	365%	377%	190%	94%	43%	39%	32%	23%	14%		

Source: Dataquest
July 1988

TABLE NUMBER: 11
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Europe
PLATFORM: Host-Dependent

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	410	526	864	1,339	2,875	3,220	3,390	3,490	3,400	3,110	63%	2%
Workstation Shipments	2,158	2,101	4,597	7,136	9,703	10,280	10,360	10,290	9,610	8,340	46%	-3%
CPU Installed Base	0	0	864	2,203	5,078	8,300	11,690	15,180	18,580	21,700	NA	34%
Workstation Installed Base	0	0	4,597	11,733	21,436	31,670	41,680	50,580	56,810	59,510	NA	23%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	585.3	621.7	581.4	543.2	213.5	191.8	172.3	154.9	139.0	124.5	-22%	-10%
Hardware-Only ASP	578.9	409.6	1014.0	542.7	270.0	237.6	209.1	188.0	164.2	142.8	-17%	-12%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	456	614	559	562	526	485	418	337	NA	-10%
CPU Revenue	NA	NA	218	267	255	218	203	186	160	128	NA	-13%
Workstation Revenue	NA	NA	166	257	225	263	246	227	195	157	NA	-7%
Peripheral Revenue	NA	NA	72	90	79	81	77	72	63	51	NA	-8%
Software Revenue	NA	NA	99	149	194	220	249	259	263	258	NA	6%
Bundled	NA	NA	87	113	91	91	90	87	79	67	NA	-6%
Unbundled	NA	NA	13	36	102	129	159	172	184	190	NA	13%
Service Revenue	50	56	58	88	170	171	168	164	152	136	36%	-4%
Total Revenue	290	354	607	851	922	954	943	908	833	730	34%	-5%
Increase over Prior Year	NA	22%	71%	40%	8%	3%	-1%	-4%	-8%	-12%		

Source: Dataquest
July 1988

TABLE NUMBER: 12
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Europe
PLATFORM: Personal Computer

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	0	1,446	6,494	11,164	14,760	17,180	18,710	19,680	18,340	16,160	NA	2%
Workstation Shipments	0	1,446	6,494	11,164	14,760	17,180	18,710	19,680	18,340	16,160	NA	2%
CPU Installed Base	0	0	6,494	17,657	32,417	49,020	65,430	79,330	87,750	90,330	NA	23%
Workstation Installed Base	0	0	6,494	17,657	32,417	49,020	65,430	79,330	87,750	90,330	NA	23%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	.0	.0	24.2	15.7	10.6	9.7	8.9	8.3	7.6	7.0	NA	-8%
Hardware-Only ASP	.0	17.3	4.6	4.9	4.4	4.0	3.6	3.2	2.9	2.6	NA	-10%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	37	59	71	72	70	65	53	42	NA	-10%
CPU Revenue	NA	NA	18	28	34	33	32	30	25	19	NA	-11%
Workstation Revenue	NA	NA	18	28	34	33	32	30	25	19	NA	-11%
Peripheral Revenue	NA	NA	2	3	4	6	6	5	4	3	NA	-3%
Software Revenue	NA	NA	7	22	38	61	78	89	92	93	NA	20%
Bundled	NA	NA	2	11	13	18	21	20	17	13	NA	1%
Unbundled	NA	NA	5	11	25	42	57	68	75	80	NA	26%
Service Revenue	0	0	1	4	7	12	14	15	15	15	NA	17%
Total Revenue	0	25	45	95	117	144	161	168	160	150	NA	5%
Increase over Prior Year	NA	NA	77%	111%	23%	24%	12%	4%	-5%	-6%		

Source: Dataquest
July 1988

TABLE NUMBER: 13
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Asia
PLATFORM: All Platforms

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	200	2,227	4,908	13,341	19,599	27,820	35,560	42,700	49,510	54,850	215%	23%
Workstation Shipments	1,646	3,653	7,966	18,186	26,829	37,290	46,290	53,820	60,190	64,260	101%	19%
CPU Installed Base	0	0	3,255	8,784	28,383	55,990	90,660	130,280	172,770	214,430	NA	50%
Workstation Installed Base	0	0	4,688	12,271	39,100	76,160	121,400	171,490	222,870	270,150	NA	47%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	814.4	659.1	125.5	97.6	90.4	79.0	69.7	64.1	60.4	56.7	-42%	-9%
Hardware-Only ASP	653.5	35.4	63.1	39.7	29.2	23.7	20.7	18.7	16.4	14.3	-54%	-13%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	430	761	967	1,127	1,207	1,260	1,271	1,217	NA	5%
CPU Revenue	NA	NA	222	318	465	460	498	526	540	524	NA	2%
Workstation Revenue	NA	NA	155	318	364	513	550	577	585	563	NA	9%
Peripheral Revenue	NA	NA	52	125	138	155	159	156	146	130	NA	-1%
Software Revenue	NA	NA	110	207	266	384	458	519	575	611	NA	18%
Bundled	NA	NA	103	180	223	314	360	394	421	430	NA	14%
Unbundled	NA	NA	7	28	43	70	98	125	154	182	NA	34%
Service Revenue	34	31	40	129	137	177	196	210	220	222	41%	10%
Total Revenue	191	270	612	1,099	1,370	1,688	1,861	1,989	2,066	2,051	64%	8%
Increase over Prior Year	NA	42%	126%	80%	25%	23%	10%	7%	4%	-1%		

Source: Dataquest
July 1988

TABLE NUMBER: 14
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Asia
PLATFORM: Technical Workstation

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	0	120	639	1,366	4,250	8,290	12,830	18,600	25,440	31,510	NA	49%
Workstation Shipments	0	120	639	1,366	4,250	8,290	12,830	18,600	25,440	31,510	NA	49%
CPU Installed Base	0	0	290	547	4,797	13,080	25,890	44,330	69,160	98,840	NA	83%
Workstation Installed Base	0	0	290	547	4,797	13,080	25,890	44,330	69,160	98,840	NA	83%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	.0	129.5	68.3	98.3	75.1	69.5	64.2	59.5	55.1	50.9	NA	-7%
Hardware-Only ASP	.0	31.1	29.5	25.4	25.4	23.0	20.7	18.9	17.1	15.3	NA	-10%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	20	62	163	308	416	528	630	677	NA	33%
CPU Revenue	NA	NA	8	26	67	136	188	242	291	316	NA	36%
Workstation Revenue	NA	NA	8	26	67	136	188	242	291	316	NA	36%
Peripheral Revenue	NA	NA	4	9	28	35	41	45	48	46	NA	10%
Software Revenue	NA	NA	11	26	77	123	171	227	294	351	NA	35%
Bundled	NA	NA	10	21	67	105	141	182	227	262	NA	31%
Unbundled	NA	NA	1	5	10	18	30	45	67	89	NA	54%
Service Revenue	0	1	2	14	29	51	70	91	111	126	NA	35%
Total Revenue	0	13	39	103	269	483	657	846	1,035	1,155	NA	34%
Increase over Prior Year	NA	NA	208%	168%	160%	80%	36%	29%	22%	12%		

Source: Dataquest
July 1988

TABLE NUMBER: 15
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Asia
PLATFORM: Host-Dependent

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	200	261	1,141	1,670	1,743	2,000	2,140	2,210	2,190	2,080	72%	4%
Workstation Shipments	1,646	1,687	4,200	6,515	8,972	11,470	12,870	13,340	12,870	11,490	53%	5%
CPU Installed Base	0	0	652	1,394	3,137	5,140	7,280	9,490	11,680	13,760	NA	34%
Workstation Installed Base	0	0	2,084	4,881	13,853	25,300	38,020	50,700	61,780	69,480	NA	38%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	814.4	876.5	416.1	507.5	523.9	481.8	443.0	406.9	373.0	341.4	-10%	-8%
Hardware-Only ASP	653.5	458.3	271.7	286.0	302.4	271.7	244.1	223.6	199.5	177.3	-18%	-10%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	362	582	673	686	658	612	542	459	NA	-7%
CPU Revenue	NA	NA	194	248	349	267	254	235	207	175	NA	-13%
Workstation Revenue	NA	NA	127	248	248	320	307	286	253	214	NA	-3%
Peripheral Revenue	NA	NA	41	86	75	100	97	91	82	71	NA	-1%
Software Revenue	NA	NA	68	118	107	134	138	136	132	122	NA	3%
Bundled	NA	NA	64	104	92	115	114	110	104	94	NA	1%
Unbundled	NA	NA	4	14	15	19	24	26	28	28	NA	13%
Service Revenue	34	29	37	97	86	98	96	90	82	72	26%	-4%
Total Revenue	191	226	494	799	866	919	892	838	756	654	46%	-5%
Increase over Prior Year	NA	18%	119%	62%	8%	6%	-3%	-6%	-10%	-14%		

Source: Dataquest
July 1988

TABLE NUMBER: 16
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Asia
PLATFORM: Personal Computer

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	0	1,845	3,127	10,306	13,606	17,540	20,580	21,880	21,880	21,260	NA	9%
Workstation Shipments	0	1,845	3,127	10,306	13,606	17,540	20,580	21,880	21,880	21,260	NA	9%
CPU Installed Base	0	0	2,314	6,844	20,450	37,780	57,490	76,450	91,920	101,830	NA	38%
Workstation Installed Base	0	0	2,314	6,844	20,450	37,780	57,490	76,450	91,920	101,830	NA	38%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	.0	.0	27.2	26.9	25.5	23.6	21.9	20.5	19.2	18.0	NA	-7%
Hardware-Only ASP	.0	17.5	9.0	4.7	4.1	3.8	3.5	3.2	2.9	2.6	NA	-9%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	47	117	132	133	133	120	100	81	NA	-9%
CPU Revenue	NA	NA	20	44	49	57	56	50	42	34	NA	-7%
Workstation Revenue	NA	NA	20	44	49	57	56	50	42	34	NA	-7%
Peripheral Revenue	NA	NA	7	29	35	19	21	20	17	13	NA	-18%
Software Revenue	NA	NA	30	63	82	126	149	156	149	138	NA	11%
Bundled	NA	NA	29	55	64	94	105	102	89	73	NA	3%
Unbundled	NA	NA	2	8	17	32	44	53	60	65	NA	30%
Service Revenue	0	0	1	17	22	27	30	29	27	24	NA	2%
Total Revenue	0	32	79	197	236	286	312	305	276	243	NA	1%
Increase over Prior Year	NA	NA	145%	149%	20%	21%	9%	-2%	-10%	-12%		

Source: Dataquest
July 1988

TABLE NUMBER: 17
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Rest of World
PLATFORM: All Platforms

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	58	364	451	1,378	4,363	6,250	8,780	11,640	13,730	15,630	194%	29%
Workstation Shipments	376	644	750	1,891	4,964	7,130	9,960	13,070	15,130	16,860	91%	28%
CPU Installed Base	311	675	1,127	2,504	6,842	13,010	21,560	32,520	44,590	56,870	116%	53%
Workstation Installed Base	1,607	2,243	2,930	4,581	9,014	15,430	24,600	36,490	49,410	62,280	54%	47%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	627.1	528.7	279.1	145.4	80.9	68.1	56.2	48.3	41.5	35.6	-40%	-15%
Hardware-Only ASP	601.2	32.0	29.6	65.1	15.9	14.7	13.7	12.7	11.2	9.6	-60%	-10%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	36	100	94	125	161	194	196	187	NA	15%
CPU Revenue	NA	NA	17	55	45	51	67	82	83	81	NA	12%
Workstation Revenue	NA	NA	15	36	38	60	77	93	94	89	NA	19%
Peripheral Revenue	NA	NA	5	9	11	14	17	20	19	17	NA	9%
Software Revenue	NA	NA	8	9	17	26	37	48	54	59	NA	28%
Bundled	NA	NA	7	6	9	15	22	30	32	32	NA	30%
Unbundled	NA	NA	1	3	8	11	15	19	23	27	NA	27%
Service Revenue	9	7	8	14	16	22	30	38	40	40	15%	21%
Total Revenue	45	58	53	124	126	172	228	281	291	286	29%	18%
Increase over Prior Year	NA	28%	-9%	135%	2%	37%	32%	23%	4%	-2%		

Source: Dataquest
July 1988

TABLE NUMBER: 18
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Rest of World
PLATFORM: Technical Workstation

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	0	39	141	382	495	1,000	1,940	3,360	4,530	5,560	NA	62%
Workstation Shipments	0	39	141	382	495	1,000	1,940	3,360	4,530	5,560	NA	62%
CPU Installed Base	0	39	180	563	1,057	2,050	3,970	7,250	11,600	16,790	NA	74%
Workstation Installed Base	0	39	180	563	1,057	2,050	3,970	7,250	11,600	16,790	NA	74%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	.0	157.5	78.6	60.9	38.5	35.0	31.9	29.0	26.3	23.8	NA	-9%
Hardware-Only ASP	.0	30.4	28.5	27.2	26.6	24.2	22.0	19.8	17.4	15.3	NA	-10%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	6	12	13	24	42	65	77	83	NA	44%
CPU Revenue	NA	NA	2	5	5	11	19	30	36	39	NA	48%
Workstation Revenue	NA	NA	2	5	5	11	19	30	36	39	NA	48%
Peripheral Revenue	NA	NA	1	1	2	2	4	5	5	5	NA	18%
Software Revenue	NA	NA	2	3	5	8	14	22	28	33	NA	47%
Bundled	NA	NA	2	2	3	5	9	14	17	18	NA	43%
Unbundled	NA	NA	0	1	2	3	5	8	11	15	NA	55%
Service Revenue	0	1	1	2	3	6	10	15	19	21	NA	46%
Total Revenue	0	7	9	17	21	38	67	102	124	137	NA	45%
Increase over Prior Year	NA	NA	40%	87%	23%	81%	74%	54%	21%	10%		

Source: Dataquest
July 1988

TABLE NUMBER: 19
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Rest of World
PLATFORM: Host-Dependent

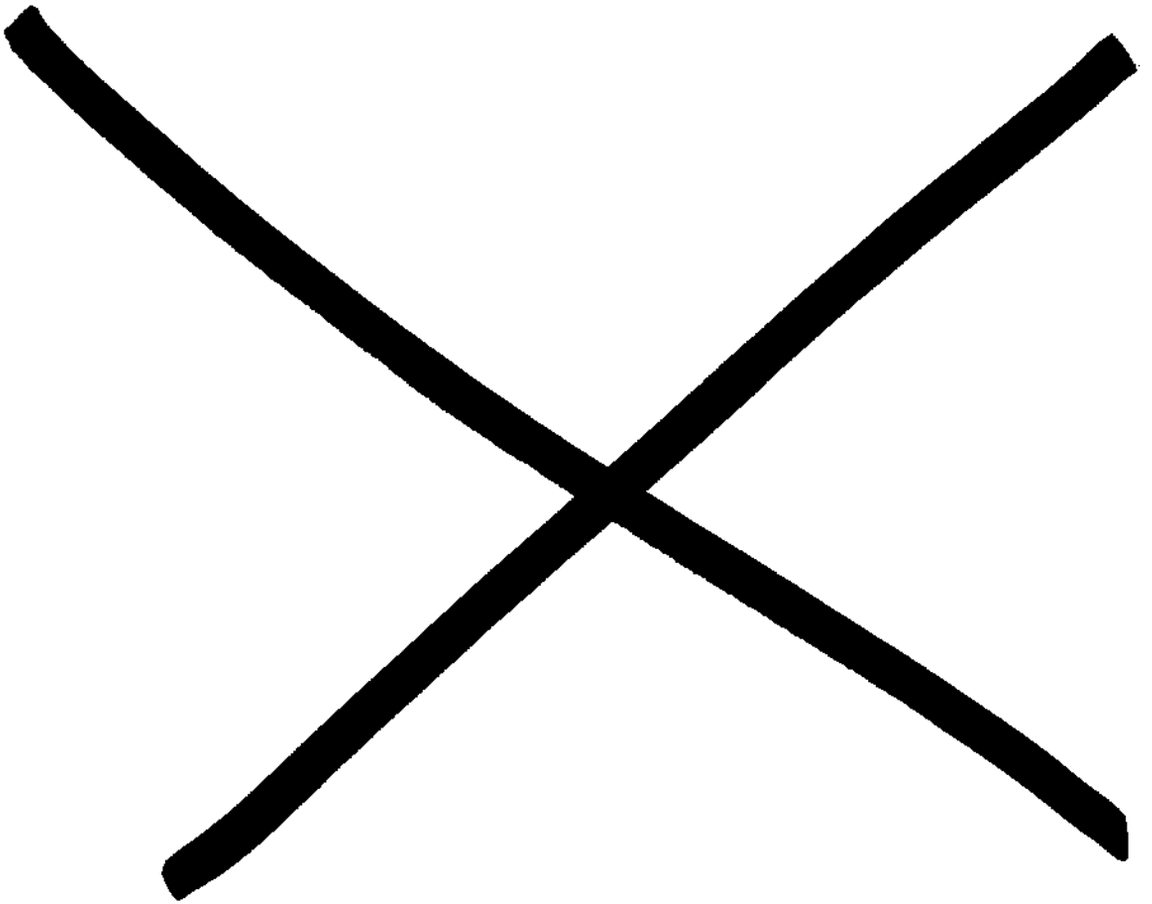
	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	58	55	61	350	229	320	410	500	500	470	41%	15%
Workstation Shipments	376	335	361	863	830	1,200	1,590	1,930	1,890	1,700	22%	15%
CPU Installed Base	311	367	428	778	1,007	1,320	1,730	2,230	2,730	3,200	34%	26%
Workstation Installed Base	1,607	1,934	2,231	2,855	3,178	3,740	4,760	6,200	7,540	8,610	19%	22%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	627.1	816.5	663.2	489.1	423.2	389.3	358.2	329.1	301.8	276.3	-9%	-8%
Hardware-Only ASP	601.2	442.6	351.6	218.0	252.5	227.3	204.5	183.4	163.8	145.7	-19%	-10%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	30	84	64	81	95	103	93	79	NA	4%
CPU Revenue	NA	NA	14	48	31	31	36	39	35	30	NA	-1%
Workstation Revenue	NA	NA	12	29	24	40	46	50	46	39	NA	10%
Peripheral Revenue	NA	NA	4	7	9	10	12	14	13	11	NA	5%
Software Revenue	NA	NA	6	4	10	14	18	21	20	20	NA	14%
Bundled	NA	NA	5	4	5	8	10	12	12	11	NA	17%
Unbundled	NA	NA	0	1	5	6	8	8	8	9	NA	11%
Service Revenue	9	6	7	11	12	15	19	22	20	18	7%	8%
Total Revenue	45	47	42	102	87	110	132	146	134	117	18%	6%
Increase over Prior Year	NA	3%	-11%	144%	-15%	27%	20%	11%	-8%	-13%		

Source: Dataquest
July 1988

TABLE NUMBER: 20
TITLE: History and Forecast
APPLICATION: Mechanical
REGION: Rest of World
PLATFORM: Personal Computer

	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	CAGR 83-87	CAGR 87-92
UNIT SHIPMENT DATA (Workstation Shipments)												
CPU Shipments	0	270	249	645	3,640	4,930	6,430	7,790	8,710	9,600	NA	21%
Workstation Shipments	0	270	249	645	3,640	4,930	6,430	7,790	8,710	9,600	NA	21%
CPU Installed Base	0	270	518	1,163	4,779	9,630	15,860	23,040	30,270	36,880	NA	50%
Workstation Installed Base	0	270	518	1,163	4,779	9,630	15,860	23,040	30,270	36,880	NA	50%
AVERAGE SYSTEM PRICE DATA (Thousands of Dollars)												
Turnkey ASP	.0	.0	31.6	18.9	13.3	12.2	11.3	10.3	9.5	8.7	NA	-8%
Hardware-Only ASP	.0	16.6	4.8	4.0	4.2	3.9	3.6	3.2	2.9	2.6	NA	-9%
REVENUE DATA (Millions of Dollars)												
Hardware Revenue	NA	NA	1	4	16	20	24	26	25	25	NA	9%
CPU Revenue	NA	NA	1	2	8	9	11	12	12	12	NA	8%
Workstation Revenue	NA	NA	1	2	8	9	11	12	12	12	NA	8%
Peripheral Revenue	NA	NA	0	0	0	1	1	1	1	1	NA	25%
Software Revenue	NA	NA	1	2	2	3	5	6	6	7	NA	28%
Bundled	NA	NA	0	0	1	2	3	3	3	3	NA	30%
Unbundled	NA	NA	1	1	1	2	2	3	3	3	NA	26%
Service Revenue	0	0	0	0	0	1	1	1	1	1	NA	21%
Total Revenue	0	5	2	5	18	24	29	32	33	33	NA	12%
Increase over Prior Year	NA	NA	-61%	170%	258%	31%	23%	11%	2%	-1%		

Source: Dataquest
July 1988



Appendix B—Market Share

INTRODUCTION

The following market share tables present Dataquest's vendor estimates for the CAD/CAM industry. It is against Dataquest's corporate policy to publish or release individual forecasts for any company.

Please refer to the section entitled "Introduction to the Service" for information on forecasting methodologies, companies contained within the data base, and caveats. Forecasting terms and definitions can be found behind the Glossary tab.

We have tried to segment the market share data in as many meaningful ways as possible. As the forecast data base tends to be quite large by nature, we have limited market shares to the following structure:

- Application by
  - Region by
    - Platform

Each market share analysis section includes data arranged by total CAD/CAM revenue, hardware revenue, software revenue, and workstation shipments. The sum of hardware and software revenue does not equal total revenue because we did not include revenue derived from servicing CAD/CAM systems for these market share analyses.

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Market Share

TABLE NUMBER: 1
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: All Platforms
REGION: Worldwide
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	1,145.7	849.6	149.2	41,535	22.9%	26.3%	14.3%	32.7%
Digital	631.0	542.3	1.5	3,334	12.6%	16.8%	.1%	2.6%
Computervision	419.1	122.6	148.6	2,673	8.4%	3.8%	14.3%	2.1%
Intergraph	179.9	111.0	32.0	1,576	3.6%	3.4%	3.1%	1.2%
McDonnell Douglas	163.8	79.6	51.8	2,508	3.3%	2.5%	5.0%	2.0%
Control Data	162.3	104.8	20.6	1,066	3.3%	3.2%	2.0%	.8%
Prime	160.7	97.6	25.1	1,744	3.2%	3.0%	2.4%	1.4%
Applicon	125.5	58.4	36.3	2,757	2.5%	1.8%	3.5%	2.2%
Hitachi	98.5	64.1	24.8	1,554	2.0%	2.0%	2.4%	1.2%
Hewlett-Packard	82.4	49.2	26.2	3,699	1.7%	1.5%	2.5%	2.9%
Fujitsu	71.1	46.6	17.4	1,252	1.4%	1.4%	1.7%	1.0%
NEC	66.5	39.5	20.3	1,318	1.3%	1.2%	1.9%	1.0%
Siemens	62.0	42.4	13.4	583	1.2%	1.3%	1.3%	.5%
Mitsubishi Electric	59.5	37.1	16.5	674	1.2%	1.1%	1.6%	.5%
Matra Datavision	55.0	43.1	6.4	600	1.1%	1.3%	.6%	.5%
Apollo	53.0	47.5	.0	2,010	1.1%	1.5%	.0%	1.6%
Hitachi Zosen	51.7	24.5	23.4	522	1.0%	.8%	2.2%	.4%
Auto-Trol	49.8	27.6	16.1	584	1.0%	.9%	1.5%	.5%
Apple Computer	46.6	46.6	.0	16,744	.9%	1.4%	.0%	13.2%
Calma	45.4	23.1	12.7	491	.9%	.7%	1.2%	.4%
Mutoh Industries (No OEM)	38.9	22.7	12.4	1,241	.8%	.7%	1.2%	1.0%
Cimlinc	35.2	16.7	13.2	917	.7%	.5%	1.3%	.7%
Silicon Graphics	35.0	31.0	.5	1,000	.7%	1.0%	.0%	.8%
Toshiba (No OEM)	34.4	20.4	10.6	422	.7%	.6%	1.0%	.3%
MacNeal-Schwendler	34.1	.0	34.1	0	.7%	.0%	3.3%	.0%
Sun	33.5	29.7	.0	1,370	.7%	.9%	.0%	1.1%
Graftek	33.3	13.7	14.8	512	.7%	.4%	1.4%	.4%
Ferranti	32.3	18.7	8.3	275	.6%	.6%	.8%	.2%
Dassault	31.4	.0	25.1	0	.6%	.0%	2.4%	.0%
Autodesk	31.0	.0	31.0	0	.6%	.0%	3.0%	.0%
Norsk	30.0	7.0	14.3	313	.6%	.2%	1.4%	.2%
Zenith	29.7	26.7	.0	9,000	.6%	.8%	.0%	7.1%

(Continued)

Market Share

TABLE NUMBER: 1 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: All Platforms
REGION: Worldwide
UNITS: Millions of Dollars/Actual Units

	Total	Hardware	Software	Wkstns	Market Share			
	Total	Hardware	Software	Wkstns	Total	Hardware	Software	Wkstns
Company	Revenue	Revenue	Revenue	Shipped	Revenue	Revenue	Revenue	Shipped
SDRC	24.5	.0	24.5	0	.5%	.0%	2.3%	.0%
CISI	24.0	10.6	10.5	850	.5%	.3%	1.0%	.7%
Gerber Systems	21.0	12.0	4.6	320	.4%	.4%	.4%	.3%
Swanson Analysis	15.5	.0	15.5	0	.3%	.0%	1.5%	.0%
PDA Engineering	15.2	.0	15.2	0	.3%	.0%	1.5%	.0%
Info. Services Int'l. Dentsu	15.0	2.5	11.2	50	.3%	.1%	1.1%	.0%
PAFEC	15.0	.0	15.0	0	.3%	.0%	1.4%	.0%
Tokyo Electron (No OEM)	13.4	7.8	3.4	55	.3%	.2%	.3%	.0%
ItalCad	9.9	6.4	2.5	98	.2%	.2%	.2%	.1%
Sharp System Products	8.8	5.1	2.8	65	.2%	.2%	.3%	.1%
CADAM	8.7	3.9	3.9	66	.2%	.1%	.4%	.1%
ICL	7.9	5.9	1.5	181	.2%	.2%	.1%	.1%
Compaq	6.8	6.8	.0	1,910	.1%	.2%	.0%	1.5%
ISICAD	6.8	3.4	2.1	61	.1%	.1%	.2%	.0%
Seiko Instruments (No OEM)	3.5	.0	3.2	0	.1%	.0%	.3%	.0%
Syscan	3.4	2.3	.6	24	.1%	.1%	.1%	.0%
Zuken	1.3	.0	1.1	0	.0%	.0%	.1%	.0%
Other Companies	664.0	522.6	117.1	21,200	13.3%	16.2%	11.2%	16.7%
All Companies	4,992.6	3,233.2	1,041.1	127,152	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	4,017.9	2,681.6	717.0	112,713	80.5%	82.9%	68.9%	88.6%
All Asian-Based Companies	644.4	387.6	202.0	9,750	12.9%	12.0%	19.4%	7.7%
All European-Based Companies	330.4	164.0	122.2	4,690	6.6%	5.1%	11.7%	3.7%
All Hardware Companies	1,386.1	1,262.5	1.3	76,368	27.8%	39.0%	.1%	60.1%
All Turnkey & SW Companies	3,606.6	1,970.7	1,039.9	50,785	72.2%	61.0%	99.9%	39.9%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 2
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Technical Workstation
REGION: Worldwide
UNITS: Millions of Dollars/Actual Units

	Total	Hardware	Software	Wkstns	Market Share			
	Total	Hardware	Software	Wkstns	Total	Hardware	Software	Wkstns
Company	Revenue	Revenue	Revenue	Shipped	Revenue	Revenue	Revenue	Shipped
Computervision	250.7	93.9	83.7	2,153	21.2%	14.5%	24.3%	9.7%
Digital	88.6	75.7	1.5	3,334	7.5%	11.7%	.4%	15.0%
Hewlett-Packard	82.4	49.2	26.2	3,699	7.0%	7.6%	7.6%	16.7%
Apollo	53.0	47.5	.0	2,010	4.5%	7.3%	.0%	9.1%
IBM	51.1	30.8	13.1	879	4.3%	4.7%	3.8%	4.0%
Auto-Trol	47.3	26.0	15.6	554	4.0%	4.0%	4.5%	2.5%
Intergraph	42.7	21.8	10.3	282	3.6%	3.4%	3.0%	1.3%
Hitachi Zosen	37.7	13.6	20.4	327	3.2%	2.1%	5.9%	1.5%
Cimlinc	35.2	16.7	13.2	917	3.0%	2.6%	3.8%	4.1%
Silicon Graphics	35.0	31.0	.5	1,000	3.0%	4.8%	.1%	4.5%
Calma	33.7	16.2	10.6	350	2.8%	2.5%	3.1%	1.6%
Sun	33.5	29.7	.0	1,370	2.8%	4.6%	.0%	6.2%
Applicon	31.4	19.7	9.2	764	2.7%	3.0%	2.7%	3.4%
Siemens	31.0	19.5	8.4	324	2.6%	3.0%	2.4%	1.5%
McDonnell Douglas	25.1	11.1	9.1	493	2.1%	1.7%	2.6%	2.2%
Gerber Systems	21.0	12.0	4.6	320	1.8%	1.8%	1.3%	1.4%
Mutoh Industries (No OEM)	16.9	10.7	4.6	309	1.4%	1.6%	1.3%	1.4%
Graftek	15.2	7.1	6.1	211	1.3%	1.1%	1.8%	.9%
SDRC	14.9	.0	14.9	0	1.3%	.0%	4.3%	.0%
Prime	14.8	8.5	2.8	212	1.2%	1.3%	.8%	1.0%
NEC	14.0	7.7	4.8	220	1.2%	1.2%	1.4%	1.0%
Control Data	13.8	8.0	2.7	255	1.2%	1.2%	.8%	1.1%
Mitsubishi Electric	13.1	8.2	3.5	145	1.1%	1.3%	1.0%	.7%
PAFEC	12.0	.0	12.0	0	1.0%	.0%	3.5%	.0%
ItalCad	9.9	6.4	2.5	98	.8%	1.0%	.7%	.4%
Sharp System Products	8.8	5.1	2.8	65	.7%	.8%	.8%	.3%
Tokyo Electron (No OEM)	8.6	4.4	2.9	37	.7%	.7%	.8%	.2%
ICL	7.9	5.9	1.5	181	.7%	.9%	.4%	.8%
ISICAD	6.8	3.4	2.1	61	.6%	.5%	.6%	.3%
Toshiba (No OEM)	5.9	3.2	2.1	144	.5%	.5%	.6%	.7%
PDA Engineering	5.3	.0	5.3	0	.5%	.0%	1.5%	.0%
Dassault	4.7	.0	3.8	0	.4%	.0%	1.1%	.0%

(Continued)

Market Share

TABLE NUMBER: 2 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Technical Workstation
REGION: Worldwide
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Seiko Instruments (No OEM)	3.5	.0	3.2	0	.3%	.0%	.9%	.0%
Info. Services Int'l. Dentsu	3.0	.4	2.3	5	.3%	.1%	.7%	.0%
Hitachi	2.9	2.9	.0	53	.2%	.4%	.0%	.2%
CISI	2.4	.9	1.2	36	.2%	.1%	.3%	.2%
Swanson Analysis	2.2	.0	2.2	0	.2%	.0%	.6%	.0%
MacNeal-Schwendler	1.4	.0	1.4	0	.1%	.0%	.4%	.0%
Zuken	1.3	.0	1.1	0	.1%	.0%	.3%	.0%
Fujitsu	.7	.0	.6	0	.1%	.0%	.2%	.0%
Ferranti	.6	.3	.2	8	.1%	.1%	.0%	.0%
Autodesk	.3	.0	.3	0	.0%	.0%	.1%	.0%
CADAM	.1	.0	.0	0	.0%	.0%	.0%	.0%
Other Companies	91.8	51.1	31.2	1,367	7.8%	7.9%	9.1%	6.2%
All Companies	1,181.9	648.6	344.3	22,182	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	926.5	519.1	243.3	19,373	78.4%	80.0%	70.7%	87.3%
All Asian-Based Companies	159.8	86.8	58.3	1,894	13.5%	13.4%	16.9%	8.5%
All European-Based Companies	95.6	42.6	42.7	916	8.1%	6.6%	12.4%	4.1%
All Hardware Companies	221.2	194.2	1.3	7,934	18.7%	29.9%	.4%	35.8%
All Turnkey & SW Companies	960.7	454.4	343.0	14,248	81.3%	70.1%	99.6%	64.2%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 3
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Host-Dependent
REGION: Worldwide
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	868.3	639.8	106.9	9,956	27.1%	29.0%	21.0%	29.8%
Digital	542.4	466.6	.0	0	16.9%	21.2%	.0%	.0%
Computervision	154.6	27.4	54.5	333	4.8%	1.2%	10.7%	1.0%
Control Data	148.5	96.9	17.9	811	4.6%	4.4%	3.5%	2.4%
Prime	144.5	89.1	21.3	1,532	4.5%	4.0%	4.2%	4.6%
McDonnell Douglas	138.7	68.4	42.7	2,015	4.3%	3.1%	8.4%	6.0%
Intergraph	134.7	89.1	19.8	1,295	4.2%	4.0%	3.9%	3.9%
Applicon	94.2	38.8	27.2	1,994	2.9%	1.8%	5.3%	6.0%
Fujitsu	64.7	46.6	11.7	1,252	2.0%	2.1%	2.3%	3.7%
Matra Datavision	55.0	43.1	6.4	600	1.7%	2.0%	1.3%	1.8%
Hitachi	53.5	38.5	9.6	359	1.7%	1.7%	1.9%	1.1%
Mitsubishi Electric	41.7	26.3	11.3	384	1.3%	1.2%	2.2%	1.1%
MacNeal-Schwendler	31.7	.0	31.7	0	1.0%	.0%	6.2%	.0%
Ferranti	31.6	18.4	8.2	267	1.0%	.8%	1.6%	.8%
Siemens	31.0	22.9	5.0	259	1.0%	1.0%	1.0%	.8%
NEC	30.4	21.9	5.5	301	.9%	1.0%	1.1%	.9%
Norsk	30.0	7.0	14.3	313	.9%	.3%	2.8%	.9%
Dassault	26.7	.0	21.3	0	.8%	.0%	4.2%	.0%
CISI	20.4	9.2	8.8	774	.6%	.4%	1.7%	2.3%
Graftek	18.0	6.6	8.7	302	.6%	.3%	1.7%	.9%
Toshiba (No OEM)	17.2	13.2	2.3	278	.5%	.6%	.5%	.8%
Swanson Analysis	11.9	.0	11.9	0	.4%	.0%	2.3%	.0%
Hitachi Zosen	11.4	9.9	1.5	64	.4%	.4%	.3%	.2%
Calma	11.3	6.6	2.0	117	.4%	.3%	.4%	.4%
PDA Engineering	9.9	.0	9.9	0	.3%	.0%	1.9%	.0%
SDRC	9.5	.0	9.5	0	.3%	.0%	1.9%	.0%
Info. Services Int'l. Dentsu	9.0	1.7	6.5	30	.3%	.1%	1.3%	.1%
CADAM	6.8	3.1	3.0	43	.2%	.1%	.6%	.1%
Tokyo Electron (No OEM)	4.7	3.5	.5	15	.1%	.2%	.1%	.0%
Syscan	3.4	2.3	.6	24	.1%	.1%	.1%	.1%
PAFEC	3.0	.0	3.0	0	.1%	.0%	.6%	.0%
Auto-Trol	2.5	1.6	.5	29	.1%	.1%	.1%	.1%

(Continued)

Market Share

TABLE NUMBER: 3 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Host-Dependent
REGION: Worldwide
UNITS: Millions of Dollars/Actual Units

					---------- Market Share ----------			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Mutoh Industries (No OEM)	.4	.3	.1	10	.0%	.0%	.0%	.0%
Other Companies	441.1	405.7	25.1	10,060	13.8%	18.4%	4.9%	30.1%
All Companies	3,202.5	2,204.2	509.0	33,415	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	2,665.9	1,866.6	369.8	27,813	83.2%	84.7%	72.6%	83.2%
All Asian-Based Companies	313.9	219.9	67.4	3,021	9.8%	10.0%	13.2%	9.0%
All European-Based Companies	222.7	117.6	71.9	2,580	7.0%	5.3%	14.1%	7.7%
All Hardware Companies	925.9	836.1	.0	9,246	28.9%	37.9%	.0%	27.7%
All Turnkey & SW Companies	2,276.7	1,368.1	509.0	24,169	71.1%	62.1%	100.0%	72.3%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 4
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Personal Computer
REGION: Worldwide
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	226.3	179.1	29.2	30,700	37.2%	47.1%	15.5%	42.9%
Apple Computer	46.6	46.6	.0	16,744	7.7%	12.3%	.0%	23.4%
Hitachi	42.1	22.7	15.1	1,143	6.9%	6.0%	8.1%	1.6%
Autodesk	30.7	.0	30.7	0	5.0%	.0%	16.3%	.0%
Zenith	29.7	26.7	.0	9,000	4.9%	7.0%	.0%	12.6%
NEC	22.1	10.0	10.0	798	3.6%	2.6%	5.3%	1.1%
Mutoh Industries (No OEM)	21.6	11.7	7.8	922	3.5%	3.1%	4.1%	1.3%
Computervision	13.8	1.3	10.4	187	2.3%	.4%	5.5%	.3%
Toshiba (No OEM)	11.4	4.1	6.1	0	1.9%	1.1%	3.3%	.0%
Compaq	6.8	6.8	.0	1,910	1.1%	1.8%	.0%	2.7%
Fujitsu	5.7	.0	5.1	0	.9%	.0%	2.7%	.0%
Mitsubishi Electric	4.8	2.6	1.7	144	.8%	.7%	.9%	.2%
Info. Services Int'l. Dentsu	3.0	.4	2.3	15	.5%	.1%	1.2%	.0%
Hitachi Zosen	2.6	1.0	1.6	131	.4%	.3%	.8%	.2%
Intergraph	2.5	.0	1.9	0	.4%	.0%	1.0%	.0%
CADAM	1.8	.8	.8	23	.3%	.2%	.4%	.0%
Prime	1.5	.0	1.1	0	.2%	.0%	.6%	.0%
Swanson Analysis	1.4	.0	1.4	0	.2%	.0%	.7%	.0%
CISI	1.2	.5	.6	39	.2%	.1%	.3%	.1%
MacNeal-Schwendler	1.0	.0	1.0	0	.2%	.0%	.5%	.0%
Calma	.5	.3	.1	23	.1%	.1%	.1%	.0%
Tokyo Electron (No OEM)	.1	.0	.0	3	.0%	.0%	.0%	.0%
Other Companies	131.1	65.9	60.9	9,774	21.6%	17.3%	32.4%	13.7%
All Companies	608.2	380.5	187.8	71,556	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	425.4	295.8	103.9	65,527	69.9%	77.8%	55.3%	91.6%
All Asian-Based Companies	170.8	80.9	76.3	4,835	28.1%	21.3%	40.6%	6.8%
All European-Based Companies	12.0	3.8	7.6	1,194	2.0%	1.0%	4.0%	1.7%
All Hardware Companies	239.0	232.3	.0	59,188	39.3%	61.0%	.0%	82.7%
All Turnkey & SW Companies	369.2	148.2	187.8	12,367	60.7%	39.0%	100.0%	17.3%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 5
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: All Platforms
REGION: North America
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	429.7	319.7	58.5	18,409	21.3%	23.9%	15.4%	28.9%
Digital	329.2	279.4	1.5	2,088	16.3%	20.9%	.4%	3.3%
Computervision	152.3	65.2	31.8	989	7.5%	4.9%	8.4%	1.6%
McDonnell Douglas	122.4	55.6	42.3	1,721	6.1%	4.2%	11.2%	2.7%
Intergraph	120.3	78.2	20.4	1,055	5.9%	5.8%	5.4%	1.7%
Control Data	103.3	64.1	10.6	587	5.1%	4.8%	2.8%	.9%
Prime	84.9	50.1	13.5	1,015	4.2%	3.7%	3.6%	1.6%
Applicon	62.8	34.6	12.8	1,371	3.1%	2.6%	3.4%	2.2%
Auto-Trol	39.5	22.4	12.4	463	2.0%	1.7%	3.3%	.7%
Apple Computer	34.1	34.0	.0	12,223	1.7%	2.5%	.0%	19.2%
Zenith	29.7	26.7	.0	9,000	1.5%	2.0%	.0%	14.1%
Apollo	27.1	23.9	.0	971	1.3%	1.8%	.0%	1.5%
Hewlett-Packard	27.0	17.4	7.4	1,411	1.3%	1.3%	2.0%	2.2%
Cimlinc	25.2	12.0	9.4	775	1.2%	.9%	2.5%	1.2%
Silicon Graphics	24.5	22.1	.0	700	1.2%	1.6%	.0%	1.1%
Calma	23.1	13.2	7.6	325	1.1%	1.0%	2.0%	.5%
Graftek	22.0	7.0	11.5	359	1.1%	.5%	3.0%	.6%
MacNeal-Schwendler	21.8	.0	21.8	0	1.1%	.0%	5.8%	.0%
Sun	20.0	17.6	.0	868	1.0%	1.3%	.0%	1.4%
Autodesk	19.0	.0	19.0	0	.9%	.0%	5.0%	.0%
SDRC	14.7	.0	14.7	0	.7%	.0%	3.9%	.0%
Swanson Analysis	12.2	.0	12.2	0	.6%	.0%	3.2%	.0%
Gerber Systems	12.2	6.9	2.7	186	.6%	.5%	.7%	.3%
PDA Engineering	12.2	.0	12.2	0	.6%	.0%	3.2%	.0%
Dassault	11.0	.0	8.8	0	.5%	.0%	2.3%	.0%
Compaq	4.8	4.8	.0	1,337	.2%	.4%	.0%	2.1%
Matra Datavision	4.4	3.5	.5	48	.2%	.3%	.1%	.1%
CADAM	3.4	1.5	1.5	26	.2%	.1%	.4%	.0%
Mutoh Industries (No OEM)	1.6	1.0	.5	111	.1%	.1%	.1%	.2%

(Continued)

Market Share

TABLE NUMBER: 5 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: All Platforms
REGION: North America
UNITS: Millions of Dollars/Actual Units

	Total	Hardware	Software	Wkstns	Market Share			
Company	Revenue	Revenue	Revenue	Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
CISI	.7	.3	.3	25	.0%	.0%	.1%	.0%
Other Companies	226.7	176.0	45.2	7,595	11.2%	13.2%	11.9%	11.9%
All Companies	2,021.7	1,337.3	379.1	63,656	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	2,003.0	1,332.5	368.0	63,472	99.1%	99.6%	97.1%	99.7%
All Asian-Based Companies	1.6	1.0	.5	111	.1%	.1%	.1%	.2%
All European-Based Companies	17.1	3.8	10.6	73	.8%	.3%	2.8%	.1%
All Hardware Companies	732.9	661.1	.0	46,183	36.2%	49.4%	.0%	72.6%
All Turnkey & SW Companies	1,288.8	676.2	379.1	17,474	63.8%	50.6%	100.0%	27.4%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 6
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Technical Workstation
REGION: North America
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Computervision	89.1	42.9	19.5	707	19.5%	16.0%	17.0%	6.9%
Digital	49.3	41.6	1.5	2,088	10.8%	15.5%	1.3%	20.5%
Auto-Trol	37.5	21.1	12.0	440	8.2%	7.9%	10.4%	4.3%
Apollo	27.1	23.9	.0	971	5.9%	8.9%	.0%	9.5%
Hewlett-Packard	27.0	17.4	7.4	1,411	5.9%	6.5%	6.5%	13.8%
Cimlinc	25.2	12.0	9.4	775	5.5%	4.5%	8.2%	7.6%
Silicon Graphics	24.5	22.1	.0	700	5.4%	8.2%	.0%	6.9%
McDonnell Douglas	20.8	8.5	8.2	335	4.6%	3.2%	7.2%	3.3%
Sun	20.0	17.6	.0	868	4.4%	6.6%	.0%	8.5%
IBM	18.4	10.3	5.5	316	4.0%	3.8%	4.8%	3.1%
Calma	16.2	8.7	5.8	221	3.5%	3.3%	5.1%	2.2%
Applicon	15.7	10.3	4.2	300	3.4%	3.8%	3.6%	2.9%
Intergraph	12.6	6.6	3.7	132	2.8%	2.5%	3.3%	1.3%
Gerber Systems	12.2	6.9	2.7	186	2.7%	2.6%	2.3%	1.8%
SDRC	9.0	.0	9.0	0	2.0%	.0%	7.8%	.0%
Graftek	7.7	2.2	4.3	119	1.7%	.8%	3.8%	1.2%
Prime	7.6	4.3	1.4	127	1.7%	1.6%	1.2%	1.2%
Control Data	7.6	3.8	1.6	140	1.7%	1.4%	1.4%	1.4%
PDA Engineering	4.3	.0	4.3	0	.9%	.0%	3.7%	.0%
Swanson Analysis	1.7	.0	1.7	0	.4%	.0%	1.5%	.0%
Dassault	1.7	.0	1.3	0	.4%	.0%	1.2%	.0%
MacNeal-Schwendler	.9	.0	.9	0	.2%	.0%	.8%	.0%
Mutoh Industries (No OEM)	.7	.4	.2	27	.1%	.2%	.1%	.3%
Autodesk	.2	.0	.2	0	.0%	.0%	.2%	.0%
CISI	.1	.0	.0	1	.0%	.0%	.0%	.0%

(Continued)

Market Share

TABLE NUMBER: 6 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Technical Workstation
REGION: North America
UNITS: Millions of Dollars/Actual Units

	Total	Hardware	Software	Wkstns	Market Share			
	Total	Hardware	Software	Wkstns	Total	Hardware	Software	Wkstns
Company	Revenue	Revenue	Revenue	Shipped	Revenue	Revenue	Revenue	Shipped
CADAM	.0	.0	.0	0	.0%	.0%	.0%	.0%
Other Companies	19.2	7.6	9.7	334	4.2%	2.8%	8.5%	3.3%
All Companies	456.2	267.9	114.6	10,197	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	453.8	267.5	113.0	10,169	99.5%	99.8%	98.7%	99.7%
All Asian-Based Companies	.7	.4	.2	27	.1%	.2%	.1%	.3%
All European-Based Companies	1.7	.0	1.4	1	.4%	.0%	1.2%	.0%
All Hardware Companies	116.8	102.1	.0	4,302	25.6%	38.1%	.0%	42.2%
All Turnkey & SW Companies	339.4	165.9	114.6	5,895	74.4%	61.9%	100.0%	57.8%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 7
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Host-Dependent
REGION: North America
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	312.6	228.5	40.3	3,584	23.5%	25.1%	20.3%	25.8%
Digital	279.9	237.9	.0	0	21.1%	26.2%	.0%	.0%
Intergraph	106.4	71.6	15.7	923	8.0%	7.9%	7.9%	6.6%
McDonnell Douglas	101.6	47.1	34.1	1,387	7.6%	5.2%	17.2%	10.0%
Control Data	95.7	60.3	9.0	447	7.2%	6.6%	4.5%	3.2%
Prime	76.4	45.8	11.5	888	5.8%	5.0%	5.8%	6.4%
Computervision	57.9	21.8	8.3	238	4.4%	2.4%	4.2%	1.7%
Applicon	47.1	24.4	8.6	1,072	3.5%	2.7%	4.3%	7.7%
MacNeal-Schwendler	20.3	.0	20.3	0	1.5%	.0%	10.2%	.0%
Graftek	14.3	4.9	7.2	240	1.1%	.5%	3.6%	1.7%
Swanson Analysis	9.4	.0	9.4	0	.7%	.0%	4.8%	.0%
Dassault	9.4	.0	7.5	0	.7%	.0%	3.8%	.0%
PDA Engineering	7.9	.0	7.9	0	.6%	.0%	4.0%	.0%
Calma	6.5	4.2	1.6	82	.5%	.5%	.8%	.6%
SDRC	5.7	.0	5.7	0	.4%	.0%	2.9%	.0%
Matra Datavision	4.4	3.5	.5	48	.3%	.4%	.3%	.3%
CADAM	2.6	1.2	1.2	17	.2%	.1%	.6%	.1%
Auto-Trol	2.0	1.3	.4	24	.1%	.1%	.2%	.2%
CISI	.6	.3	.3	23	.0%	.0%	.1%	.2%
Mutoh Industries (No OEM)	.1	.1	.0	3	.0%	.0%	.0%	.0%
Other Companies	167.3	155.7	8.9	4,937	12.6%	17.1%	4.5%	35.5%
All Companies	1,328.1	908.6	198.4	13,910	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	1,313.6	904.8	190.1	13,836	98.9%	99.6%	95.8%	99.5%
All Asian-Based Companies	.1	.1	.0	3	.0%	.0%	.0%	.0%
All European-Based Companies	14.4	3.7	8.3	71	1.1%	.4%	4.2%	.5%
All Hardware Companies	475.0	420.9	.0	4,811	35.8%	46.3%	.0%	34.6%
All Turnkey & SW Companies	853.1	487.7	198.4	9,098	64.2%	53.7%	100.0%	65.4%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 8
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Personal Computer
REGION: North America
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	98.8	81.0	12.7	14,508	41.6%	50.4%	19.1%	36.7%
Apple Computer	34.1	34.0	.0	12,223	14.3%	21.2%	.0%	30.9%
Zenith	29.7	26.7	.0	9,000	12.5%	16.6%	.0%	22.8%
Autodesk	18.8	.0	18.8	0	7.9%	.0%	28.4%	.0%
Computervision	5.3	.5	4.0	44	2.2%	.3%	6.1%	.1%
Compaq	4.8	4.8	.0	1,337	2.0%	3.0%	.0%	3.4%
Intergraph	1.2	.0	1.0	0	.5%	.0%	1.5%	.0%
Swanson Analysis	1.1	.0	1.1	0	.5%	.0%	1.7%	.0%
Prime	.9	.0	.6	0	.4%	.0%	1.0%	.0%
Mutoh Industries (No OEM)	.8	.5	.3	81	.4%	.3%	.5%	.2%
CADAM	.7	.3	.3	9	.3%	.2%	.5%	.0%
MacNeal-Schwendler	.7	.0	.7	0	.3%	.0%	1.0%	.0%
Calma	.5	.3	.1	22	.2%	.2%	.2%	.1%
CISI	.0	.0	.0	1	.0%	.0%	.0%	.0%
Other Companies	40.2	12.7	26.6	2,324	16.9%	7.9%	40.1%	5.9%
All Companies	237.4	160.8	66.2	39,550	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	235.6	160.3	64.9	39,467	99.2%	99.7%	98.1%	99.8%
All Asian-Based Companies	.8	.5	.3	81	.4%	.3%	.5%	.2%
All European-Based Companies	1.0	.0	1.0	1	.4%	.0%	1.5%	.0%
All Hardware Companies	141.1	138.1	.0	37,070	59.4%	85.9%	.0%	93.7%
All Turnkey & SW Companies	96.4	22.7	66.2	2,480	40.6%	14.1%	100.0%	6.3%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 9
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: All Platforms
REGION: Europe
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	317.0	231.4	45.5	10,873	21.5%	27.7%	12.0%	34.3%
Computervision	236.9	41.2	109.7	1,487	16.1%	4.9%	28.9%	4.7%
Digital	142.5	121.1	.0	556	9.7%	14.5%	.0%	1.8%
Siemens	62.0	42.4	13.4	583	4.2%	5.1%	3.5%	1.8%
Applicon	59.0	21.7	22.8	1,304	4.0%	2.6%	6.0%	4.1%
Prime	56.6	33.5	9.0	590	3.8%	4.0%	2.4%	1.9%
Control Data	52.6	37.4	8.9	415	3.6%	4.5%	2.3%	1.3%
Intergraph	47.6	24.7	9.6	422	3.2%	3.0%	2.5%	1.3%
Matra Datavision	41.3	32.3	4.8	450	2.8%	3.9%	1.3%	1.4%
Hewlett-Packard	35.1	20.6	11.7	1,838	2.4%	2.5%	3.1%	5.8%
McDonnell Douglas	34.1	19.1	8.3	652	2.3%	2.3%	2.2%	2.1%
Ferranti	32.3	18.7	8.3	275	2.2%	2.2%	2.2%	.9%
Norsk	29.0	6.8	13.8	303	2.0%	.8%	3.6%	1.0%
CISI	23.3	10.3	10.2	824	1.6%	1.2%	2.7%	2.6%
Apollo	15.9	14.0	.0	569	1.1%	1.7%	.0%	1.8%
Calma	15.1	6.5	2.0	121	1.0%	.8%	.5%	.4%
PAFEC	15.0	.0	15.0	0	1.0%	.0%	4.0%	.0%
Dassault	14.1	.0	11.3	0	1.0%	.0%	3.0%	.0%
Cimlinc	10.0	4.7	3.8	142	.7%	.6%	1.0%	.4%
ItalCad	9.9	6.4	2.5	98	.7%	.8%	.7%	.3%
Autodesk	9.5	.0	9.5	0	.6%	.0%	2.5%	.0%
Graftek	8.0	5.7	1.6	100	.5%	.7%	.4%	.3%
Apple Computer	7.9	7.9	.0	2,846	.5%	1.0%	.0%	9.0%
Silicon Graphics	7.7	6.9	.0	220	.5%	.8%	.0%	.7%
ICL	7.5	5.6	1.4	171	.5%	.7%	.4%	.5%
MacNeal-Schwendler	6.8	.0	6.8	0	.5%	.0%	1.8%	.0%
ISICAD	6.8	3.4	2.1	61	.5%	.4%	.5%	.2%
Auto-Trol	6.4	3.1	2.6	75	.4%	.4%	.7%	.2%
SDRC	6.1	.0	6.1	0	.4%	.0%	1.6%	.0%
Gerber Systems	4.2	2.4	.9	64	.3%	.3%	.2%	.2%
Sun	4.0	3.6	.0	174	.3%	.4%	.0%	.5%
Syscan	3.4	2.3	.6	24	.2%	.3%	.2%	.1%

(Continued)

Market Share

TABLE NUMBER: 9 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: All Platforms
REGION: Europe
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Mutoh Industries (No OEM)	2.7	1.6	.8	185	.2%	.2%	.2%	.6%
CADAM	2.6	1.2	1.2	20	.2%	.1%	.3%	.1%
PDA Engineering	2.6	.0	2.6	0	.2%	.0%	.7%	.0%
Swanson Analysis	2.4	.0	2.4	0	.2%	.0%	.6%	.0%
Compaq	1.7	1.7	.0	478	.1%	.2%	.0%	1.5%
Other Companies	135.1	96.5	30.1	5,784	9.2%	11.6%	7.9%	18.2%
All Companies	1,474.7	834.5	379.2	31,704	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	1,176.6	680.6	274.2	27,024	79.8%	81.6%	72.3%	85.2%
All Asian-Based Companies	2.7	1.6	.8	185	.2%	.2%	.2%	.6%
All European-Based Companies	295.3	152.3	104.2	4,494	20.0%	18.2%	27.5%	14.2%
All Hardware Companies	290.3	263.8	.0	15,009	19.7%	31.6%	.0%	47.3%
All Turnkey & SW Companies	1,184.4	570.7	379.2	16,695	80.3%	68.4%	100.0%	52.7%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 10
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Technical Workstation
REGION: Europe
UNITS: Millions of Dollars/Actual Units

	Total	Hardware	Software	Wkstns	Market Share			
	Total	Hardware	Software	Wkstns	Total	Hardware	Software	Wkstns
Company	Revenue	Revenue	Revenue	Shipped	Revenue	Revenue	Revenue	Shipped
Computervision	138.6	38.0	59.1	1,291	31.8%	18.6%	40.0%	17.8%
Hewlett-Packard	35.1	20.6	11.7	1,838	8.1%	10.1%	7.9%	25.4%
Siemens	31.0	19.5	8.4	324	7.1%	9.5%	5.7%	4.5%
Intergraph	29.2	14.7	6.3	139	6.7%	7.2%	4.3%	1.9%
Digital	18.5	15.7	.0	556	4.3%	7.7%	.0%	7.7%
Apollo	15.9	14.0	.0	569	3.6%	6.8%	.0%	7.9%
Applicon	14.8	8.8	4.8	446	3.4%	4.3%	3.2%	6.2%
IBM	14.3	8.0	4.3	246	3.3%	3.9%	2.9%	3.4%
PAFEC	12.0	.0	12.0	0	2.8%	.0%	8.1%	.0%
Calma	10.6	4.3	1.7	89	2.4%	2.1%	1.1%	1.2%
Cimlinc	10.0	4.7	3.8	142	2.3%	2.3%	2.6%	2.0%
ItalCad	9.9	6.4	2.5	98	2.3%	3.1%	1.7%	1.4%
Silicon Graphics	7.7	6.9	.0	220	1.8%	3.4%	.0%	3.0%
ICL	7.5	5.6	1.4	171	1.7%	2.7%	.9%	2.4%
ISICAD	6.8	3.4	2.1	61	1.6%	1.7%	1.4%	.8%
Graftek	6.4	4.6	1.2	74	1.5%	2.3%	.8%	1.0%
Auto-Trol	6.1	2.9	2.5	72	1.4%	1.4%	1.7%	1.0%
Control Data	5.4	3.8	1.0	99	1.2%	1.8%	.6%	1.4%
Prime	5.1	2.9	1.0	67	1.2%	1.4%	.7%	.9%
Gerber Systems	4.2	2.4	.9	64	1.0%	1.2%	.6%	.9%
Sun	4.0	3.6	.0	174	.9%	1.7%	.0%	2.4%
SDRC	3.7	.0	3.7	0	.9%	.0%	2.5%	.0%
CISI	2.3	.9	1.1	35	.5%	.4%	.8%	.5%
Dassault	2.1	.0	1.7	0	.5%	.0%	1.1%	.0%
Mutoh Industries (No OEM)	1.1	.7	.3	45	.2%	.3%	.2%	.6%
McDonnell Douglas	1.0	.5	.3	36	.2%	.2%	.2%	.5%
PDA Engineering	.9	.0	.9	0	.2%	.0%	.6%	.0%
Ferranti	.6	.3	.2	8	.1%	.2%	.1%	.1%
Swanson Analysis	.3	.0	.3	0	.1%	.0%	.2%	.0%
MacNeal-Schwendler	.3	.0	.3	0	.1%	.0%	.2%	.0%
Autodesk	.1	.0	.1	0	.0%	.0%	.1%	.0%

(Continued)

Market Share

TABLE NUMBER: 10 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Technical Workstation
REGION: Europe
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
CADAM	.0	.0	.0	0	.0%	.0%	.0%	.0%
Other Companies	30.5	11.6	14.3	376	7.0%	5.7%	9.7%	5.2%
All Companies	436.0	204.7	147.6	7,240	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	343.2	161.8	107.5	6,292	78.7%	79.0%	72.8%	86.9%
All Asian-Based Companies	1.1	.7	.3	45	.2%	.3%	.2%	.6%
All European-Based Companies	91.7	42.2	39.9	903	21.0%	20.6%	27.0%	12.5%
All Hardware Companies	47.8	41.7	.0	1,608	11.0%	20.4%	.0%	22.2%
All Turnkey & SW Companies	388.2	163.0	147.6	5,632	89.0%	79.6%	100.0%	77.8%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 11
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Host-Dependent
REGION: Europe
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	243.1	177.7	31.4	2,788	26.4%	31.8%	16.2%	28.7%
Digital	124.0	105.4	.0	0	13.4%	18.9%	.0%	.0%
Computervision	90.0	2.5	44.4	55	9.8%	.4%	22.9%	.6%
Prime	50.9	30.6	7.6	523	5.5%	5.5%	3.9%	5.4%
Control Data	47.2	33.6	7.9	315	5.1%	6.0%	4.1%	3.3%
Applicon	44.3	12.9	18.0	858	4.8%	2.3%	9.3%	8.8%
Matra Datavision	41.3	32.3	4.8	450	4.5%	5.8%	2.5%	4.6%
McDonnell Douglas	33.1	18.6	8.0	616	3.6%	3.3%	4.1%	6.3%
Ferranti	31.6	18.4	8.2	267	3.4%	3.3%	4.2%	2.8%
Siemens	31.0	22.9	5.0	259	3.4%	4.1%	2.6%	2.7%
Norsk	29.0	6.8	13.8	303	3.1%	1.2%	7.1%	3.1%
CISI	19.8	8.9	8.5	751	2.1%	1.6%	4.4%	7.7%
Intergraph	17.3	10.0	2.5	283	1.9%	1.8%	1.3%	2.9%
Dassault	12.0	.0	9.6	0	1.3%	.0%	5.0%	.0%
MacNeal-Schwendler	6.3	.0	6.3	0	.7%	.0%	3.3%	.0%
Calma	4.5	2.2	.3	32	.5%	.4%	.2%	.3%
Syscan	3.4	2.3	.6	24	.4%	.4%	.3%	.2%
PAFEC	3.0	.0	3.0	0	.3%	.0%	1.5%	.0%
SDRC	2.4	.0	2.4	0	.3%	.0%	1.2%	.0%
CADAM	2.0	.9	.9	13	.2%	.2%	.5%	.1%
Swanson Analysis	1.9	.0	1.9	0	.2%	.0%	1.0%	.0%
PDA Engineering	1.7	.0	1.7	0	.2%	.0%	.9%	.0%
Graftek	1.6	1.0	.4	26	.2%	.2%	.2%	.3%
Auto-Trol	.3	.2	.1	4	.0%	.0%	.0%	.0%

(Continued)

Market Share

TABLE NUMBER: 11 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Host-Dependent
REGION: Europe
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Mutoh Industries (No OEM)	.2	.2	.0	5	.0%	.0%	.0%	.1%
Other Companies	80.3	71.3	6.3	2,134	8.7%	12.8%	3.2%	22.0%
All Companies	922.2	558.6	193.6	9,703	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	729.3	452.1	135.7	7,301	79.1%	80.9%	70.1%	75.2%
All Asian-Based Companies	.2	.2	.0	5	.0%	.0%	.0%	.1%
All European-Based Companies	192.7	106.3	57.8	2,398	20.9%	19.0%	29.9%	24.7%
All Hardware Companies	191.3	171.4	.0	1,776	20.7%	30.7%	.0%	18.3%
All Turnkey & SW Companies	730.9	387.2	193.6	7,927	79.3%	69.3%	100.0%	81.7%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 12
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Personal Computer
REGION: Europe
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	59.6	45.8	9.8	7,839	51.2%	64.2%	25.9%	53.1%
Autodesk	9.4	.0	9.4	0	8.1%	.0%	24.7%	.0%
Computervision	8.3	.8	6.2	141	7.1%	1.1%	16.4%	1.0%
Apple Computer	7.9	7.9	.0	2,846	6.8%	11.1%	.0%	19.3%
Compaq	1.7	1.7	.0	478	1.5%	2.4%	.0%	3.2%
Mutoh Industries (No OEM)	1.4	.8	.5	136	1.2%	1.1%	1.3%	.9%
Intergraph	1.2	.0	.9	0	1.0%	.0%	2.2%	.0%
CISI	1.2	.5	.6	38	1.0%	.6%	1.4%	.3%
Prime	.6	.0	.4	0	.5%	.0%	1.1%	.0%
CADAM	.6	.2	.3	7	.5%	.3%	.7%	.0%
Swanson Analysis	.2	.0	.2	0	.2%	.0%	.6%	.0%
MacNeal-Schwendler	.2	.0	.2	0	.2%	.0%	.5%	.0%
Other Companies	24.3	13.6	9.6	3,275	20.9%	19.1%	25.1%	22.2%
All Companies	116.5	71.3	38.0	14,760	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	104.2	66.7	31.0	13,432	89.4%	93.7%	81.5%	91.0%
All Asian-Based Companies	1.4	.8	.5	136	1.2%	1.1%	1.3%	.9%
All European-Based Companies	10.9	3.8	6.5	1,193	9.4%	5.3%	17.2%	8.1%
All Hardware Companies	51.1	50.8	.0	11,624	43.9%	71.2%	.0%	78.8%
All Turnkey & SW Companies	65.4	20.5	38.0	3,136	56.1%	28.8%	100.0%	21.2%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 13
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: All Platforms
REGION: Asia
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	374.8	280.4	42.0	11,175	27.3%	29.0%	15.8%	41.7%
Digital	127.1	114.5	.0	566	9.3%	11.8%	.0%	2.1%
Hitachi	98.5	64.1	24.8	1,554	7.2%	6.6%	9.3%	5.8%
Fujitsu	71.1	46.6	17.4	1,252	5.2%	4.8%	6.5%	4.7%
NEC	66.5	39.5	20.3	1,318	4.8%	4.1%	7.6%	4.9%
Mitsubishi Electric	59.5	37.1	16.5	674	4.3%	3.8%	6.2%	2.5%
Hitachi Zosen	51.7	24.5	23.4	522	3.8%	2.5%	8.8%	1.9%
Toshiba (No OEM)	34.4	20.4	10.6	422	2.5%	2.1%	4.0%	1.6%
Mutoh Industries (No OEM)	33.5	19.4	10.7	870	2.4%	2.0%	4.0%	3.2%
Computervision	25.7	14.3	6.2	170	1.9%	1.5%	2.3%	.6%
Hewlett-Packard	18.0	9.7	6.5	325	1.3%	1.0%	2.4%	1.2%
Info. Services Int'l. Dentsu	15.0	2.5	11.2	50	1.1%	.3%	4.2%	.2%
Prime	14.4	11.2	1.8	82	1.1%	1.2%	.7%	.3%
Tokyo Electron (No OEM)	13.4	7.8	3.4	55	1.0%	.8%	1.3%	.2%
Sun	9.5	8.5	.0	328	.7%	.9%	.0%	1.2%
Sharp System Products	8.8	5.1	2.8	65	.6%	.5%	1.0%	.2%
Matra Datavision	8.3	6.5	1.0	90	.6%	.7%	.4%	.3%
Apollo	7.3	7.3	.0	373	.5%	.8%	.0%	1.4%
Calma	6.2	2.8	2.8	31	.5%	.3%	1.1%	.1%
McDonnell Douglas	6.1	4.4	.9	119	.4%	.5%	.3%	.4%
Control Data	5.3	2.8	1.0	53	.4%	.3%	.4%	.2%
MacNeal-Schwendler	5.1	.0	5.1	0	.4%	.0%	1.9%	.0%
Gerber Systems	4.2	2.4	.9	64	.3%	.2%	.3%	.2%
Applicon	3.8	2.1	.8	82	.3%	.2%	.3%	.3%
SDRC	3.7	.0	3.7	0	.3%	.0%	1.4%	.0%
Seiko Instruments (No OEM)	3.5	.0	3.2	0	.3%	.0%	1.2%	.0%
Apple Computer	3.3	3.3	.0	1,172	.2%	.3%	.0%	4.4%
Graftek	3.2	1.0	1.7	53	.2%	.1%	.6%	.2%
Intergraph	3.1	2.3	.5	21	.2%	.2%	.2%	.1%
Silicon Graphics	2.8	2.0	.5	80	.2%	.2%	.2%	.3%
CADAM	2.6	1.2	1.2	20	.2%	.1%	.4%	.1%
Autodesk	2.3	.0	2.3	0	.2%	.0%	.8%	.0%

(Continued)

Market Share

TABLE NUMBER: 13 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: All Platforms
REGION: Asia
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Zuken	1.3	.0	1.1	0	.1%	.0%	.4%	.0%
Swanson Analysis	.7	.0	.7	0	.1%	.0%	.3%	.0%
Auto-Trol	.4	.2	.1	4	.0%	.0%	.0%	.0%
Compaq	.3	.3	.0	96	.0%	.0%	.0%	.4%
PDA Engineering	.3	.0	.3	0	.0%	.0%	.1%	.0%
Other Companies	275.1	223.2	41.0	5,142	20.1%	23.1%	15.4%	19.2%
All Companies	1,370.3	967.3	265.9	26,829	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	722.6	576.4	64.2	17,359	52.7%	59.6%	24.1%	64.7%
All Asian-Based Companies	639.0	384.4	200.3	9,379	46.6%	39.7%	75.3%	35.0%
All European-Based Companies	8.8	6.5	1.4	91	.6%	.7%	.5%	.3%
All Hardware Companies	296.6	275.9	1.3	11,030	21.6%	28.5%	.5%	41.1%
All Turnkey & SW Companies	1,073.7	691.4	264.7	15,799	78.4%	71.5%	99.5%	58.9%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 14
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Technical Workstation
REGION: Asia
UNITS: Millions of Dollars/Actual Units

	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Market Share: Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Company								
Hitachi Zosen	37.7	13.6	20.4	327	14.0%	8.3%	26.3%	7.7%
Computervision	20.5	11.8	4.6	136	7.6%	7.3%	6.0%	3.2%
Hewlett-Packard	18.0	9.7	6.5	325	6.7%	6.0%	8.3%	7.7%
IBM	17.4	12.0	3.0	299	6.5%	7.3%	3.9%	7.0%
Digital	16.5	14.9	.0	566	6.2%	9.2%	.0%	13.3%
Mutoh Industries (No OEM)	14.8	9.3	4.0	219	5.5%	5.7%	5.1%	5.2%
NEC	14.0	7.7	4.8	220	5.2%	4.7%	6.3%	5.2%
Mitsubishi Electric	13.1	8.2	3.5	145	4.9%	5.1%	4.6%	3.4%
Sun	9.5	8.5	.0	328	3.5%	5.3%	.0%	7.7%
Sharp System Products	8.8	5.1	2.8	65	3.3%	3.1%	3.6%	1.5%
Tokyo Electron (No OEM)	8.6	4.4	2.9	37	3.2%	2.7%	3.8%	.9%
Apollo	7.3	7.3	.0	373	2.7%	4.5%	.0%	8.8%
Calma	6.2	2.8	2.8	31	2.3%	1.7%	3.6%	.7%
Toshiba (No OEM)	5.9	3.2	2.1	144	2.2%	1.9%	2.7%	3.4%
Gerber Systems	4.2	2.4	.9	64	1.6%	1.5%	1.2%	1.5%
Seiko Instruments (No OEM)	3.5	.0	3.2	0	1.3%	.0%	4.1%	.0%
McDonnell Douglas	3.1	2.1	.5	119	1.1%	1.3%	.7%	2.8%
Info. Services Int'l. Dentsu	3.0	.4	2.3	5	1.1%	.2%	3.0%	.1%
Hitachi	2.9	2.9	.0	53	1.1%	1.8%	.0%	1.2%
Silicon Graphics	2.8	2.0	.5	80	1.0%	1.2%	.6%	1.9%
SDRC	2.2	.0	2.2	0	.8%	.0%	2.9%	.0%
Prime	1.6	1.1	.3	11	.6%	.7%	.4%	.3%
Zuken	1.3	.0	1.1	0	.5%	.0%	1.4%	.0%
Graftek	1.1	.3	.6	18	.4%	.2%	.8%	.4%
Applicon	.9	.6	.3	18	.4%	.4%	.3%	.4%
Fujitsu	.7	.0	.6	0	.3%	.0%	.8%	.0%
Control Data	.7	.4	.2	13	.3%	.2%	.2%	.3%
Auto-Trol	.4	.2	.1	4	.1%	.1%	.1%	.1%
MacNeal-Schwendler	.2	.0	.2	0	.1%	.0%	.3%	.0%
PDA Engineering	.1	.0	.1	0	.0%	.0%	.1%	.0%
Swanson Analysis	.1	.0	.1	0	.0%	.0%	.1%	.0%
CADAM	.0	.0	.0	0	.0%	.0%	.0%	.0%

(Continued)

Market Share

TABLE NUMBER: 14 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Technical Workstation
REGION: Asia
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Autodesk	.0	.0	.0	0	.0%	.0%	.0%	.0%
Other Companies	41.7	31.8	6.8	651	15.5%	19.5%	8.8%	15.3%
All Companies	268.6	162.6	77.4	4,250	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	110.4	77.1	19.3	2,446	41.1%	47.4%	24.9%	57.5%
All Asian-Based Companies	157.7	85.4	57.7	1,804	58.7%	52.5%	74.5%	42.4%
All European-Based Companies	.5	.1	.5	1	.2%	.0%	.6%	.0%
All Hardware Companies	49.6	44.5	1.3	1,797	18.5%	27.3%	1.6%	42.3%
All Turnkey & SW Companies	218.9	118.2	76.2	2,453	81.5%	72.7%	98.4%	57.7%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 15
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Host-Dependent
REGION: Asia
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	295.2	220.9	33.0	3,385	34.1%	32.8%	30.9%	37.7%
Digital	110.6	99.6	.0	0	12.8%	14.8%	.0%	.0%
Fujitsu	64.7	46.6	11.7	1,252	7.5%	6.9%	10.9%	14.0%
Hitachi	53.5	38.5	9.6	359	6.2%	5.7%	9.0%	4.0%
Mitsubishi Electric	41.7	26.3	11.3	384	4.8%	3.9%	10.5%	4.3%
NEC	30.4	21.9	5.5	301	3.5%	3.2%	5.1%	3.4%
Toshiba (No OEM)	17.2	13.2	2.3	278	2.0%	2.0%	2.2%	3.1%
Prime	12.8	10.0	1.5	71	1.5%	1.5%	1.4%	.8%
Hitachi Zosen	11.4	9.9	1.5	64	1.3%	1.5%	1.4%	.7%
Info. Services Int'l. Dentsu	9.0	1.7	6.5	30	1.0%	.3%	6.1%	.3%
Matra Datavision	8.3	6.5	1.0	90	1.0%	1.0%	.9%	1.0%
Computervision	5.1	2.5	1.6	34	.6%	.4%	1.5%	.4%
MacNeal-Schwendler	4.8	.0	4.8	0	.5%	.0%	4.5%	.0%
Tokyo Electron (No OEM)	4.7	3.5	.5	15	.5%	.5%	.5%	.2%
Control Data	4.6	2.5	.8	41	.5%	.4%	.8%	.5%
Intergraph	3.1	2.3	.5	21	.4%	.3%	.4%	.2%
McDonnell Douglas	3.1	2.3	.3	0	.4%	.3%	.3%	.0%
Applicon	2.8	1.5	.5	64	.3%	.2%	.5%	.7%
Graftek	2.1	.7	1.1	35	.2%	.1%	1.0%	.4%
CADAM	2.0	.9	.9	13	.2%	.1%	.9%	.1%
SDRC	1.4	.0	1.4	0	.2%	.0%	1.3%	.0%
Swanson Analysis	.6	.0	.6	0	.1%	.0%	.5%	.0%

(Continued)

Market Share

TABLE NUMBER: 15 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Host-Dependent
REGION: Asia
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
PDA Engineering	.2	.0	.2	0	.0%	.0%	.2%	.0%
Other Companies	176.5	161.7	9.9	2,536	20.4%	24.0%	9.2%	28.3%
All Companies	865.7	672.7	106.9	8,972	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	544.0	446.6	38.6	5,871	62.8%	66.4%	36.1%	65.4%
All Asian-Based Companies	313.4	219.6	67.3	3,011	36.2%	32.6%	63.0%	33.6%
All European-Based Companies	8.3	6.5	1.0	90	1.0%	1.0%	.9%	1.0%
All Hardware Companies	214.6	203.1	.0	2,205	24.8%	30.2%	.0%	24.6%
All Turnkey & SW Companies	651.1	469.6	106.9	6,768	75.2%	69.8%	100.0%	75.4%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 16
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Personal Computer
REGION: Asia
UNITS: Millions of Dollars/Actual Units

	Total	Hardware	Software	Wkstns	Market Share			
	Total	Hardware	Software	Wkstns	Total	Hardware	Software	Wkstns
Company	Revenue	Revenue	Revenue	Shipped	Revenue	Revenue	Revenue	Shipped
IBM	62.2	47.6	6.0	7,491	26.3%	36.0%	7.3%	55.1%
Hitachi	42.1	22.7	15.1	1,143	17.8%	17.2%	18.5%	8.4%
NEC	22.1	10.0	10.0	798	9.4%	7.5%	12.2%	5.9%
Mutoh Industries (No OEM)	18.8	10.1	6.8	651	7.9%	7.7%	8.3%	4.8%
Toshiba (No OEM)	11.4	4.1	6.1	0	4.8%	3.1%	7.5%	.0%
Fujitsu	5.7	.0	5.1	0	2.4%	.0%	6.3%	.0%
Mitsubishi Electric	4.8	2.6	1.7	144	2.0%	2.0%	2.1%	1.1%
Apple Computer	3.3	3.3	.0	1,172	1.4%	2.5%	.0%	8.6%
Info. Services Int'l. Dentsu	3.0	.4	2.3	15	1.3%	.3%	2.9%	.1%
Hitachi Zosen	2.6	1.0	1.6	131	1.1%	.8%	1.9%	1.0%
Autodesk	2.2	.0	2.2	0	.9%	.0%	2.7%	.0%
CADAM	.6	.2	.3	7	.2%	.2%	.3%	.1%
Compaq	.3	.3	.0	96	.1%	.3%	.0%	.7%
MacNeal-Schwendler	.2	.0	.2	0	.1%	.0%	.2%	.0%
Tokyo Electron (No OEM)	.1	.0	.0	3	.1%	.0%	.0%	.0%
Swanson Analysis	.1	.0	.1	0	.0%	.0%	.1%	.0%
Other Companies	56.8	29.7	24.3	1,955	24.1%	22.5%	29.7%	14.4%
All Companies	236.1	132.0	81.7	13,606	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	68.2	52.7	6.3	9,042	28.9%	39.9%	7.8%	66.5%
All Asian-Based Companies	168.0	79.3	75.3	4,564	71.1%	60.1%	92.2%	33.5%
All European-Based Companies	.0	.0	.0	0	.0%	.0%	.0%	.0%
All Hardware Companies	32.4	28.4	.0	7,029	13.7%	21.5%	.0%	51.7%
All Turnkey & SW Companies	203.7	103.7	81.7	6,577	86.3%	78.5%	100.0%	48.3%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 17
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: All Platforms
REGION: Rest of World
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Digital	32.2	27.3	.0	124	25.5%	29.0%	.0%	2.5%
IBM	24.2	18.0	3.3	1,078	19.2%	19.2%	19.3%	21.7%
Intergraph	9.0	5.9	1.5	79	7.1%	6.2%	9.0%	1.6%
Dassault	6.2	.0	5.0	0	4.9%	.0%	29.4%	.0%
Prime	4.8	2.8	.8	57	3.8%	3.0%	4.6%	1.2%
Computervision	4.2	1.8	.9	27	3.4%	1.9%	5.2%	.6%
Auto-Trol	3.5	2.0	1.1	41	2.7%	2.1%	6.5%	.8%
Apollo	2.7	2.4	.0	97	2.2%	2.5%	.0%	2.0%
Hewlett-Packard	2.4	1.5	.7	124	1.9%	1.6%	3.9%	2.5%
Apple Computer	1.4	1.4	.0	502	1.1%	1.5%	.0%	10.1%
McDonnell Douglas	1.1	.5	.4	16	.9%	.5%	2.3%	.3%
Matra Datavision	1.1	.9	.1	12	.9%	.9%	.8%	.2%
Mutoh Industries (No OEM)	1.1	.7	.3	74	.9%	.7%	2.0%	1.5%
Control Data	1.1	.6	.2	11	.8%	.6%	1.1%	.2%
Calma	1.1	.6	.3	15	.8%	.7%	2.0%	.3%
Norsk	1.1	.3	.5	10	.8%	.3%	3.0%	.2%
ICL	.4	.3	.1	10	.3%	.3%	.5%	.2%
Gerber Systems	.4	.2	.1	6	.3%	.3%	.5%	.1%
MacNeal-Schwendler	.3	.0	.3	0	.3%	.0%	2.0%	.0%
Autodesk	.3	.0	.3	0	.2%	.0%	1.6%	.0%
PDA Engineering	.2	.0	.2	0	.1%	.0%	.9%	.0%
CADAM	.1	.0	.0	1	.1%	.0%	.2%	.0%

(Continued)

Market Share

TABLE NUMBER: 17 (Continued)
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: All Platforms
REGION: Rest of World
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Swanson Analysis	.1	.0	.1	0	.1%	.0%	.5%	.0%
Other Companies	27.2	26.9	.8	2,679	21.6%	28.6%	4.8%	54.0%
All Companies	126.0	94.1	16.9	4,964	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	115.7	92.0	10.5	4,857	91.9%	97.8%	62.5%	97.9%
All Asian-Based Companies	1.1	.7	.3	74	.9%	.7%	2.0%	1.5%
All European-Based Companies	9.2	1.5	6.0	32	7.3%	1.6%	35.5%	.7%
All Hardware Companies	66.3	61.7	.0	4,146	52.7%	65.6%	.0%	83.5%
All Turnkey & SW Companies	59.6	32.4	16.9	818	47.3%	34.4%	100.0%	16.5%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 18
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Technical Workstation
REGION: Rest of World
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
Digital	4.2	3.6	.0	124	19.7%	26.6%	.0%	25.1%
Auto-Trol	3.3	1.9	1.1	38	15.5%	13.9%	22.5%	7.8%
Apollo	2.7	2.4	.0	97	12.8%	17.9%	.0%	19.6%
Computervision	2.5	1.2	.5	20	11.6%	8.9%	11.6%	4.0%
Hewlett-Packard	2.4	1.5	.7	124	11.2%	11.6%	14.1%	25.2%
IBM	1.0	.6	.3	18	4.8%	4.3%	6.6%	3.6%
Intergraph	.9	.5	.3	10	4.4%	3.8%	6.0%	2.0%
Dassault	.9	.0	.7	0	4.4%	.0%	15.8%	.0%
Calma	.7	.4	.3	10	3.5%	3.1%	5.6%	2.0%
ICL	.4	.3	.1	10	2.1%	2.4%	1.7%	2.0%
Mutoh Industries (No OEM)	.4	.3	.1	18	2.0%	2.1%	2.6%	3.6%
Prime	.4	.3	.1	7	2.0%	1.9%	1.7%	1.5%
Gerber Systems	.4	.2	.1	6	2.0%	1.8%	1.9%	1.3%
McDonnell Douglas	.2	.1	.1	3	.9%	.6%	1.5%	.6%
Control Data	.1	.1	.0	3	.7%	.5%	.6%	.5%
PDA Engineering	.1	.0	.1	0	.2%	.0%	1.1%	.0%
MacNeal-Schwendler	.0	.0	.0	0	.0%	.0%	.2%	.0%
Swanson Analysis	.0	.0	.0	0	.0%	.0%	.2%	.0%
Other Companies	.4	.1	.3	6	2.0%	.8%	6.2%	1.3%
All Companies	21.2	13.3	4.7	495	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	19.2	12.7	3.5	466	90.3%	95.3%	75.2%	94.3%
All Asian-Based Companies	.4	.3	.1	18	2.0%	2.1%	2.6%	3.6%
All European-Based Companies	1.6	.3	1.0	10	7.6%	2.6%	22.3%	2.1%
All Hardware Companies	7.0	6.0	.0	227	33.0%	45.1%	.0%	45.9%
All Turnkey & SW Companies	14.2	7.3	4.7	268	67.0%	54.9%	100.0%	54.1%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 19
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Host-Dependent
REGION: Rest of World
UNITS: Millions of Dollars/Actual Units

	Total	Hardware	Software	Wkstns	Market Share			
	Total	Hardware	Software	Wkstns	Total	Hardware	Software	Wkstns
Company	Revenue	Revenue	Revenue	Shipped	Revenue	Revenue	Revenue	Shipped
Digital	28.0	23.8	.0	0	32.3%	37.0%	.0%	.0%
IBM	17.4	12.7	2.2	199	20.1%	19.7%	21.9%	24.0%
Intergraph	7.9	5.4	1.2	69	9.2%	8.3%	11.4%	8.3%
Dassault	5.3	.0	4.2	0	6.1%	.0%	41.2%	.0%
Prime	4.3	2.6	.7	50	5.0%	4.0%	6.3%	6.1%
Computervision	1.6	.6	.2	7	1.9%	.9%	2.1%	.8%
Matra Datavision	1.1	.9	.1	12	1.3%	1.4%	1.3%	1.4%
Norsk	1.1	.3	.5	10	1.2%	.4%	4.9%	1.2%
McDonnell Douglas	1.0	.4	.3	13	1.1%	.7%	3.1%	1.6%
Control Data	.9	.5	.2	8	1.1%	.8%	1.6%	1.0%
MacNeal-Schwendler	.3	.0	.3	0	.4%	.0%	3.1%	.0%
Calma	.3	.2	.1	4	.3%	.3%	.7%	.4%
Auto-Trol	.2	.1	.0	2	.2%	.2%	.4%	.2%
PDA Engineering	.1	.0	.1	0	.1%	.0%	1.0%	.0%
Mutoh Industries (No OEM)	.1	.1	.0	2	.1%	.1%	.1%	.2%
CADAM	.1	.0	.0	0	.1%	.0%	.3%	.1%
Swanson Analysis	.1	.0	.1	0	.1%	.0%	.6%	.0%
Other Companies	16.9	16.9	.0	454	19.5%	26.3%	.0%	54.7%
All Companies	86.6	64.4	10.2	830	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	79.0	63.2	5.4	806	91.3%	98.2%	52.5%	97.1%
All Asian-Based Companies	.1	.1	.0	2	.1%	.1%	.1%	.2%
All European-Based Companies	7.4	1.1	4.9	22	8.6%	1.7%	47.4%	2.7%
All Hardware Companies	44.9	40.7	.0	454	51.9%	63.2%	.0%	54.7%
All Turnkey & SW Companies	41.6	23.7	10.2	376	48.1%	36.8%	100.0%	45.3%

Source: Dataquest
July 1988

Market Share

TABLE NUMBER: 20
TITLE: 1987 Market Share
APPLICATION: Mechanical
PLATFORM: Personal Computer
REGION: Rest of World
UNITS: Millions of Dollars/Actual Units

					Market Share			
Company	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped	Total Revenue	Hardware Revenue	Software Revenue	Wkstns Shipped
IBM	5.8	4.8	.7	861	31.7%	29.1%	36.1%	23.7%
Apple Computer	1.4	1.4	.0	502	7.7%	8.5%	.0%	13.8%
Mutoh Industries (No OEM)	.6	.3	.2	54	3.1%	1.9%	10.3%	1.5%
Autodesk	.3	.0	.3	0	1.5%	.0%	13.9%	.0%
Computervision	.2	.0	.1	1	.8%	.1%	5.7%	.0%
Intergraph	.1	.0	.1	0	.5%	.0%	3.6%	.0%
Prime	.1	.0	.0	0	.3%	.0%	2.1%	.0%
CADAM	.0	.0	.0	0	.1%	.0%	.5%	.0%
Calma	.0	.0	.0	1	.1%	.1%	.0%	.0%
MacNeal-Schwendler	.0	.0	.0	0	.1%	.0%	.5%	.0%
Swanson Analysis	.0	.0	.0	0	.1%	.0%	.5%	.0%
Other Companies	9.9	9.9	.5	2,220	54.2%	60.3%	26.8%	61.0%
All Companies	18.2	16.4	1.9	3,640	100.0%	100.0%	100.0%	100.0%
All U.S.-Based Companies	17.5	16.1	1.6	3,585	96.4%	98.1%	84.5%	98.5%
All Asian-Based Companies	.6	.3	.2	54	3.1%	1.9%	10.3%	1.5%
All European-Based Companies	.1	.0	.1	0	.5%	.0%	5.2%	.0%
All Hardware Companies	14.4	15.0	.0	3,466	79.4%	91.4%	.0%	95.2%
All Turnkey & SW Companies	3.8	1.4	1.9	174	20.6%	8.6%	100.0%	4.8%

Source: Dataquest
July 1988

Appendix G—Glossary

DATAQUEST CAD/CAM GLOSSARY

accelerator. Hardware used to increase throughput by decreasing processing time. An accelerator may be in the form of a plug-in board or a self-contained, standalone unit used in a network.

AEC. Architecture, engineering, and construction. See **facilities design.**

analog. Denotes the dominant component type, function(s), or circuit characteristics of a particular design. May include software-generated analog test instruments, such as oscilloscopes.

annual GDP growth. The percentage change in the gross domestic product (GDP), in local currency, from the previous year's GDP. This statistic allows one to view a country's growth independent of the dollar exchange rates.

architectural. Computer-aided tools intended for use in design and drafting of facilities' architectural aspects.

A.S.E.A.N. (Association of Southeast Asian Nations). An international organization whose members include Brunei, Indonesia, Malaysia, Philippines, Singapore, and Thailand.

Asia. Includes China, Hong Kong, Japan, Korea, Singapore, and Taiwan.

ASIC. Application-specific integrated circuit.

automated mapping/facilities management (AM/FM). Software used to create and/or develop a digital map data base of corporate facility assets (AM) and the related software whose purpose is to efficiently and effectively manage the capital assets of the company through utilization of the digital data base.

average price per seat. The price a buyer pays for accessing a workstation or a CAD/CAM seat. (In the case of host-dependent systems, the system price takes into account the average workstation price and the average number of workstations per system. In the case of a technical workstation and personal computer-based workstation, there is a 1:1 ratio between the price of the system and the price of the workstation.)

average system selling price. The price a buyer pays for a CAD/CAM system, workstation, and all of the system's peripherals and software. (In the case of technical workstations and personal computer-based workstations, there is a 1:1 ratio between the price of the system and the price of the workstation.)

balance of payments. A double-entry accounting of the value of all exchanges and transfers of goods, services, capital loans, investments, and gold and international reserves between the public and private sectors of a given country and the rest of the world over a given time, usually one year. Balance of payments is divided into three accounts—current, capital, and the reserve and gold account.

balance of trade. The difference between the value of a country's exports and imports of *tangible goods* over a given period, usually one year.

balance on current account. See **current account.**

behavioral simulation. Simulation of ICs or systems that are based on high-level models, as opposed to gate, transistor, or switch-level models. Behavioral models can be of an entire section of an IC or system (e.g., I/O management) or of a specific complex component (e.g., a microprocessor or register).

block place and route. An IC design methodology for interconnecting large blocks in a design. The blocks can be made up of smaller cells or handcrafted custom blocks. A special placer positions the blocks to minimize the routing distances and optimize the IC performance. The blocks are then connected by a router or routers that takes into account the block topology.

bundled software revenue. The value of a turnkey system that is associated with application-related software.

CAD. Computer-aided design. The use of a computer for automated product design.

CAM. Computer-aided manufacturing. See **manufacturing automation.**

capacity utilization. The ratio of actual production output to potential production output, with existing plant, workers, and equipment.

capital account. Balance of payments category for the inward and outward flow of investment capital.

capital goods. All goods used for the *production* of other goods and services. See also **consumer goods.**

cell-based IC. An IC design methodology that allows creation of ICs or blocks within ICs from predefined cells that are placed and then routed together to create logic functions. See **block place and route.**

channel type. Identifies how CAD/CAM systems reach the end user; distinguishes the various distribution channels and marketing arrangements used when selling CAD/CAM systems.

c.i.f. Cost, insurance, and freight, or charged-in-full. For example, most nations record imports in terms of their c.i.f. value and exports in terms of f.o.b. (See **f.o.b.**)

circuit simulation. The process of simulating an IC at the switch, transistor, or device level. This is the most accurate form of IC verification. The best-known circuit simulator is SPICE, which was invented at Berkeley and is now available in the public domain. It is also available in enhanced forms from several suppliers.

compound annual growth rate (CAGR). Determines the average compound rate of growth over a specified period. (The formula used to calculate CAGR is (future value/present value) raised to the power of (1/number of years) - 1.)

consumer. An individual who buys goods and services for personal use, rather than for manufacturing, processing, or resale.

consumer goods. Products used directly to satisfy human needs or wants, such as food and clothing. The distinction between consumer and capital goods lies in how products are used rather than in the products themselves.

consumer price indices (CPI). Monthly measures by the U.S. Bureau of Labor Statistics of the average retail prices of products commonly bought by households, compared with the average prices of a selected base year.

consumption. Expenditures for durable goods, nondurable goods, and services.

copyright. An intangible right granted by statute to the author of certain works; a form of intellectual property.

Council for Mutual Economic Aid (Comecon). A council set up in 1949 to develop the member nations' economies for the purpose of achieving self-sufficiency. Members include: Bulgaria, Czechoslovakia, German Democratic Republic, Hungary, Poland, Romania, and the U.S.S.R. with outer Mongolia.

CPU installed base. The installed base of CPUs at the end of a given year, minus any system retirements. (This element takes into account current year system shipments, estimated current year system retirements, and previous year system population.)

CPU revenue. The portion of revenue derived from a system sale that is related to the value of the CPU. (In the case of technical workstations and personal computer-based workstations, CPU revenue and workstation revenue are equal.)

CPUs shipped. The unit number of systems shipped. (In the case of technical workstations and personal computers, there is a 1:1 ratio of systems shipped and workstations shipped.)

current account. Balance of payments category for goods and services. The difference between total exports and imports of goods and services is the balance on current account.

custom IC. A handcrafted IC that has been constructed for a specific use by designing at the polygon level.

dealer. A product reseller with storefront selling to end users. A dealer's primary added value is distribution; secondary added values are service, training, and support.

design rule checking. The process of verifying that an IC or board layout meets known fabrication tolerances. Examples of such tolerances or rules include trace-to-trace spacing, via adjacency, or trace-to-via spacing.

design service. An organization that creates and/or executes CAD designs for external customers.

deutsche mark. German currency.

direct channels. The sale of CAD/CAM equipment directly to the end user by a vendor who contributes significant development or integration to the product. Can be either sales of complete systems by turnkey vendors or components of systems sold by individual suppliers.

disposable income. An individual's income remaining after any payments to government (taxes, fines) and thus available for either spending or saving.

distributor. (1) A wholesaler selling to dealers and large end users. Distributors primarily provide dealers and VARs with a warehouse of suitable inventory. (2) A company providing sales and product support services for another company that manufactures the product. Distributors in this case are usually based in a different country than the manufacturer.

documentation. A general term used to describe a large family of related documents, including drawings, specification or operation sheets, bills of materials, schematics, training manuals, technical illustrations, diagrams, or other documents. All or part of these documents may be created using CAD/CAM tools.

dollar. Currency term used for different currencies in Canada, Hong Kong, Singapore, Taiwan, and the United States.

drachma. Greek currency.

drafting. A process used to generate drawings in virtually all CAD/CAM applications.

drafting software. A program used to create mostly two-dimensional representations of a drawing or design. Drawings typically include noted information describing material, processing, and/or unusual manufacturing specifications.

DRC/ERC. Design rule check/electrical rule check.

durable goods. Items that yield their services over an extended period of time, generally three years or more. Durables are often divided into the categories of *producer durables* (e.g., metals, machinery, equipment) and *consumer durables* (e.g., automobiles, appliances).

ECAE. Electronic computer-aided engineering. Computer-aided tools used in the engineering or design phase of electronic products (as opposed to the physical layout of the product). Examples of ECAE applications are schematic capture, simulation, and test pattern creation. ECAE systems are used most often by electrical engineers.

EDA. Electronic design automation. Computer-based tools that are used to automate the process of designing an electronic product, including boards, ICs, and systems. Formerly referred to as ECAD.

electrical. Creation of a diagram of the logical arrangement of hardware in an electrical circuit/system using conventional component symbols.

electrical rule checking. A term used to describe two distinct types of design verification. ERC can refer to verifying that a final layout corresponds to the original design that was done prior to layout (netlist vs. layout). It can also refer to making sure that a logic design conforms to known process limitations (e.g., maximum fanout from a component). This second process is also called logic design rule checking (LDRC).

electronic testing. ECAE software applications used to create the test patterns that will be used during the manufacture of a product. Electronic test products include pattern editing, pattern generation, and fault grading or simulation.

escudo. Portuguese currency.

Europe. Includes Benelux countries, France, Italy, Scandinavian countries, United Kingdom, West Germany, and the rest of Europe.

European Economic Community (EEC). European countries that have joined together to form a common market. The 12 member nations include Belgium, Denmark, France, Greece, Ireland, Italy, Luxembourg, The Netherlands, Portugal, Spain, West Germany, and the United Kingdom. The EEC provides a common external tariff, a common agricultural policy, a joint transportation policy, and the free movement of goods, labor, and capital.

European Free Trade Association (EFTA). In principle similar to the EEC, EFTA members include Austria, Finland, Iceland, Norway, Sweden, and Switzerland. Member nations have eliminated all import duties originating from goods of its members. Free trade agreements exist between the EFTA and EEC, exempting most industrial products and certain processed agricultural products from import duties.

external debt. The total sum of a country's public and private debt owed to foreigners.

facilities design. Also known as *AEC and facilities design/management*. The use of computer-aided tools by architects, contractors, plant engineers, civil engineers, and others associated with these disciplines to aid in designing buildings, power plants, process plants, ships, and other types of nondiscrete entities.

Far East. See Asia.

fault simulation. Also referred to as fault grading. A fault simulator is used to evaluate or grade the quality of test patterns relative to a design. Quality is determined by a measure of the coverage of the test vectors (i.e., the percent of the time that the patterns will identify potential errors in a circuit).

federal debt, federal deficit. See public debt, public deficit.

FEM/FEA. Finite element modeling/finite element analysis.

finite element analysis. Method for determining the structural integrity of a mechanical design by analyzing a finite element model to determine a structure's strength, safety, or performance characteristics. Typical applications include stress analysis, vibration analysis, acoustics, electromagnetics, and fluid/structure interaction.

finite element modeling. Creation of a mathematical model to represent a mechanical design by subdividing the design model into smaller and simpler elements, such as triangles or bricks, which are interconnected. The finite element model is composed of all interconnected elements, attributes such as material and thickness, as well as boundary conditions and loads.

fixed investment. Assets for production of goods or services that cannot be quickly converted into money without disrupting operations, such as plant and equipment.

flat pattern. The design and unfolding of a three-dimensional design of a sheet metal part.

f.o.b. (free on board). A term applied to the valuation of goods up to the point of embarkation; trade unit applied to exports.

franc (Fr). Currency term used in Belgium (BFr), France (FFr) and Switzerland (SFr). Different national francs trade at different exchange rates.

gate array. Software tools used to create ASICs. The gate array itself is a predefined pattern of transistors that a semiconductor supplier prefabricates on wafers. It is customized for users by interconnecting the transistors using one or more layers of metal.

geographic information systems (GIS). A computer-based technology, composed of hardware, software, and data used to capture, edit, display, and, most importantly, analyze geographic information.

geologic modeling. Software used to model the geology of the earth's surface and subsurface strata. Models may be several miles deep and are often used for geologic exploration.

goods. Tangible items of trade, such as automobiles or shoes. Merchandise.

gross domestic product (GDP). The market value of an economy's domestically produced goods and services. GDP is calculated as the **gross national product** (GNP) minus the **net factor income from abroad.** As used here, GDP is expressed in two ways: (1) in terms of 1980 US dollars and (2) in terms of a country's 1987 valuation of local currency. **The 1987 GDP ($US 1980)** provides a basis for comparing the economic status of different countries, independent of short-term variations in exchange rates. **The 1987 GDP (local currency)** provides a basis for evaluating an individual country's growth, independent of the value of the US dollar in that country. From a CAD/CAM business perspective, this makes sense because most prices are set in local currency.

gross national product (GNP). GNP equals GDP plus the net of income accrued by domestic residents from investments abroad minus income earned in the domestic market by foreigners abroad.

gross national product deflator. A revision in the calculation of GNP derived by adjusting each component of GNP for price changes, then summing each into a weighted total. The result thus measures both changes in prices and shifts in consumption patterns.

group technology. A coding and classification system for combining similar, often-used parts into families to allow groups of similar parts to be retrieved, processed, and fabricated in an efficient, economical batch mode.

guilder. Currency used in The Netherlands; also known as gulden.

hardware revenue. The sum of revenue derived from the sale of CPUs, workstations, and peripherals.

host-dependent. A shared logic system in which the external workstations' functions are dependent on a host computer.

HVAC. Heating, ventilation, and air-conditioning design and analysis.

hybrids. A hybrid is made by putting several integrated circuit dies and/or passive components into a single package and interconnecting the dies inside of the package.

IC layout. Software tools that are used to create and validate physical implementations of an integrated circuit. IC layout tools include polygon editors for creating geometric data, symbolic editors, placement and routing (gate array, cell, and block), and DRC/ERC verification tools.

image processing. A variety of techniques for processing pictorial information by computer.

increase over prior year. Total revenue percent change over the prior year's total revenue. (The formula used for this calculation is (present year revenue minus previous year revenue) divided by previous year revenue.)

indirect channels. The sale of CAD/CAM equipment through independent dealers and distributors that do not contribute significant development or integration to the product. This channel is typically used for sales of personal computer-based CAD/CAM systems. Examples of indirect CAD/CAM suppliers include Businessland, ComputerLand, and National CAD Pro.

industrial production index. A monthly measure of the quantity of U.S. output in mining, manufacturing, and utilities industries compared with a base year and seasonally adjusted.

inflation. A sustained increase in the average level of all prices.

input devices. A variety of data entry devices, such as mice, digitizers, or scanners, that allow users to communicate with CAD/CAM systems.

intellectual property. The intangible product of intellectual, scientific or artistic creation associated with four bodies of law: copyright, patent, trade secret, and (in the United States and other countries) legislation providing specific protection for semiconductor mask designs.

internal debt. The total sum of a country's public and private debt owed to citizens of the same country.

International Monetary Fund (IMF). A fund established to provide international cooperation in the monetary field and the removal of foreign exchange restrictions, to stabilize exchange rates and to facilitate a multilateral payments system between member countries.

investment. Expenditures for capital goods.

invisibles. Items of foreign trade that are intangible, such as banking, insurance, tourism, and transportation . Unlike visibles, such items are not recognized by customs and until recently were not reported in trade statistics.

kinematics. An MCAE process for plotting or animating the motion of parts in a design. Kinematics simulation allows the motion of mechanisms to be studied for interference, acceleration, and force.

krona (SKr). Swedish currency.

krone. Currency term used to refer to Danish (DKr) and Norwegian (NKr) currencies. The different krone trade at different exchange rates.

lira. Italian currency.

logic design automation. Tools used to automate the process of design specification and creation of electronic circuits, including behavioral/architectural tools, logic minimization, technology conversion, and automatic schematic synthesis/generation.

logic simulation. ECAE software that verifies the logic and timing behavior of a digital electronic design.

manufacturing. The process of producing finished goods; the people and equipment used to plan, build, and operate production, fabrication, assembly, and test equipment. It also refers to the use of CAD/CAM in the manufacturing process.

manufacturing automation. Use of a computer to aid and improve a manufacturing process.

manufacturing engineering. An organization responsible for the efficient design of the manufacturing process. It involves the design of tooling, fixtures, and procedures.

manufacturing process simulation. Computer-aided simulation of the manufacturing process. Numerical control, off-line robot, and coordinate measuring machine programming are examples of CAD/CAM manufacturing applications.

map compilation. Software used in the process of manually entering discrete spatial data items, including symbols and text, into a digital map file.

map conversion. Software that converts existing hard-copy maps to a computer data base.

mapping. Computer-aided tools that allow geographically related data to be captured, edited, analyzed, and managed. Typical users are civil and utility engineers, geophysicists, and geologists.

mechanical. Mechanical CAD/CAM is the application of computer-aided tools to design, analyze, document, and manufacture discrete parts, components, and assemblies.

mechanical computer-aided engineering (MCAE). The application of CAD/CAM tools for mechanical design and analysis. MCAE applications range from conceptual product design through detail product design and analysis, and supporting production product design. Commonly used MCAE products are solid modeling and finite element analysis technology.

mechanical testing. Software that combines and compares simulated test data with laboratory test data for further analysis prior to manufacture; includes modal analysis.

mechanisms. Software that models machinery capable of mechanical action. See **kinematics.**

mold design/analysis. Typically means design of plastic injection molds and analysis of material flow; can also include design and analysis of molds for any material.

nesting. Arrangement of multiple parts on a larger sheet or plate for optimum use of material.

net factor income from abroad. Income earned by residents of a country from labor supplied to foreign countries or from net claims on foreign assets.

newly industrializing nations (NIC). Reference to countries with GNPs that only recently show a significant industrial component, e.g., Hong Kong, Korea, People's Republic of China, Singapore, and Taiwan.

N.I.C. See newly industrializing nations.

nominal GDP/GNP. GDP/GNP valued in prices prevailing at the time of measurement. Year-to-year changes then reflect differences in both quantities and market prices.

nondurable goods. Items that yield their services over a short period of time, generally less than three years. Examples are food, clothing, paper, chemicals, petroleum, and rubber.

nonturnkey channels. These channels allow users to pick and choose individual system components (e.g., computers, software) and perform system integration to assemble complete CAD/CAM systems. Examples of vendors who sell components directly to end users include software vendors such as Futurenet, MacNeal-Schwendler, and PDA Engineering. Examples of nonturnkey hardware vendors include Apollo, Digital Equipment, and IBM.

North America. Includes the United States, Canada, and Mexico.

numerical control. A technique of simulating the operation of a machine tool. Also the process that generates the data or tapes necessary to guide a machine tool in the manufacture of a part.

Organization for Economic Cooperation and Development (OECD). The OECD arose from the European Recovery Program, originally set up to guide efficient distribution of U.S. aid to Europe following World War II. Under the original agreement, multilateral trading was reestablished along with a system of trade adjustments and restrictions. The organization's activities have more recently included freeing labor and capital payments. Member nations include: Austria, Belgium, Denmark, and France.

output devices. A variety of devices, such as plotters and printers, that make hard copies of designs, documentation, or analysis created on a CAD system.

patent. A legal monopoly granted to an inventor. The U.S. Patent Act defines patentable inventions as any new and useful process, machine, manufacture, or composition of matter.

PCB layout. Products that are used to create the layout of the traces and components to be placed on a printed circuit board.

penetration. The amount of the total available market (TAM) that is using a CAD/CAM system. It is expressed as either a ratio of the number of users per system or as a percent of TAM using a system.

peripherals revenue. The value of all peripherals of a system sale. (Peripherals include all hardware except the CPU itself and any associated workstations.)

personal computer. A single-user computer with a nonvirtual operating system whose networking, high-performance graphics, or multitasking capabilities are optional features rather than integrated capabilities. A personal computer's operating system is typically DOS, OS/2, or Apple's Macintosh System.

peseta. Spanish currency.

piping. Software for design and analysis of a facility's pipe network.

platform. A group of computer products with common characteristics, i.e., the personal computer platform.

PLD. Programmable logic device. A type of application-specific IC that is user programmable rather than mask programmable. The function of a PLD is determined by blowing fuse links or programming memory devices to create the desired interconnections between the fixed logic elements on the device.

pound. Currency used in the United Kingdom.

private. Relating to individuals and businesses, rather than government.

producer price indices (PPI). Monthly measures by the U.S. Bureau of Labor Statistics of the prices of 2,800 representative commodities compared with those prices of a given base year.

production planning. Software used to plan for all factory resources of a manufacturing company.

public. Relating to local, state, or national governments.

public debt. The sum of debts outstanding of local, state, and national governments in a given country. Debt of the national government alone is the *national public debt* or *national debt*. In effect, the public debt is a measure of the extent to which government expenditures are financed by borrowing rather than taxation.

public deficit. Circumstance where government outlays for goods and services exceed receipts for a fiscal year.

real effective exchange rate. An exchange rate measure that takes into account inflation differences between countries. This is the exchange rate multiplied by the real exchange rate.

real exchange rate. The exchange rate between two currencies divided by the ratio of the price levels of the two countries.

real GDP/GNP. GDP/GNP valued in *constant* prices prevailing in a reference base year—1982 in this publication. Year-to-year changes thus reflect changes only in *quantities* produced.

real GDP growth rates. GDP growth, expressed as a percentage, here represents aggregates at 1980 prices and 1980 exchange rates. This measure factors out inflation.

recession. A broad downward movement of the economy over an extended time. Generally defined for the United States as two successive quarterly decreases in U.S. GNP.

renminbi. Internally traded currency of the People's Republic of China.

rest of world. Includes territories not included in North America, Europe, or the Far East.

retirement. The number of CPUs or workstations that are retired in any given year from general day-to-day CAD/CAM use. The retirement model takes into account product life cycles.

robotics. Programs for controlling robots.

schematic capture. Automated graphic design entry method that allows a designer to define the logic of a circuit to create a schematic design. Following schematic capture, a netlist (list of logic components and their logical connections) can be produced.

schilling. Austrian currency.

seasonal variation. A regularly recurring pattern of change in economic activity owing to factors such as periodic climate changes, holidays, and vacations. Seasonal variations are commonly adjusted for in the analysis of data to clarify overall trends.

server. A hardware device attached to a network to facilitate sharing or managing resources.

service revenue. Revenue derived from the service and support of CAD/CAM systems. (Service revenue does not include revenue from the portions of a company's business related to service bureaus or product designs.)

services. Intangible items of trade, such as education, transportation, banking, and legal and medical care.

shipment. Shipment estimates include only products actually delivered to paying customers, not the total number manufactured (the backlog).

silicon compilation. IC design methodology that employs high-level specifications to automatically generate the mask tooling as output. A silicon compiler is a layout system; silicon compilation is a design method.

site engineering. Software used for the modeling of the earth's surface, permitting the development of manipulated models to examine alternative designs for cut and fill operations.

software revenue. The sum of bundled and unbundled software revenue.

solid modeling. Representation of all the external and internal geometry of a part, allowing the solid nature of an object to be represented in a computer. Solid models are constructed in two ways: using primitive building blocks (constructive solid geometry) and/or using boundary definitions (boundary representation).

specification/assessment. Software that allows definition of high-level behavioral and performance characteristics of an electronic product.

structural. Software for modeling and analysis of the integrity of a structure.

surface-mount design. Design methodology that supports designs using surface-mount devices (SMDs). SMD is a type of IC package that can be attached to the surface of a PC board, as opposed to through-hole mounted devices.

system. Comprises many parts, including the computer, operating system, peripherals, graphics devices, and application software. (The lowest common denominator of a system is that it contains the CPU that runs the operating system. By this definition, technical workstations and personal computer-based workstations are also counted as systems.)

system revenue. Revenue derived from system sales. (System revenue does not include service revenue. System revenue is the sum of CPU revenue, workstation revenue, bundled software revenue, and peripherals revenue.)

technical publications. Software to create product information in a format suitable for use outside of the engineering and manufacturing environments. Products provide for merging of text and graphics; typical applications include operating/maintenance manuals and technical illustrations.

technical workstation. A single-user computer with a virtual, multitasking operating system designed to run high-performance graphic applications in a networked environment. A technical workstation's operating system is typically UNIX, VMS, or DOMAIN.

terms of trade. The ratio of the average price of a country's exports to the average price of its imports.

third-party software. Software sold directly to end users or resellers, as opposed to software that is a part of a turnkey system.

three-dimensional. A representation of the surface or edges of a design that contains X, Y, and Z coordinates.

total available market (TAM). The universe of technical professionals that could benefit from the use of a CAD/CAM system.

total revenue. Total CAD/CAM-related revenue received, measured in U.S. dollars. It is the sum of system, unbundled software, and service revenue. Total revenue as reported does not include revenue that a company may receive from products that are sold to another company for resale (OEM revenue).

total workstations shipped. The sum of workstations shipped.

trademark. The U.S. federal trademark laws define a trademark as "any word, name, symbol or device . . . used by a manufacturer or merchant to identify his goods"; a form of intellectual property.

turnkey. A complete CAD/CAM system that includes a computer, a graphics workstation, an operating system, application software, and any applicable peripherals. A turnkey sale also typically provides full system support, including system maintenance, product training, and software for applications support.

turnkey channels. The sale of a complete CAD/CAM system, including computers, graphic workstations, operating systems, applications software, and any applicable peripherals. A turnkey sale also typically provides full system support, including system maintenance, product training, and software or applications support. Turnkey vendors essentially act as systems integrators by integrating the various components into complete systems. Examples of turnkey CAD/CAM vendors include Computervision, Daisy Systems, IBM, Intergraph, Mentor, and Prime Computer.

unbundled software. *See* **third-party software.**

unbundled software revenue. Revenue derived from the sale of software only, or software that is not sold as part of a turnkey system. (Unbundled software is sold by software-only companies as well as by a growing number of turnkey companies.)

value-added reseller (VAR). A product reseller whose primary added value is to the product itself, in the form of software or integration. VARs typically operate from one geographic area, do not maintain a storefront, and sell a specific application solution to end users.

value-added tax (VAT). A general tax applied at each point of exchange of goods or services from production to final consumption. The tax is levied on the difference between the sale price of the goods and services and the cost of goods and services bought for use in production. The VAT is a form of indirect taxation applied by the EEC, used as a basis for contributing to the community budget.

visibles or visible goods. Tangible items of foreign trade.

workstation. Commonly referred to as a "seat," a workstation is where CAD/CAM activities are performed. It may be any one of the three platforms.

workstation installed base. The workstation installed base at the end of a given year, less any workstation retirements. (This element takes into account current year workstation shipments and retirements and the previous year workstation installed base.)

workstation revenue. Revenue derived from the sale of workstations that are used to graphically create, analyze, or manipulate designs. In the case of technical workstations and personal computers, CPU revenue and workstation revenue are equal.

workstations shipped. The total number of workstations shipped as parts of systems. (In the case of technical workstations and personal computer-based workstations, there is a 1:1 ratio of system shipments and workstation shipments.)

workstations-shipped-to-date. The cumulative number of workstations shipped by a CAD/CAM vendor. This differs from installed base in that it does not take into account retirements.

World Bank, The. International bank with the purpose of encouraging capital investment for the reconstruction and development of its member countries, either by channeling the necessary private funds or by making loans. The bank began operations in June 1946 as a post-war reconstruction effort.

yen. Japanese currency.

yuan. The externally traded currency of the People's Republic of China.

Appendix L—Lotus Disks

DATA BASE WORKSHEETS

What You Are Getting

- Diskette containing CAD/CAM Industry Service's application forecast in Lotus format
- Hard copy of the tables—one set per application
- Directions on:
  - How to install the worksheet files
  - How to use the worksheet within Lotus
- A map of the worksheet format
- Hot line number
- Form for comments and suggestions
- Disclaimer

FORECAST DISKETTE

What Is on the Diskette

The Dataquest CAD/CAM Industry service is pleased to offer clients its forecast data base in Lotus format. The diskette you are receiving contains one or more Lotus worksheet files with the same forecast information as that published in Appendix A.

Why We Are Supplying Worksheets

By offering our forecast data base in electronic form, in addition to the published tables in the binders, clients can now easily use our data for a wide range of applications. Some suggestions follow:

- Reformatting Dataquest data for company reports
- Making presentation graphics
- Supplementing internally generated forecasts
- Comparing Dataquest forecasts with other forecasts

- Performing regression and other mathematical analysis
- Segmenting the data differently from the way Dataquest published it

HOW TO INSTALL THE WORKSHEET FILES

If using a PC with a hard disk, copy the files onto the hard disk into the appropriate directory (such as the directory in which Lotus 1-2-3 resides).

If using a PC with two floppy disk drives, make a copy of the worksheet files and work from your copy, *not* from the original files sent to you.

In any case, make a copy of the files and *do not* write over the original files from Dataquest. There is no write protection for these worksheets.

Keep the original Dataquest diskettes and this documentation in the jacket provided in the appropriate application module behind the blue tab marked "Appendix L—Lotus Disks."

HOW TO USE THE WORKSHEET WITHIN LOTUS 1-2-3

These directions assume a working knowledge of Lotus. They are intended to explain what Dataquest is providing and how to use it, not how to use Lotus.

Retrieving a File (/FR)

Once in an empty Lotus worksheet, retrieve the file in which you want to work. Depending on which application modules you subscribe to, and therefore which worksheets you have, the valid choices for retrieval once you are in Lotus are:

Module	File Name	Application
Industry Overview	ALL	All applications
Mechanical	MECH	Mechanical CAD/CAM
Facilities and Mapping	FD	Facilities Design
	MAPP	Mapping
Electronic Design Automation	EDA	Electronic Design
	ECAE	Electronic CAE
	IC	IC Layout
	PCB	PCB Layout

What You See upon Retrieving a File

After the file is retrieved, you will automatically be sent to several screens, each of which asks you to page down for more information. These screens contain information about what is in the file and how to move around. Press the Home key to get to the beginning of the data.

What Is in the Worksheet

Line Items

First, refer to the "Worksheet Map" for a description of the worksheet. Once in the worksheet, you will see the same line items for all segments. The line items include the following data:

- Workstation Shipments
- Workstation Installed Base
- Average Price per Seat
- CPU Revenue
- Workstation Revenue
- Software Revenue
- Peripheral Revenue
- Service Revenue
- Total Revenue

Percentages

All data are for 1985 through 1991. The compound annual growth rate (CAGR) is shown for each line.

What Is the Menu Macro? (ALT M)

When you retrieve the worksheet, you are in control of a macro that shows you several screens about the worksheet. It then puts you into a custom Lotus menu that operates like the standard Lotus menu. You have four choices in this menu: Go To, View Graph, HP Print, and Quit. Each command is explained further.

Go To

Type in the appropriate response, and you can quickly and easily move around the worksheet. The menu will prompt you to choose one of the following named worksheet locations:

Name	Data for Segment:
WW	Worldwide
NA	North America
EUR	Europe
FE	Far East

(In addition to using the Menu Macro to move around the worksheet, you can use your cursor keys to move within the worksheet, or use page up and down, or use the home key. You can also just press the F5 function key (GOTO) and type in one of the ranges named above.)

View Graph

There are 12 predefined graphs; however, you need a graphics card to view them. The View Graph command asks you to select the graph, lets you view it, then returns you to the menu. The graph names and their contents are shown below:

Data by the Platform Segments (PT):

PTREV	Platform revenue
PTREV%	Platform revenue percent change
PTSHIP	Platform workstation shipments
PTSHIP%	Platform workstation shipments percent change

(The three platform segments are technical workstation (TW), host-dependent (HD), and personal computer (PC).)

Data by the Regional Segments (REG):

REGREV	Regional revenue
REGREV%	Regional revenue percent change
REGSHIP	Regional workstation shipments
REGSHIP%	Regional workstation shipments percent change

(The four regional segments are North America (NA), Europe (EUR), Far East (FE), and Rest of World (ROW).)

Data For Worldwide (WW):

WWREV	Worldwide revenue
WWREV%	Worldwide revenue percent change
WWSHIP	Worldwide workstation shipments
WWSHIP%	Worldwide workstation shipments percent change

HP Print

This command allows you to print the entire worksheet formatted for the HP Laser printer. Because of the printer setup strings in Lotus, this command works *only* with the HP Laser. (To print on another printer, you will have to manually change the setup strings, and possibly adjust the margins. The print command in the menu should then work.)

Quit

This command allows you to quit the Menu Macro and return control to yourself.

Note that to quit the worksheet, not the Menu Macro, type the normal Lotus command: \QY.

Remember, you can return to the Menu Macro at any time by pressing ALT M.

WORKSHEET MAP FORMAT

The data base worksheet format is as follows:

- Data: columns A through I, rows 12 through 248
- Percent Changes: columns K through P, rows 12 through 248
- Years: 1985 through 1991
- Segments:
  - Worldwide
    - Technical Workstation
    - Host-Dependent
    - Personal Computer

- North America
  - Technical Workstation
  - Host-Dependent
  - Personal Computer
- Europe
  - Technical Workstation
  - Host-Dependent
  - Personal Computer
- Far East
  - Technical Workstation
  - Host-Dependent
  - Personal Computer
- Rest of World
  - Technical Workstation
  - Host-Dependent
  - Personal Computer

Line Items for Each Segment Above

- Workstation Shipments
- Workstation Installed Base
- Average Price per Seat
- CPU Revenue
- Workstation Revenue
- Software Revenue
- Peripheral Revenue
- Service Revenue
- Total Revenue

DATA BASE WORKSHEETS DISCLAIMER

IMPORTANT MESSAGE—READ THIS

By accepting this worksheet file, you agree that Dataquest is not responsible for any changes that you may make to the data. If changes are made, Dataquest is no longer the source of the data.

You also agree that you will not divulge, publish, loan, give, sell, or permit anyone else to divulge, publish, loan, give, or sell copies of this data to any person outside your organization.

Dataquest's liability with respect to the data provided is limited to the following:

Dataquest Incorporated represents and warrants to the subscriber that the information contained in the service has been compiled by and is the original product of Dataquest, and that it has the exclusive and unrestricted right to sell the same to the subscriber. The research represents our interpretation and analysis of information generally available to the public but is not guaranteed as to accuracy and completeness. Dataquest will indemnify and hold harmless the subscriber from any obligation or liability to a third party based upon any adverse proprietary claim to such information, but shall not be liable for any other actual, special, or consequential damages.

HOT LINE INFORMATION

If your questions concern the data base format, calculations, or the worksheet and how to use it, call:

Beth Tucker Romig
CAD/CAM Industry Service
Dataquest Incorporated
(408) 971-9000, Ext. 257

If your questions concern the market, application, or the trends and assumptions used to develop the forecast data base, please call one of the following people in the CAD/CAM Industry Service:

Electronic Design Automation	Isadore Katz (408) 971-9000, Ext. 632
Mechanical CAD/CAM	Mike Seely (408) 971-9000, Ext. 600
Workstations	Dave Burdick (408) 971-9000, Ext. 274
Facilities Design or Mapping	Mike Gunville (408) 971-9000, Ext. 670

DATAQUEST'S CAD/CAM INDUSTRY SERVICE
DATA BASE WORKSHEETS

COMMENT AND SUGGESTION FORM

Please return to Dataquest

Name _____

Company _____

Application Modules _____

How useful is the Lotus formatted diskette?

___ Very ___ Somewhat ___ Not at All

How often do you use the worksheet?

___ Very ___ Somewhat ___ Not at All

What other information would you like contained in the worksheet?

_____

_____

_____

What other comments do you have about the worksheet?

_____

_____

_____

_____

Return to: Beth Tucker Romig
CAD/CAM Industry Service
Dataquest Incorporated
1290 Ridder Park Drive
San Jose, California 95131

	1985	1986	1987	1988	1989	1990	1991	86-91 CAGR	ANNUAL PERCENT CHANGES 1986	1987	1988	1989	1990	1991
WORLDWIDE ALL PLATFORMS														
Wkstn Shipments	50,485	77,669	101,655	120,394	133,048	141,753	147,796	13.7%	53.8%	30.9%	18.4%	10.5%	6.5%	4.3%
Wkstn Installed Base	99,736	177,405	276,463	393,349	520,425	651,563	784,442	34.6%	77.9%	55.8%	42.3%	32.3%	25.2%	20.4%
Average Price Per Seat	50.3	43.6	37.7	32.9	28.9	26.0	23.4	-11.7%	-13.4%	-13.4%	-12.9%	-12.0%	-10.1%	-9.9%
CPU Revenue	956	1,203	1,354	1,389	1,347	1,283	1,196	-.1%	25.8%	12.6%	2.6%	-3.1%	-4.7%	-6.8%
Workstation Revenue	854	1,252	1,405	1,438	1,391	1,321	1,227	-.4%	46.5%	12.2%	2.3%	-3.3%	-5.0%	-7.1%
Software Revenue	565	738	928	1,075	1,202	1,343	1,465	14.7%	30.5%	25.9%	15.8%	11.8%	11.7%	9.1%
Peripheral Revenue	255	379	429	441	430	413	388	.4%	49.1%	13.1%	2.9%	-2.7%	-4.0%	-5.9%
Service Revenue	419	551	727	931	1,121	1,302	1,464	21.6%	31.5%	32.1%	27.9%	20.5%	16.1%	12.4%
Total Revenue	3,049	4,122	4,844	5,274	5,491	5,662	5,739	6.8%	35.2%	17.5%	8.9%	4.1%	3.1%	1.4%
WORLDWIDE TECHNICAL WORKSTATION														
Wkstn Shipments	4,834	10,815	16,295	22,410	29,958	39,556	50,303	36.0%	123.7%	50.7%	37.5%	33.7%	32.0%	27.2%
Wkstn Installed Base	7,233	18,048	34,343	56,753	86,711	125,400	174,448	57.4%	149.5%	90.3%	65.3%	52.8%	44.6%	39.1%
Average Price Per Seat	56.9	46.6	41.9	35.3	28.8	24.9	21.8	-14.1%	-18.1%	-10.1%	-15.8%	-18.4%	-13.5%	-12.4%
CPU Revenue	76	160	217	251	274	312	348	16.8%	110.3%	35.6%	16.0%	9.0%	14.1%	11.2%
Workstation Revenue	76	157	213	247	269	307	341	16.8%	106.6%	35.6%	16.0%	9.0%	14.1%	11.2%
Software Revenue	103	173	249	319	400	513	653	30.4%	68.6%	43.8%	28.1%	25.2%	28.4%	27.2%
Peripheral Revenue	40	59	81	93	102	116	129	16.8%	50.0%	35.6%	16.0%	9.0%	14.1%	11.2%
Service Revenue	38	83	117	176	240	312	395	36.7%	117.7%	41.2%	50.3%	36.5%	30.4%	26.3%
Total Revenue	332	632	876	1,086	1,284	1,561	1,865	24.2%	90.3%	38.5%	24.0%	18.2%	21.6%	19.5%

Workstations in actual units, Revenue in millions of dollars, Price in thousands of dollars

	1985	1986	1987	1988	1989	1990	1991	86-91 CAGR	ANNUAL PERCENT CHANGES 1986	1987	1988	1989	1990	1991
WORLDWIDE HOST-DEPENDENT														
Wkstn Shipments	23,071	28,369	33,013	35,852	37,056	36,875	35,303	4.5%	23.0%	16.4%	8.6%	3.4%	-.5%	-4.3%
Wkstn Installed Base	58,161	86,531	116,947	149,291	180,375	210,036	234,837	22.1%	48.8%	35.2%	27.7%	20.8%	16.4%	11.8%
Average Price Per Seat	89.7	88.5	79.7	70.5	63.1	56.4	50.9	-10.5%	-1.4%	-10.0%	-11.5%	-10.5%	-10.5%	-9.9%
CPU Revenue	809	918	961	924	855	761	657	-6.5%	13.5%	4.7%	-3.8%	-7.6%	-11.0%	-13.7%
Workstation Revenue	707	970	1,016	977	903	804	694	-6.5%	37.2%	4.7%	-3.8%	-7.6%	-11.0%	-13.7%
Software Revenue	407	415	446	448	437	413	385	-1.5%	1.9%	7.4%	.4%	-2.4%	-5.4%	-6.8%
Peripheral Revenue	203	283	297	285	264	235	203	-6.5%	39.2%	4.7%	-3.8%	-7.6%	-11.0%	-13.7%
Service Revenue	376	438	574	698	805	895	958	17.0%	16.4%	31.1%	21.7%	15.3%	11.1%	7.1%
Total Revenue	2,502	3,023	3,293	3,333	3,263	3,108	2,896	-.9%	20.8%	8.9%	1.2%	-2.1%	-4.8%	-6.8%
WORLDWIDE PERSONAL COMPUTER														
Wkstn Shipments	22,580	38,484	52,347	62,132	66,035	65,322	62,190	10.1%	70.4%	36.0%	18.7%	6.3%	-1.1%	-4.8%
Wkstn Installed Base	34,341	72,826	125,173	187,305	253,340	316,128	375,157	38.8%	112.1%	71.9%	49.6%	35.3%	24.8%	18.7%
Average Price Per Seat	8.5	9.6	10.0	10.2	9.8	9.5	9.1	-1.1%	12.8%	4.2%	2.0%	-3.9%	-3.1%	-4.2%
CPU Revenue	72	125	176	214	218	210	191	8.9%	74.9%	40.9%	21.2%	2.1%	-3.9%	-8.7%
Workstation Revenue	72	125	176	214	218	210	191	8.9%	74.9%	40.9%	21.2%	2.1%	-3.9%	-8.7%
Software Revenue	55	149	234	308	366	417	427	23.4%	170.9%	56.5%	32.0%	18.6%	13.9%	2.4%
Peripheral Revenue	11	37	52	63	64	62	56	8.9%	220.0%	40.9%	21.2%	2.1%	-3.9%	-8.7%
Service Revenue	5	30	37	57	77	95	112	29.9%	562.4%	22.5%	53.8%	35.1%	24.0%	17.4%
Total Revenue	214	467	675	855	943	993	978	15.9%	117.9%	44.7%	26.7%	10.2%	5.3%	-1.6%

Workstations in actual units, Revenue in millions of dollars, Price in thousands of dollars

	1985	1986	1987	1988	1989	1990	1991	86-91 CAGR	ANNUAL PERCENT CHANGES 1986	1987	1988	1989	1990	1991
NORTH AMERICA ALL PLATFORMS														
Wkstn Shipments	25,652	35,200	45,563	52,833	56,715	59,461	61,317	11.7%	37.2%	29.4%	16.0%	7.3%	4.8%	3.1%
Wkstn Installed Base	58,409	93,608	137,685	188,593	242,109	296,284	350,195	30.2%	60.3%	47.1%	37.0%	28.4%	22.4%	18.2%
Average Price Per Seat	49.9	43.0	36.5	32.1	28.9	26.4	24.0	-11.0%	-13.8%	-15.1%	-12.1%	-10.0%	-8.7%	-8.8%
CPU Revenue	470	561	590	599	578	552	517	-1.6%	19.4%	5.1%	1.5%	-3.5%	-4.6%	-6.3%
Workstation Revenue	440	591	613	622	600	571	534	-2.0%	34.3%	3.8%	1.4%	-3.6%	-4.7%	-6.5%
Software Revenue	301	318	451	521	581	642	681	16.4%	5.6%	41.7%	15.7%	11.4%	10.5%	6.0%
Peripheral Revenue	130	157	187	190	184	176	166	1.2%	20.7%	19.0%	1.7%	-3.2%	-4.1%	-5.7%
Service Revenue	249	259	331	409	481	551	614	18.9%	3.8%	28.1%	23.4%	17.8%	14.5%	11.4%
Total Revenue	1,591	1,886	2,172	2,341	2,424	2,493	2,513	5.9%	18.6%	15.2%	7.8%	3.5%	2.8%	.8%
NORTH AMERICA TECHNICAL WORKSTATION														
Wkstn Shipments	2,866	5,605	7,735	10,149	13,011	16,238	20,005	29.0%	95.6%	38.0%	31.2%	28.2%	24.8%	23.2%
Wkstn Installed Base	4,745	10,350	18,086	28,234	41,245	57,071	76,505	49.2%	118.1%	74.7%	56.1%	46.1%	38.4%	34.1%
Average Price Per Seat	59.1	41.2	36.9	31.1	25.3	21.7	18.9	-14.4%	-30.3%	-10.4%	-15.7%	-18.6%	-14.2%	-12.9%
CPU Revenue	47	75	91	100	104	112	120	9.8%	59.0%	20.2%	10.6%	4.2%	7.3%	7.3%
Workstation Revenue	47	74	89	98	102	110	118	9.9%	55.4%	20.8%	10.6%	4.2%	7.3%	7.3%
Software Revenue	63	86	113	135	155	180	211	19.6%	36.7%	31.1%	19.2%	14.8%	16.0%	17.5%
Peripheral Revenue	25	26	34	37	39	42	45	11.6%	3.9%	30.3%	10.6%	4.2%	7.3%	7.3%
Service Revenue	25	44	57	81	106	133	162	29.8%	73.9%	30.0%	42.2%	30.9%	25.1%	21.9%
Total Revenue	208	305	383	452	507	576	656	16.5%	46.7%	25.7%	17.8%	12.2%	13.7%	13.8%

Workstations in actual units, Revenue in millions of dollars, Price in thousands of dollars

	1985	1986	1987	1988	1989	1990	1991	86-91 CAGR	ANNUAL PERCENT CHANGES 1986	1987	1988	1989	1990	1991
NORTH AMERICA HOST-DEPENDENT														
Wkstn Shipments	12,659	14,110	16,142	17,717	18,738	19,367	19,367	6.5%	11.5%	14.4%	9.8%	5.8%	3.4%	.0%
Wkstn Installed Base	35,410	49,520	64,176	79,968	95,507	111,053	124,868	20.3%	39.8%	29.6%	24.6%	19.4%	16.3%	12.4%
Average Price Per Seat	82.9	82.8	74.9	66.7	59.8	53.8	48.7	-10.1%	-.2%	-9.5%	-11.0%	-10.2%	-10.2%	-9.5%
CPU Revenue	395	440	442	432	410	381	345	-4.8%	11.3%	.5%	-2.3%	-5.0%	-7.2%	-9.5%
Workstation Revenue	365	471	467	456	433	402	364	-5.0%	29.1%	-.8%	-2.3%	-5.0%	-7.2%	-9.5%
Software Revenue	224	173	215	221	223	221	217	4.7%	-22.7%	24.3%	2.8%	1.0%	-.7%	-1.9%
Peripheral Revenue	104	126	136	133	127	117	106	-3.4%	22.0%	8.0%	-2.3%	-5.0%	-7.2%	-9.5%
Service Revenue	223	207	264	313	356	395	426	15.5%	-7.0%	27.5%	18.4%	13.9%	11.0%	7.7%
Total Revenue	1,310	1,417	1,525	1,555	1,549	1,517	1,458	.6%	8.2%	7.6%	2.0%	-.4%	-2.1%	-3.9%
NORTH AMERICA PERSONAL COMPUTER														
Wkstn Shipments	10,127	15,484	21,686	24,967	24,967	23,856	21,945	7.2%	52.9%	40.1%	15.1%	.0%	-4.4%	-8.0%
Wkstn Installed Base	18,254	33,738	55,424	80,391	105,357	128,160	148,823	34.6%	84.8%	64.3%	45.0%	31.1%	21.6%	16.1%
Average Price Per Seat	6.0	7.4	7.8	7.9	7.5	7.3	7.0	-1.1%	23.3%	5.4%	1.3%	-5.1%	-2.7%	-4.1%
CPU Revenue	28	46	57	67	64	59	52	2.5%	66.4%	24.4%	17.1%	-5.0%	-7.3%	-11.6%
Workstation Revenue	28	46	57	67	64	59	52	2.5%	66.4%	24.4%	17.1%	-5.0%	-7.3%	-11.6%
Software Revenue	15	59	123	166	203	241	252	33.7%	302.9%	108.4%	34.8%	22.5%	18.6%	4.8%
Peripheral Revenue	2	5	17	20	19	17	15	25.8%	195.2%	245.8%	17.1%	-5.0%	-7.3%	-11.6%
Service Revenue	1	8	10	15	19	23	26	28.2%	612.1%	33.5%	46.3%	29.2%	19.9%	14.4%
Total Revenue	73	164	265	335	368	399	399	19.5%	125.0%	61.7%	26.4%	10.1%	8.4%	-.2%

Workstations in actual units, Revenue in millions of dollars, Price in thousands of dollars

	1985	1986	1987	1988	1989	1990	1991	86-91 CAGR	ANNUAL PERCENT CHANGES 1986	1987	1988	1989	1990	1991
EUROPE ALL PLATFORMS														
Wkstn Shipments	15,815	23,339	30,889	35,981	39,398	41,939	43,240	13.1%	47.6%	32.4%	16.5%	9.5%	6.4%	3.1%
Wkstn Installed Base	22,162	45,501	75,850	111,019	148,954	188,045	227,291	37.9%	105.3%	66.7%	46.4%	34.2%	26.2%	20.9%
Average Price Per Seat	40.9	41.3	37.7	33.4	29.1	25.8	22.9	-11.1%	1.1%	-8.7%	-11.5%	-12.9%	-11.3%	-11.3%
CPU Revenue	242	333	410	420	398	372	337	.2%	37.8%	22.9%	2.4%	-5.1%	-6.5%	-9.6%
Workstation Revenue	224	373	424	433	410	381	343	-1.7%	66.8%	13.8%	2.1%	-5.4%	-6.9%	-10.1%
Software Revenue	140	206	261	296	321	353	379	13.0%	46.9%	26.4%	13.5%	8.6%	9.9%	7.4%
Peripheral Revenue	64	97	132	136	130	123	113	3.0%	53.0%	35.4%	3.0%	-4.4%	-5.3%	-8.4%
Service Revenue	112	156	202	274	340	401	453	23.8%	38.6%	30.0%	35.4%	24.1%	18.0%	13.0%
Total Revenue	782	1,166	1,429	1,559	1,599	1,631	1,625	6.9%	49.1%	22.6%	9.1%	2.6%	2.0%	-.4%
EUROPE TECHNICAL WORKSTATION														
Wkstn Shipments	1,196	3,448	6,034	8,448	11,489	15,281	18,948	40.6%	188.3%	75.0%	40.0%	36.0%	33.0%	24.0%
Wkstn Installed Base	1,452	4,900	10,935	19,383	30,872	45,844	64,334	67.4%	237.4%	123.1%	77.3%	59.3%	48.5%	40.3%
Average Price Per Seat	53.0	52.6	47.1	39.7	32.3	27.7	24.2	-14.4%	-.8%	-10.5%	-15.7%	-18.6%	-14.2%	-12.6%
CPU Revenue	17	57	90	106	118	135	145	20.6%	230.3%	58.2%	18.0%	10.6%	14.4%	8.0%
Workstation Revenue	17	56	89	104	116	132	143	20.5%	225.3%	57.8%	18.0%	10.6%	14.4%	8.0%
Software Revenue	25	57	87	108	131	164	200	28.7%	131.2%	52.8%	25.3%	20.9%	25.4%	21.9%
Peripheral Revenue	9	20	33	40	44	50	54	21.6%	126.4%	64.8%	18.0%	10.6%	14.4%	8.0%
Service Revenue	9	22	39	62	88	118	150	46.4%	148.1%	72.9%	61.0%	42.0%	33.5%	27.3%
Total Revenue	77	213	337	421	496	599	692	26.6%	176.1%	58.7%	24.8%	17.9%	20.7%	15.6%

Workstations in actual units, Revenue in millions of dollars, Price in thousands of dollars

	1985	1986	1987	1988	1989	1990	1991	86-91 CAGR	ANNUAL PERCENT CHANGES 1986	1987	1988	1989	1990	1991
EUROPE HOST-DEPENDENT														
Wkstn Shipments	5,488	7,888	9,611	10,342	10,145	9,374	8,128	.6%	43.7%	21.9%	7.6%	-1.9%	-7.6%	-13.3%
Wkstn Installed Base	10,103	17,991	27,063	36,593	45,274	52,838	58,323	26.5%	78.1%	50.4%	35.2%	23.7%	16.7%	10.4%
Average Price Per Seat	96.3	89.2	80.8	72.0	64.8	58.3	52.8	-10.0%	-7.3%	-9.5%	-10.9%	-10.0%	-10.0%	-9.3%
CPU Revenue	202	243	284	272	240	200	157	-8.4%	20.7%	16.5%	-4.1%	-11.8%	-16.9%	-21.4%
Workstation Revenue	183	284	300	288	254	211	166	-10.2%	54.9%	5.6%	-4.1%	-11.8%	-16.9%	-21.4%
Software Revenue	106	121	128	128	120	109	98	-4.2%	14.0%	5.5%	.1%	-5.7%	-9.1%	-10.7%
Peripheral Revenue	52	74	88	84	74	62	48	-8.1%	42.4%	18.3%	-4.1%	-11.8%	-16.9%	-21.4%
Service Revenue	100	128	156	201	238	266	284	17.3%	27.2%	22.3%	28.6%	18.3%	12.0%	6.5%
Total Revenue	644	850	955	972	926	848	753	-2.4%	32.1%	12.3%	1.8%	-4.8%	-8.4%	-11.2%
EUROPE PERSONAL COMPUTER														
Wkstn Shipments	9,131	12,002	15,243	17,191	17,764	17,284	16,164	6.1%	31.4%	27.0%	12.8%	3.3%	-2.7%	-6.5%
Wkstn Installed Base	10,607	22,609	37,853	55,044	72,807	89,363	104,634	35.9%	113.2%	67.4%	45.4%	32.3%	22.7%	17.1%
Average Price Per Seat	5.9	6.6	7.0	7.1	6.7	6.5	6.3	-.9%	11.5%	6.1%	1.4%	-5.6%	-3.0%	-3.1%
CPU Revenue	23	33	36	41	40	38	34	.9%	43.0%	9.3%	14.7%	-1.8%	-5.6%	-10.1%
Workstation Revenue	23	33	36	41	40	38	34	.9%	43.0%	9.3%	14.7%	-1.8%	-5.6%	-10.1%
Software Revenue	10	29	47	60	70	79	81	23.1%	189.5%	61.8%	28.4%	16.9%	13.6%	2.3%
Peripheral Revenue	3	3	11	12	12	11	10	28.6%	11.2%	267.9%	14.7%	-1.8%	-5.6%	-10.2%
Service Revenue	3	6	7	11	14	17	20	28.8%	92.4%	33.2%	46.7%	30.3%	20.9%	15.3%
Total Revenue	61	103	136	165	177	184	180	11.8%	67.9%	32.5%	21.1%	7.0%	4.1%	-2.4%

Workstations in actual units, Revenue in millions of dollars, Price in thousands of dollars

	1985	1986	1987	1988	1989	1990	1991	86-91 CAGR	ANNUAL PERCENT CHANGES 1986	1987	1988	1989	1990	1991
FAR EAST ALL PLATFORMS														
Wkstn Shipments	8,266	16,982	20,922	24,568	27,353	28,717	29,713	11.8%	105.4%	23.2%	17.4%	11.3%	5.0%	3.5%
Wkstn Installed Base	14,562	31,543	52,043	76,036	102,423	129,260	156,387	37.7%	116.6%	65.0%	46.1%	34.7%	26.2%	21.0%
Average Price Per Seat	68.7	47.1	40.1	34.6	30.0	27.2	24.7	-12.1%	-31.5%	-14.8%	-13.8%	-13.2%	-9.2%	-9.1%
CPU Revenue	227	258	296	298	286	270	252	-.5%	13.4%	14.8%	.5%	-4.0%	-5.5%	-6.6%
Workstation Revenue	176	247	306	307	293	276	257	.8%	40.5%	24.0%	.1%	-4.3%	-5.9%	-7.0%
Software Revenue	115	203	187	218	252	294	347	11.3%	76.5%	-8.0%	16.7%	15.7%	16.6%	17.9%
Peripheral Revenue	56	116	92	93	89	85	81	-7.1%	107.2%	-21.0%	.6%	-3.7%	-4.7%	-5.3%
Service Revenue	49	122	171	217	259	298	334	22.3%	148.4%	40.0%	26.7%	19.3%	15.2%	11.9%
Total Revenue	624	947	1,052	1,132	1,179	1,223	1,270	6.0%	51.7%	11.1%	7.5%	4.2%	3.7%	3.8%
FAR EAST TECHNICAL WORKSTATION														
Wkstn Shipments	641	1,317	1,739	2,504	3,580	5,299	7,789	42.7%	105.6%	32.0%	44.0%	43.0%	48.0%	47.0%
Wkstn Installed Base	864	2,181	3,919	6,423	10,003	15,202	22,838	60.0%	152.5%	79.7%	63.9%	55.7%	52.0%	50.2%
Average Price Per Seat	55.0	58.2	51.5	42.9	34.7	29.8	26.0	-14.9%	5.8%	-11.5%	-16.7%	-19.1%	-14.1%	-12.8%
CPU Revenue	9	22	28	34	39	50	64	24.3%	129.9%	31.4%	20.0%	15.5%	27.3%	28.0%
Workstation Revenue	9	21	28	33	39	49	63	24.0%	128.4%	29.9%	20.0%	15.5%	27.3%	28.1%
Software Revenue	13	27	42	65	100	152	220	51.8%	108.1%	53.8%	55.3%	54.2%	51.1%	44.9%
Peripheral Revenue	5	12	11	13	15	19	24	14.9%	151.5%	-11.5%	20.0%	15.6%	27.3%	28.0%
Service Revenue	3	14	17	26	36	48	64	35.6%	418.1%	24.4%	47.8%	37.7%	35.2%	34.1%
Total Revenue	39	96	126	171	229	318	435	35.2%	144.5%	31.0%	35.5%	33.6%	39.0%	37.0%

Workstations in actual units, Revenue in millions of dollars, Price in thousands of dollars

	1985	1986	1987	1988	1989	1990	1991	86-91 CAGR	ANNUAL PERCENT CHANGES 1986	1987	1988	1989	1990	1991
FAR EAST HOST-DEPENDENT														
Wkstn Shipments	4,552	5,306	5,542	5,542	5,332	4,977	4,457	-3.4%	16.6%	4.5%	.0%	-3.8%	-6.7%	-10.5%
Wkstn Installed Base	8,742	14,047	19,168	24,136	28,502	32,339	35,179	20.2%	60.7%	36.5%	25.9%	18.1%	13.5%	8.8%
Average Price Per Seat	100.2	103.9	93.2	82.1	73.5	65.9	59.5	-10.5%	3.6%	-10.3%	-11.8%	-10.4%	-10.4%	-9.7%
CPU Revenue	198	192	189	166	143	120	97	-12.8%	-3.0%	-1.6%	-11.9%	-13.8%	-16.4%	-19.1%
Workstation Revenue	146	181	200	176	152	127	102	-10.8%	23.9%	10.1%	-11.9%	-13.8%	-16.4%	-19.1%
Software Revenue	72	116	85	78	70	59	48	-16.1%	61.3%	-26.5%	-8.4%	-10.6%	-15.6%	-18.3%
Peripheral Revenue	44	76	58	51	44	37	30	-16.9%	70.9%	-22.9%	-11.9%	-13.8%	-16.4%	-19.1%
Service Revenue	46	91	135	161	182	198	208	17.9%	98.9%	47.7%	19.6%	12.9%	8.9%	4.9%
Total Revenue	506	656	667	633	591	541	485	-5.9%	29.6%	1.6%	-5.1%	-6.6%	-8.5%	-10.3%
FAR EAST PERSONAL COMPUTER														
Wkstn Shipments	3,073	10,359	13,641	16,522	18,441	18,441	17,467	11.0%	237.1%	31.7%	21.1%	11.6%	.0%	-5.3%
Wkstn Installed Base	4,956	15,315	28,956	45,477	63,918	81,720	98,369	45.1%	209.0%	89.1%	57.1%	40.5%	27.9%	20.4%
Average Price Per Seat	24.8	16.6	17.1	17.4	16.5	16.0	15.4	-1.5%	-33.1%	3.0%	1.8%	-5.2%	-3.0%	-3.7%
CPU Revenue	20	44	79	97	103	100	91	15.4%	119.4%	77.8%	23.2%	6.0%	-3.0%	-9.0%
Workstation Revenue	20	44	79	97	103	100	91	15.4%	119.4%	77.8%	23.2%	6.0%	-3.0%	-9.0%
Software Revenue	30	60	59	75	82	83	79	5.7%	99.3%	-.4%	25.6%	9.8%	1.8%	-5.4%
Peripheral Revenue	7	29	23	29	30	29	27	-1.6%	299.2%	-19.8%	23.2%	6.0%	-3.0%	-8.9%
Service Revenue	1	17	19	30	41	52	61	29.6%	2801.7%	11.8%	58.5%	38.3%	25.9%	18.4%
Total Revenue	78	194	259	328	360	365	349	12.4%	148.2%	33.5%	26.3%	9.8%	1.4%	-4.3%

Workstations in actual units, Revenue in millions of dollars, Price in thousands of dollars

	1985	1986	1987	1988	1989	1990	1991	86-91 CAGR	ANNUAL PERCENT CHANGES 1986	1987	1988	1989	1990	1991
REST OF WORLD ALL PLATFORMS														
Wkstn Shipments	752	2,149	4,281	7,013	9,582	11,637	13,526	44.5%	185.8%	99.2%	63.8%	36.6%	21.5%	16.2%
Wkstn Installed Base	4,603	6,752	10,884	17,701	26,939	37,974	50,568	49.6%	46.7%	61.2%	62.6%	52.2%	41.0%	33.2%
Average Price Per Seat	57.4	49.7	38.3	29.4	24.9	21.7	18.9	-17.6%	-13.3%	-23.0%	-23.3%	-15.1%	-13.0%	-12.8%
CPU Revenue	17	50	58	73	85	89	90	12.4%	202.8%	16.6%	25.0%	15.7%	5.2%	.9%
Workstation Revenue	15	41	61	76	88	92	93	17.7%	175.7%	48.4%	24.6%	15.6%	4.9%	.7%
Software Revenue	8	10	30	40	48	54	58	42.4%	23.0%	204.8%	31.8%	20.0%	12.5%	7.9%
Peripheral Revenue	5	9	18	23	27	28	29	26.9%	85.7%	112.2%	25.3%	15.7%	5.7%	1.3%
Service Revenue	8	14	23	31	41	52	63	35.3%	79.4%	62.0%	37.2%	32.3%	26.4%	21.9%
Total Revenue	52	124	191	243	288	315	332	21.8%	138.6%	53.9%	27.4%	18.5%	9.4%	5.5%
REST OF WORLD TECHNICAL WORKSTATION														
Wkstn Shipments	131	444	786	1,309	1,877	2,739	3,561	51.6%	239.2%	76.9%	66.5%	43.4%	45.9%	30.0%
Wkstn Installed Base	173	617	1,403	2,713	4,590	7,283	10,771	77.2%	257.5%	127.4%	93.3%	69.2%	58.7%	47.9%
Average Price Per Seat	52.4	34.4	30.8	26.0	21.1	18.1	15.8	-14.4%	-34.4%	-10.5%	-15.6%	-18.8%	-14.2%	-12.7%
CPU Revenue	2	6	8	11	13	16	18	24.5%	197.0%	28.6%	40.4%	16.6%	25.5%	13.3%
Workstation Revenue	2	6	8	11	12	15	18	24.6%	190.0%	29.3%	40.5%	16.6%	25.4%	13.2%
Software Revenue	2	3	7	11	13	17	21	48.9%	50.3%	152.2%	44.0%	24.4%	31.9%	23.0%
Peripheral Revenue	1	1	3	4	5	6	7	37.9%	27.9%	114.3%	40.4%	16.8%	25.5%	13.1%
Service Revenue	1	3	4	7	10	14	18	49.0%	131.2%	48.4%	74.3%	49.8%	41.8%	33.4%
Total Revenue	8	19	29	43	53	68	82	34.6%	130.5%	57.2%	45.6%	23.6%	30.1%	19.8%

Workstations in actual units, Revenue in millions of dollars, Price in thousands of dollars

	1985	1986	1987	1988	1989	1990	1991	86-91 CAGR	1986	1987	1988	1989	1990	1991
									ANNUAL PERCENT CHANGES					
REST OF WORLD HOST-DEPENDENT														
Wkstn Shipments	372	1,066	1,717	2,251	2,841	3,157	3,352	25.7%	186.5%	61.1%	31.1%	26.2%	11.1%	6.2%
Wkstn Installed Base	3,907	4,973	6,541	8,595	11,092	13,805	16,466	27.1%	27.3%	31.5%	31.4%	29.1%	24.5%	19.3%
Average Price Per Seat	94.0	82.0	74.2	65.8	58.8	52.6	47.4	-10.4%	-12.7%	-9.5%	-11.4%	-10.6%	-10.5%	-9.8%
CPU Revenue	14	42	47	54	61	61	58	6.5%	204.3%	10.0%	16.1%	12.8%	-.6%	-4.3%
Workstation Revenue	12	33	49	57	65	64	61	12.9%	172.8%	47.3%	16.1%	12.8%	-.6%	-4.3%
Software Revenue	5	5	18	21	23	23	22	34.3%	-7.7%	256.3%	15.6%	12.4%	-1.1%	-4.7%
Peripheral Revenue	4	7	14	17	19	19	18	19.8%	100.3%	97.8%	16.1%	12.8%	-.6%	-4.3%
Service Revenue	7	11	18	23	29	35	41	29.2%	69.2%	62.3%	27.2%	25.3%	19.8%	16.2%
Total Revenue	42	99	147	172	197	202	200	15.0%	137.0%	47.4%	17.4%	14.5%	2.4%	-.8%
REST OF WORLD PERSONAL COMPUTER														
Wkstn Shipments	249	639	1,778	3,453	4,864	5,741	6,614	59.6%	156.7%	178.3%	94.2%	40.9%	18.0%	15.2%
Wkstn Installed Base	524	1,163	2,940	6,393	11,257	16,886	23,331	82.2%	121.9%	152.9%	117.4%	76.1%	50.0%	38.2%
Average Price Per Seat	5.2	6.5	6.9	7.0	6.6	6.4	6.2	-.9%	25.0%	6.2%	1.4%	-5.7%	-3.0%	-3.1%
CPU Revenue	1	2	4	8	11	12	14	50.7%	187.1%	132.0%	97.3%	33.9%	14.5%	10.7%
Workstation Revenue	1	2	4	8	11	12	14	50.7%	187.1%	132.0%	97.3%	33.9%	14.5%	10.7%
Software Revenue	1	2	5	8	11	13	14	49.6%	211.5%	148.4%	74.4%	33.4%	18.2%	9.8%
Peripheral Revenue	0	0	1	2	3	4	4	114.2%	800.0%	1244.4%	98.3%	33.8%	14.3%	10.6%
Service Revenue	0	0	1	1	2	3	4	94.5%	650.0%	266.7%	121.8%	72.1%	47.1%	35.3%
Total Revenue	2	6	15	28	38	45	50	54.2%	207.5%	156.3%	91.0%	35.3%	17.4%	12.1%

Workstations in actual units, Revenue in millions of dollars, Price in thousands of dollars