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COMPUTER AIDED DESIGN AND MANUFACTURING (CAD/CAM) OF PLASTICS PRODUCTS

UNIVERSITY OF LOWELL M.S. 1982

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COMPUTER AIDED DESIGN AND MANUFACTURING (CAD/CAM) OF PLASTICS PRODUCTS

BY

JULLIETTE M. CARIGNAN

B.S. BIOLOGICAL SCIENCE AND ART,
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SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN PLASTICS.

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Signature of Author Julliette M. Carignan Date 11/21/82

Signature of Thesis Supervisor Stephen Burke Driscoll

Signatures of Other Thesis Committee Members [signature]

[signature]

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ABSTRACT OF THESIS
SUBMITTED IN PARTIAL FULFILLMENT
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UNIVERSITY OF LOWELL

Thesis Supervisor: Stephen Burke Driscoll
Professor, Department of Plastics

ABSTRACT

CAD/CAM, computer-aided design and manufacturing, is a valuable engineering tool which incorporates integrated computer hardware and software modules to create design systems for particular applications. CAD/CAM has been heralded as the answer to America's productivity decline and the means of bringing her back into a competitive position in world markets. Its advantages include shorter lead times, better products through improved design and analysis, improved communications, and increased design capacity. These factors result in significant cost savings and improved employee morale.

This thesis provides information for engineers involved with the design, development, manufacturing, and testing of mechanical products, specifically those made of plastics/composite materials. Topics include basic concepts, hardware and software components of commercial CAD/CAM turnkey systems, the application of CAD/CAM tools in the process of designing and manufacturing products, and CAD/CAM resources available to engineers. Included is the results of a survey of U.S. CAD/CAM educational offerings.

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DEDICATION

I would like to dedicate this thesis to my parents for their gift of warmth and love, for their open-minded career guidance, even before it was fashionable, and for their encouragement that I march to the beat of my own drummer.

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I. PREFACE

This thesis is written for the student, designer, engineer, manager, or technology buff who has been hearing and reading about CAD/CAM and desires an increased understanding of the field. The reader might have limited formal computer education, and therefore may find it difficult to put CAD/CAM systems into perspective with other more familiar computer technologies.

This was the case for the author, who had been trained in various computing applications such as FORTRAN programming, computer-aided drafting and word processing, but only in a "black box" sense. The training provided the basic ability to accomplish objectives with the aid of the systems, but left many unanswered questions. The functions of the various hardware components was unclear, as was the relationship between the software programs for text editing and those for graphical manipulation. The ability to utilize computer systems fully and efficiently would clearly be limited by such ignorance of the fundamentals. However, it was necessary to gather a great number of articles and books from a variety of related fields in order to begin to get a handle on the subject. This thesis is the carefully edited compilation of the most relevant reference information gathered.

Ned Chapin's well-organized classic book called Computers, A Systems Approach (New York: Van Nostrand, 1971) is a comprehensive text which covers basic concepts, computer applications, people's interactions with computers, computer hardware and software, and system management.

II. INTRODUCTION

Everyone seems to be talking about CAD/CAM today; it is the new buzzword in the high technology industries. Yet most people who use the term appear to have only a vague notion of what it means and what it involves. This thesis shall introduce this subject in as much depth as possible, beginning with a few formal definitions.

2.1 DEFINITIONS

A COMPUTER is a high-speed, automatic, electronic digital data processing machine which manipulates symbols representing real-world phenomena self-directly but algorithmically. In other words, the computer is a machine which can perform operations on symbols automatically, but must be supplied with a strategy or plan (ALGORITHM) which controls its operation. A COMPUTER PROGRAM represents a restatement of an algorithm in a form consisting of a set of sequenced directions for directing the computer to perform an operation (1). A SYSTEM is a way of combining the actions of machines, the properties of materials, and the services of man to accomplish work (2).

CAD/CAM is a computer system which utilizes integrated computer aids in the design and manufacture of products, while COMPUTER-AIDED DESIGN is a methodological engineering support discipline involving the integration of appropriate computer hardware and software modules to create design systems for particular requirements (3).

Many companies and universities have been using computers since the 1950's for engineering problems. What fundamentally distinguishes CAD, as a discipline, from other uses of computers in the design process, is its systematic, rather than random collection of programs.

Because CAD/CAM technology is often thought of as a miracle technology which will solve all productivity problems, it must be emphasized that a CAD/CAM system, like any computer system, is merely a lever to multiply the power of man's mind. It is precisely because of the complementary nature of man and computer in their characteristics and abilities, as shown in Table I, that the marriage of man and machine in CAD is so effective.

TABLE I

THE CHARACTERISTICS OF MAN AND COMPUTER

	MAN	COMPUTER
Method of logic and reasoning	Intuitive by experience, imagination, and judgement	Systematic and stylised
Level of intelligence	Learns rapidly but sequentially. Unreliable intelligence	Little learning capability but reliable level of intelligence.
Organization of information	Informal & intuitive	Formal and detailed
Effort involved in organizing information	Small	Large
Storage of detailed information	Small capacity, highly time dependent	Large capacity, time independent
Tolerance for mundane work	Poor	Excellent
Ability to extract significant information	Good	Poor
Production of errors	Frequent	Rare
Tolerance for erroneous information	Good intuitive correction of errors	Highly intolerant
Method of editing information	Easy & instanteous	Difficult & involved
Analysis capabilities	Good intuitive analysis, poor numerical analysis ability	No intuitive analysis, good numerical analysis ability

The following definitions will delineate the relationship of CAD/CAM systems to other closely related systems (4).

-INFORMATION SYSTEM: A total integrated composite system comprised of all of the formal data handling systems in a particular organization.

-DATA HANDLING SYSTEM: Any system which processes and communicates data.

-DATA PROCESSING SYSTEM: Any system which processes data.

-COMMUNICATION SYSTEM: A system whose processing is limited to changing the form or format of data.

Thus a CAD/CAM system is a data processing system, may be a data handling system if it has communications capability, and may be a subsystem in an integrated information system.

A technology closely related to CAD/CAM is COMPUTER GRAPHICS, a discipline concerned with the theories and techniques to input, output, generate, transform, manipulate, and transmit visually meaningful data with the aid of computers (5). Computer Graphics techniques and devices, used throughout the design process, include any device which converts computer language into people language, and vice versa.

Such devices may be GRAPHIC or NON-GRAPHIC, the former using lines, curves, circles, and characters to build pictures, in contrast to the latter, which use characters such as "x" and "o" to develop non-textual images (6).

Graphics devices may also be BATCH (PASSIVE), or INTERACTIVE. The difference is one of time, the latter having a considerable time-lag between information delivery and answer receipt. Some examples of the different types of CG devices are shown in the figure below.

	BATCH	INTERACTIVE
GRAPHIC	DIGITAL PLOTTER COM	C.R.T. TERMINALS
NON-GRAPHIC	LINE PRINTER	TELETYPE ALPHANUMERIC INQUIRY TERMINAL

FIGURE I

COMPUTER GRAPHICS DEVICES CLASSIFICATION

Passive graphics applications include graph and chart plotting, and computer output on microfilm (COM). All engineering industries rely heavily on communication through drawings. With a large design firm having to store and access over 100,000 drawings, COM greatly increases filing efficiency.

Interactive CG are particularly prevalent in CAD. By presenting large, confusing amounts of data graphically, man can use his skill in pattern recognition to note special features, errors, and trends. Computer Graphics can also help the designer in defining and editing complex geometrical or topological relationships in the input data for CAD programs. CG techniques are particularly useful in allowing the representation and manipulation of design components.

2.2 CAD MARKETING STATUS

Since their introduction in 1968 by Calma Co., an estimated 6,000 CAD systems have come into use in the U.S. (7). Manufacturers started snapping up CAD systems in the late 70's; since 1978, U.S. sales have tripled (8). Purchases are expected to climb more than 30% annually to an estimated $2.5 Billion in 1985 (9). Of the total units shipped in 1981, 41% were destined for mechanical-design end use. Shipments of mechanical design systems are projected to grow 28% per year worldwide through 1995 (10). The inevitability of CAD has already been universally recognized in some industries, the electronics and shipbuilding industries, for example, where no firm can maintain a competitive position without it. In many other fields, including automotive, chemical, transportation, civil, and architectural engineering, utilization is widespread and rapidly growing. Dick Allen, who developed the system at Rubbermaid, declares that the people who get into CAD/CAM today are the ones who will survive in the next 10 years (11). Sentiments like these are being echoed across the country. CAD and CAM are being welcomed as the answer to America's productivity decline and the means of bringing her back into a competitive position in world markets. According to a recent study by the Center for Productivity of the National Science Foundation, CAD/CAM "has more potential to increase radically productivity than any development since electricity" (12). A senior computer industry executive estimates that over the last decade computer usage has provided at least 15% of the 2% annual growth in productivity in the U.S.A. He further estimates that this can be improved even further due to new computer price/performance ratios being achieved, and that an incremental percentage point improvement in productivity achieved in this way could accelerate economic growth in the a U.S.A. sufficiently to drive unemployment down to 3.4% by 1990.

2.3 ADVANTAGES AND BENEFITS OF CAD

One of the most attractive features of CAD is the significant return on investment which can be realized. However, this is just one of the many objectives achieved by using CAD. Others include:

Economics

- studies show that pretax earnings usually improve by at least 10% annually when CAD/CAM systems are installed. The devices can cost anywhere from $100,000 to $1M, but generally pay for themselves within 12 - 18 months. Not only do they boost the productivity of engineers and designers, but they sharply reduce the amount of assembly parts that a manufacturer must stockpile (13).
- reduced design costs through reduction in man hours
- reduced interest on payments on borrowed funds for a project because the project can be completed sooner
- reduced space requirements for equivalent productions

Employee Morale

- to speak of the benefits of CAD/CAM in terms only of functional capabilities and technological potential omits a significant ingredient: People get "turned-on" by graphics. There is an excitement generated by the futuristic visions of all that can be done with this new powerful tool. The potential for greatly increasing the engineer's personal capability is at his or her fingertips!
- less time spent on routine, repetitive tasks
- more pleasant environment

Reduced Design Time

- reduced lead time to get a new product onto the market
- may eliminate the need for models and preliminary prototypes
- decreased modification time: A large proportion of designers' and draftsmen's time is spent making

modifications to existing drawings. With CAD's storage and retieval simplicity and its ease of modification, changes may easily be made to the part, without having to separately modify any dimensions affected, and a new drawing obtained. The part may then replace an existing part in an assembly and be checked to ensure the modification does not cause any interference problems.

-improved information perception: A human being must process data in order to obtain information. Pictures tend to communicate information, while text, especially that which contains numbers, tends to communicate raw data. A person's most valuable asset is time, and time spent processing data into information is wasted time. CG techniques of CAD enable a person to quickly identify relationships, trends, and exceptions, which are frequently embedded in masses of data. Thus, with graphics, the user can draw analyses and conclusions much more readily (14).

-faster response to customer inquiries and faster delivery

Better Products through Improved Design

-reduction in design errors

-facilitates the investigation of alternatives and the evaluation of special cases that might cause problems.

-improved decision making and reduction of product liability risks due to ready access to relevant data and availability of analysis techniques

-improved data management and interrelation of information between documents

-improved design documentation more quickly, reliably, and cheaply

-improved compliance with standards which can be locked into the software: because graphics systems have built into them all of the drafting standards, the actual detailing of components proceeds quite rapidly without the need to consult drafting reference manuals. Thus it is possible for relatively inexperienced designers who have recently graduated from college to quickly become proficient in producing quality designs. Drawing quality becomes more of a function of the output plotter quality than the artistic skill of the designer.

-improved interdepartmental communication through sharing of common databases

Greater Design Capacity

-breakdown of the bottleneck in the design office, especially important in view of the difficulty in recruiting skilled labor

Improved Management of Design Projects

-better informed management and control of engineering data and projects, data distribution, production scheduling, estimating, and order entry.

-it is now the case that with many complex design projects, the size of the engineering design teams is significantly larger than those used in the same industry a few years ago. In order to complete a complex design, improved communication is required among more individuals requiring access to the current design data in order to integrate his activity to finalise the product design. The coordination of such relationships, particularly where projects are operating on short time scales, is not possible using most of the manual methods or even the simpler CAD systems now on the market.

Ability to Solve Problems which require outputs of such volume and precision that they cannot be easily tackled without a computer

-examples include Finite Element Analysis, and the design of three-dimensional multilayered integrated circuits.

Tables II and III detail the benefits of CAD/CAM from a productivity and a management and control standpoint, respectively.

TABLE II
PRODUCTIVITY BENEFITS OF CAD/CAM (59)

Function	Productivity Benefits
Drafting	Drawings with recurring features or which require frequent updates are more efficently drafted & maintained.
Documentation	Bills-of-material & technical illustrations are very quickly produced if they can be derived from data already stored in a CAD/CAM data base.
Design	Calculations necessary in design activities are best performed by computer. CAD systems can either perform these calculations themselves or prepare input for larger general purpose computers from graphical data already stored in the system. Design tasks that involve fitting together or housing a number of parts are very efficiently done with some CAD systems.
Estimating	The ability of some CAD systems to associate, store, and recall graphical and text data makes estimating more easily accomplished and more accurate.
Order entry	A lot of time can be saved by integrating order entry with CAD systems. Major savings can occur when an order must be tied to specific engineering drawings.
Manufacturing	Many systems include software for producing NC tapes and other items which reduce the effort necessary to get a part into production.

TABLE III
MANAGEMENT AND CONTROL BENEFITS OF CAD/CAM (60)

Function	Management & Control Benefits
Data Management	Some CAD systems have significant capabilities for organizing project information for easy retrieval. Also provided are access control facilities.
Data Distribution	With telecommunication capabilities, CAD systems provide a means of distributing up-to-the-minute engineering information to all departments and plants.
Project Management	CAD systems provide management with information and easily revised tools for decision making and project control.
Scheduling	The interface of the manufacturing data base with order entry and shop schedule data enables management to schedule and adjust machine tool usage to achieve greatest possible utilization.
Estimating	CAD systems can ensure that all material costs and labor charges are captured and that uniform estimating procedures are followed, while making available up to date data and cost information to all operators.
Order entry	Integrating CAD systems with order entry can provide greater scheduling flexibility especially where drawings or manufacturing control tapes must be linked to each other.

2.4 COMPUTER ORGANIZATION

The computer has three main functional aspects:

-the input function,
-the processing function,
-the output function.

The hardware of a data processing system is of two types:

-the Central Processing Unit, consisting of the main memory, the control unit, the arithmetic and logic unit, and the external storage.
-the peripheral units, for input and output functions.

Appendix A provides a more detailed review of computer organization.

The Loop of Control

When people interface with a computer, there is a loop which is created which has four steps:

-data acquisition: The computer collects the symbols which represent a real-world situation,

-processing: The computer reduces and processes the symbols and presents the results of the processing to the man,

-comparison: the man compares the results of the processing with known standards,

-selection: The man converts the results of the comparison into a decision on an appropriate course of action, then communicates to the computer the symbols which represent the course of action.

This 4-stage operation, repeated many times, serves to maintain control of a process, a machine, an experiment, a situation etc.

2.5 OPERATIONAL FACTORS

There are several factors which influence the behavior of people as they attempt to adapt to the computer, and influence the performance of the computer.

Timing of the Feedback

The first operational factor is the timing of the feedback in the loop:

- in REAL-TIME SYSTEMS, time is treated in its normal clock-measured value. The data involved must be handled rapidly enough for results of the processing and communication to be utilized before the operation being controlled has reached a conclusion. The timing is critical to the operation. Real-time systems are employed where close control over fast-changing operations is essential, for example the guiding of a rocket's flight or the automatic control of a laboratory experiment. The computer is the dominating party in the loop.

- in INTERACTIVE SYSTEMS, also called ON-LINE, information is exchanged between the man and the computer in an on-going, conversational or alternating manner. This is a real-time exchange but the timing in this case is not critical to the outcome. The man dominates the loop. Interaction is appropriate to CAD/CAM because of the ITERATIVE nature of design, in which the designer tries to optimize the design by repeatedly changing parameters and evaluating the results. This is a natural task for the computer, but the choice of parameters is better left to the experience and intuition of the designer. Interactive systems require a time-sharing operating system or a stand-alone configuration.

- in DELAYED TIME, or BATCH SYSTEMS, data is accumulated, held and processed at a convenient later time. The man has little or no interaction with the computer during the operation; the effects of the processing are independent of the effects of the events. Batch systems have the advantage of being far easier to cost, control, and operate, but they lack the design flexibility inherent in interactive systems.

Data Access

Another operational factor is that of data access. CAD systems are dependent for their flexibility and interactiveness on having a sophisticated data access mode. Data access and databases will be discussed further at a later time. There are five levels:

-some systems have no facility for data access other than data that has been input locally. An example of such a system is one that displays tax tables. There is no need to access the data in the system in order to use it.

-sequential access to specific data files: This is a more complicated access which involves both permanent and transitory data.

-random access to specific files: This access mode allows the interaction between man and computer.

-random access to many files: This is the creation of a DATABASE. A database associates and integrates data from many parts of an organization, and is an essential ingredient in a CAD/CAM system.

-random access to many databases: This system requires a great deal of computer-to-computer communication, is very advanced, and is not used to any great extent at present.

Concurrency

A third operational factor is that of concurrency, i.e., the number of users and jobs the computer is capable of processing at any one time. There are four degrees:

-CONSECUTIVE EXECUTION is the oldest mode, and is still common today. The computer does one job a a time, finishing one before starting another.

-with TIMESHARING EXECUTION, better use is made of the computer's resources as up to hundreds of independent programs can be executed in an interlaced manner. The resulting impression, because of the speed of the computer, is that many people have simultaneous use. This execution provides for interactive, conversational data communication between the user and the computer.

-a computer system capable of MULTIPROGRAMMING is one which provides for the shared use of the computer's facilites for more than one job at a time. Each job is given a priority rating. This system does not necessarily provide for interactive timing or conversational interaction.

-a MULTIPROCESSING EXECUTION provides for the simultaneous execution of two or more jobs. This system requires a lot of hardware, and can be used for timesharing and multiprogramming applications.

Geographic Distribution of Computer Facilities

The last operational factor of affecting CAD/CAM system users is that of the geographic distribution of computer facilities:

-CENTRALIZED systems utilize a central large computer with an extensive network of communications facilities,

-in a DECENTRALIZED system, data is processed partially or completely near or at remote locations,

-in a COMBINED CENTRALIZED/DECENTRALIZED system, a host central computer is supported by satellites which handle local data processing tasks, communicating only summary data to the central facility.

In the 1940's and 1950's digital computer installations tended to be centralized due to their cost, complexity and the specialized skills required for maintenance and operation. It was then common to bring "batch" jobs to the computer and to prepare manually the input data in a form that was convenient for the computer. When CAD/CAM systems first started taking hold in the early '70's, manufacturers followed suit, concentrating on cramming more capability into stand-alone systems, while providing only crude interfaces to other computing systems.

The trend in the '80's is toward more and more DISTRIBUTED PROCESSING NETWORKS. The advent of distributed computing aims to spread the computer processing requirement to stations where the work can be most efficiently effected. The required task is split into subtasks whose requirements are matched by the appropriate computing enviroment or configuration (see below). The range of central processor hardware extends from the supercomputer to the microprocessor with a complimentary range of storage devices. This range of equipment presents a large menu for choice of equipment to fulfill the required tasks.

The traditional configurations of central processor hardware are (15, 16):

-the company MAINFRAME: Commercial software developed for a mainframe is usually a general purpose system providing a solution to a range of applications of the same type, for example finite element codes. The use of the company mainframe nearly always gives the engineer poor access to resources with slow response and access at unsociable hours. In this environment, the engineer uses computing only where there is no alternative, for example large analysis programs and repetitive single code check calculations. Maxicomputers are expensive but cost-effective for large jobs that require brute force computing power. Ideal applications are characterized by:

-large "batch" programs of optimized code
-prepared databases
-buffered input/output
-a minimum of direct, interactive communication with users
-non-real-time, non-sensor-based operations

Examples of applications: data reduction, interactive graphics, theoretical calculations, and report generation.

-the REMOTE BUREAU SERVICE: The company buys time on an off-site computer via communications links, rather than owning an in-house system. Budgetary considerations and the requirement to pre-plan use impose a strict discipline, discouraging investigative studies or the implemenatation of new systems. However, computer bureaux offer not only raw computer power, but also access to proprietary application software on very short lead times. If either were required infrequently and at short notice, then computer access through a bureau is likely to prove most cost-effective.

-the MINICOMPUTER: The minicomputer is used for special purpose local processing, for example graphics. A minicomputer can also form the basis of a hardware/software system tuned to provide an efficient solution to a specialized problem area, for example general drafting systems. In-house mini's encourage more widespread use but are inherently restrictive on the size of problem which can be solved. Restrictions arise mainly from lack of processor power and/or the ability to store and manipulate large data volumes. In applications, minicomputers occupy the broad middle ground between maxi- and micro-computers. Applications are characterized by:

-being interactive
-real-time and sensor-based
-user programmed for specific applications

Functions within the laboratory, such as supervision of experimental sequences, preliminary checking and display of data, and interactive development of real-time, sensor-based computer programs generally require the hardware and software support associated with minicomputer systems.

-the DESKTOP or MICROCOMPUTER: The microcomputer can also be used in the stand-alone mode, but suffers even more from lack of power and suitable secondary storage media. In addition, it is restrictive in the amount of directly addressable storage and also in the language facilities provided. The most commonly provided language is BASIC which is not useable for high processing requirements or for all but simple input/output (I/O) operations.

Many of the most popular microcomputers have the same general architecture as today's minicomputers and are frequently used for similar (but perhaps smaller scale) applications. The significantly reduced cost and size of these processors has had a profound effect on the number and type of applications. They are regarded by most user-programmers as "small minicomputers".

Another class of microcomputers is special-purpose "computer systems on a chip", that are currently being developed for EMBEDDED or dedicated applications. These chips are programmed by the manufacturer and appear in products as simply user-oriented functions, or "intelligence", rather than "computers".

Microcomputers find their place as integrated controllers for individual pieces of equipment such as analytical instruments, as interfaces for analog and digital data acquisition from experimental equipment, and as communication controllers and buffers.

In general, a distributed processing system can consist of any of the processors above connected together in any form of network arrangement. The arrangement is customized for each application to fit the equipment to the need at each site with the appropriate control and redundancy being provided.

The choice of computer depends on the local processing requirements, availability of software, the user interface including graphics requirements and the control and scale of the data.

The main advantage of distributed processing is the additional flexibility it provides in choosing and locating equipment, and additional flexibility derived from the ability to split complete tasks and intercommunicate data among them. Other advantages include:

- Control of access to information
- Customization of computer and storage equipment to minimize costs
- Local, hence more "friendly" communication
- Faster interaction in conversational mode
- Access to subset of facilities relevant to user's task only
- Control of processing location
- Customization of processing equipment to minimise costs.

Another important advantage is the ability to support the desired mode of interaction with the computing equipment on specific input and/or output devices. For example, the need for interactive CRT graphics is completely incompatible with simultaneous timesharing access to a remote mainframe computer. This might enforce a mixture of computers to satisfy the total need cost-effectively.

From the point of view of the management of a manufacturing operation, the advantages are (17, 18):

- -Lower hardware costs
- -Improved performance per unit cost
- -Reduced software development costs
- -Reduced communication costs
- -Resource sharing
- -Increased reliability and availability
- -Flexibility
- -Database management

In conclusion, distributed processing is appropriate in CAD applications when disparity exists in either data storage or processing reqirements between modules of a single task and frequent interaction between the modules is required. However, disadvantages are the lack of appropriate software to operate in this mode and the cost of communications. It is not unheard of to find that the cost of communications in a computer network exceed all other costs. Hence a careful appraisal of the cost of communication equipment and the running costs is necessary. For these reasons, this mode of processing should only be considered where there are clear operating advantages.

III. COMMERCIAL TURNKEY CAD/CAM SYSTEMS

3.1 INTRODUCTION TO TURNKEY SYSTEMS

A CAD/CAM system is basically a data processing system designed to be operated interactively in a conversational mode. Give and take between man and machine takes place in a natural manner, the user making known his intentions, and the machine providing essential information, prompting him along, showing him his progress, and acknowledging his actions.

Although it is possible for a design or manufacturing firm to install CAD/CAM facilities in bits and pieces, there is a great deal of interest in "TURNKEY" systems, i.e., complete hardware/software packages for particular applications which enable the user to ignore programming problems. An example of an integrated turnkey CAD/CAM system is one which is available to the plastics industry from Calma Co., recently bought by General Electric. Calma uses its system for the design of parts and molds and the direction of NC machinery used in mold production. It is also be used for the design and control of automated equipment systems such as processing machines and robots, for optimizing injection mold design, and for structural dynamics research. Calma plans to provide a link to the MOLDFLOW program, to be discussed later, and, with the establishment of technical service centers throughout the U.S., to provide consultation in CAD/CAM applications (19). Other suppliers of turnkey CAD/CAM systems for mechanical design are listed in Appendix B.

As stated earlier, computer systems are built up of devices that fall into the categories of input devices, processing devices, or output devices. In CAD/CAM systems, input devices are used to input graphical and textual data, operational instructions, and previously stored data. Input devices include:

-alphanumeric keyboard,
-function menu,
-light pen.

Processing devices in CAD/CAM systems include:

-the processing unit itself,
-the operating software and CAD/CAM software,
-telecommunications hardware and software,
-interface hardware and software.

CAD/CAM output devices include:

- -data displays,
- -data plotters,
- -printers,
- -storage facilities.

Keeping this classification in mind will help to clarify the purpose of each device in the turnkey system and underscore the direction of data flow. However, the nature of interactive CAD/CAM and the way which turnkey systems are sold makes it more convenient to discuss their hardware in terms of functional units.

3.2 CAD/CAM SYSTEM CONFIGURATION

The first functional unit of a turnkey CAD/CAM system is the WORKSTATION, which is the location for all man/machine interaction. It is composed of coordinated input and output devices including:

- -displays,
- -keyboards,
- -function menus,
- -digitizers.

More than one workstation may be provided with a turnkey system.

PRODUCTION STATIONS are where output is produced, and include:

- -plotters,
- -tape punches,
- -magnetic tapes,
- -microfilm systems.

SYSTEM PROCESSORS are the central computing facilities of the system, and include:

- the CPU with all its collateral data processing equipment,
- main memory,
- on-line storage,
- off-line (magnetic tape) storage,
- software.

Workstations are connected to the system processor via a bidirectional data link which allows both input and output transactions at each workstation. The production stations are also connected to the system processor but require only unidirectional data links because they are strictly output devices.

While most links between CAD/CAM system components work best when they are local (less than 1000 feet apart), remote linking, usually with a reduced data transmission rate, is frequently possible. Thus distributed processing systems are possible with CAD/CAM systems. Workstations may be located off-site and linked via telephone lines. Plotters, computer-output-microfilm and tape units may also be remotely located.

3.2.1. THE WORK STATION

The work station is the focal point for man/machine interaction, from which the whole gamut of CAD/CAM functions can be requested. Here, the engineer converses with the system for the following purposes:

-to enter or retrieve model or drawing data,

-to manipulate geometric shapes,

-to request computations,

-to initiate engineering drawing plots.

Work station design varies considerably from manufacturer to manufacturer. In general, however, it consists of:

-a graphics display unit,

-a text display unit,

-a keyboard,

-either a function meun implemented with pushbuttons or a menu pad (tablet) or both,

-a light pen or stylus,

-a cursor digitizer or other means of indicating cursor position on the graphics display screen.

The components of a workstation are shown in Figure II.

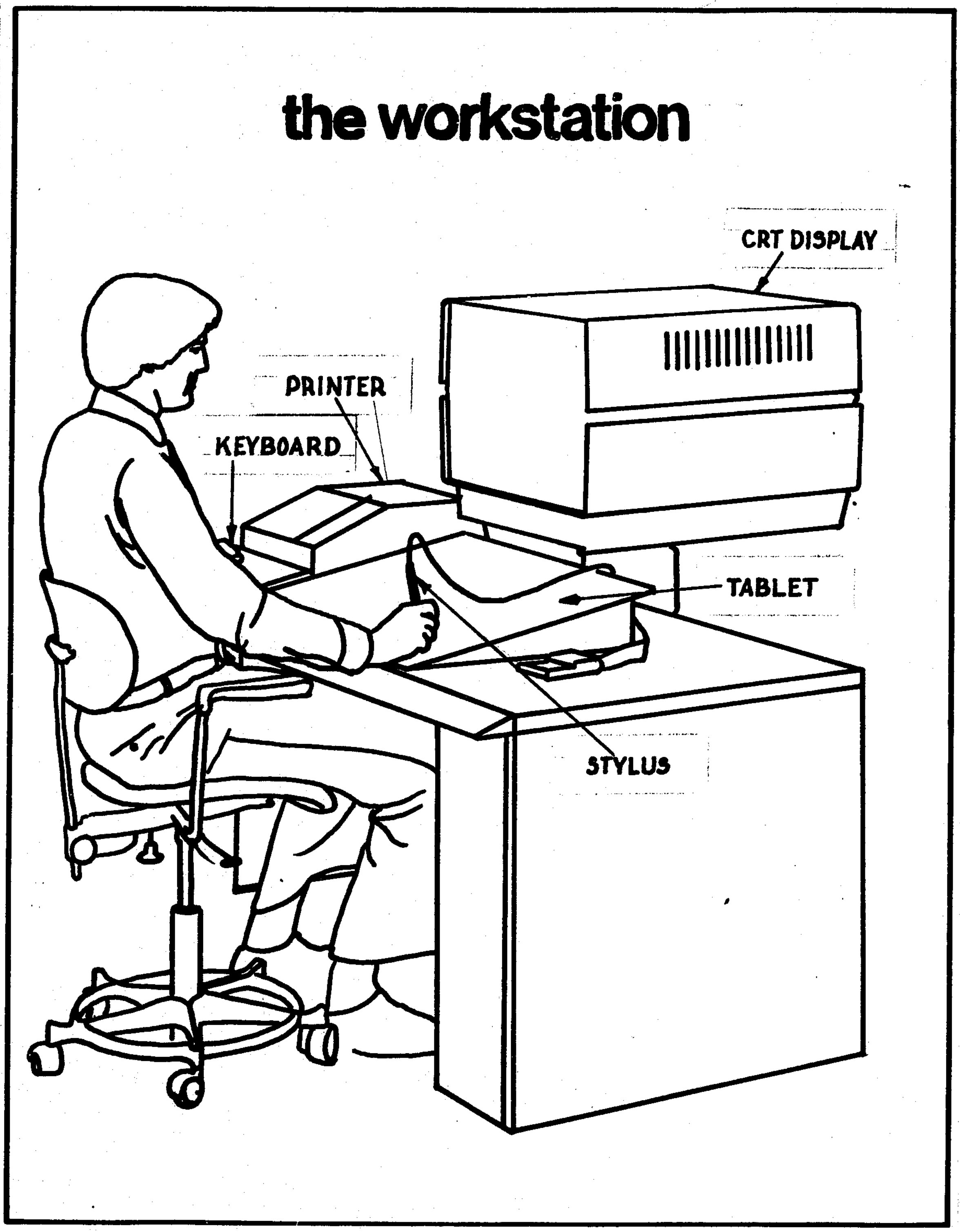


FIGURE II

THE CAD/CAM WORKSTATION

3.2.1.1. The Graphic Display Unit

The graphic display unit (GDU) is a window through which the user can view the graphics data in the computer. The unit accepts computer signals and processes them into commands for hardware units called function generators which display the output as letters, numbers, and circles on a TV-like screen. A number of different types and sizes of displays are presently in use. The characteristics of each type are quite different and must be considered very carefully when selecting a display for a particular application.

The GDU is usually mounted on or built into the workstation furniture. Most suppliers provide adustable mounts so that the viewing angle and screen height can be changed to suit the individual operator. The importance of the display mounting style and workstation layout should not be underrated. The operator's view of the display is part of the interactive link between him and the system; if the interaction takes place in a naturally comfortable position, he will be able to sustain a higher level of concentration over a longer period of time.

All current commercial CAD/CAM systems use CRT technology to display graphics. Although much work has been done on "solid state" flat-panel picture displays, they have still not progressed beyond the introductory stages.

A CRT, shown in Figure III, draws a picture by illuminating a uniform layer of phosphor which coats the inside of the display screen. The illumination is the result of a controlled beam of electrons which are deflected horizontally or vertically using a magnetic or electrostatic field, or a combination or both, to trace a pattern on the screen. The electrons, which are emitted from a cathode inside the evacuated glass tube, have extremely low inertia so they can be moved very quickly (hundreds of thousands of inches per second).

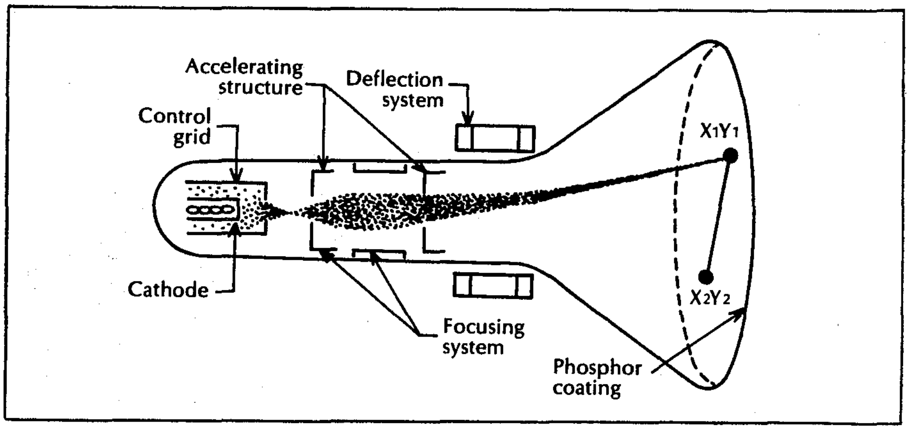


FIGURE III

THE CRT (61)

In order to produce a graphic symbol, a computer data word designates the X and Y locations of the symbol on the screen. The electron beam is moved to those locations and illuminates the phosphor at those points. Any symbol can be produced as a series of these dots. Most graphic display units have 1024 X 1024 addressable locations on the screen.

As shown in figure IV, there is a good deal of hardware involved in a graphic display unit. Following will be a short discussion of the function of each of the components.

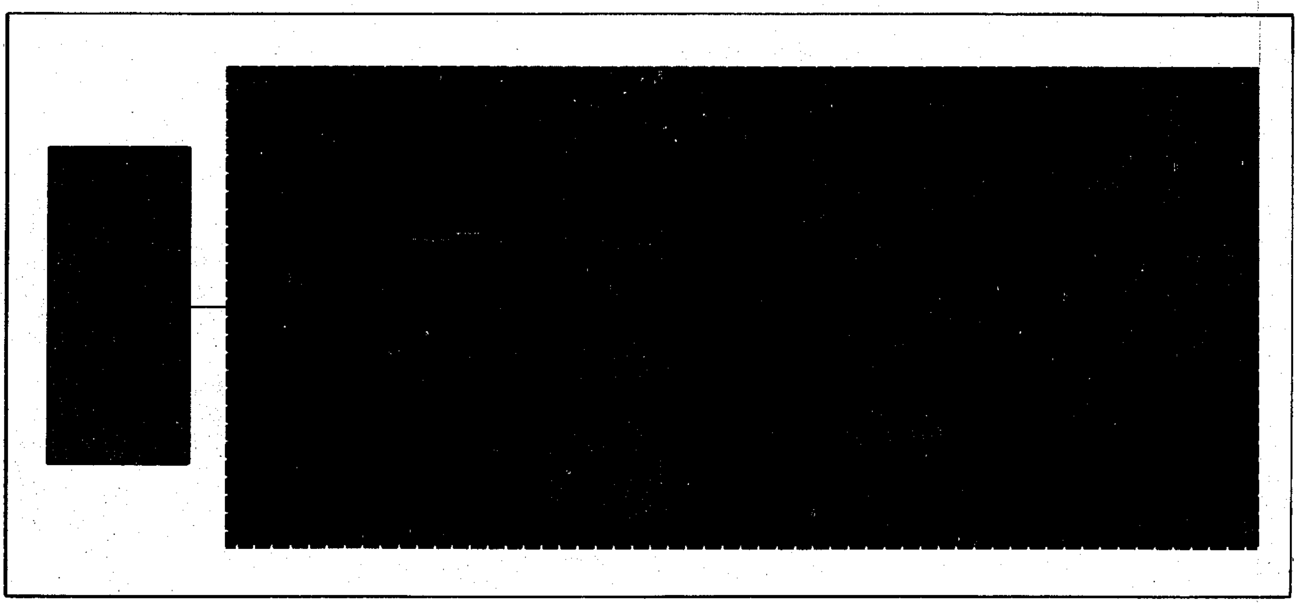


FIGURE IV

GRAPHIC DISPLAY HARDWARE (62)

A set of ANALOG CONVERTERS are required in order to change the digital X and Y designation into corresponding analog symbols for beam positioning and modularity.

An INTERFACE is needed between the computer and the display generator to convert data word organization and logical level so that the computer and display generator can communicate, and provides the necessary sequence signals so that the two elements can properly communicate.

Because software has become so much more expensive to write and maintain than hardware, a DISPLAY GENERATOR combines hardware elements which serve to minimize the amount of computer software which is required to generate a symbol.

Several FUNCTION GENERATORS, such as character, vector, and curve generators specify characteristic information in order to utililize a minimum number of data words to define a geometric shape. For example, a circle can be defined with a vector generator with only its center location and its diameter, rather than with the X,Y locations of each of the points on its circumference.

In order to further minimize the software requirement, the typical CRT also contains other elements which modify the outputs of the function generator. For example, a digital size control is usually associated with the character generator. It uses just 1 or 2 bits to program character size. Associated with the vector generator is often a line structure controller which determines whether lines will appear as dotted, dashed, dash-dotted, etc.

With all of the function generators and function generator modifiers, it is necessary to provide logic to decode the data words from the computer and route the information to the appropriate function generator or modifier. This is accomplished by the DISPLAY PROCESSING UNIT, which is often a microprocessor. The DPU may have several other hardware functions as well, including image rotation, windowing, scaling, depth cueing, autoplotting, etc.

GDU Technology Summary

There are basically four types of interactive graphics display technologies in use today:

-refresh, or directed-beam CRT displays,
-video or TV-type displays,
-raster/scan converter displays,
-storage, or direct-view storage tube displays (DVST).

Each offers its own advantages and disadvantages, and are employed for different applications. The choice of graphics display is an important one, because drawing quality and complexity limitations, dynamic capability, cost, compatibility with input devices such as light pens, and other important system capabilities are dependent on the display system chosen. The technologies are detailed in Appendix C and compared in Table IV.

-raster scan: uses a raster, or matrix, which is regularly scanned in a succession of scan lines. Such systems may be considered as interactive color TV sets, or TVs with memory. They have very high to high resolution and produce both static and dynamic pictures. The technology is suited to drawings of areas and surfaces and produces realistic pictures. Prices range from very low to fairly high.

-storage tube: Stores the picture in the tube. The technology produces high-resolution static pictures and is good for fast plotting and line drawings. The display is green on green. Such systems are medium priced.

-refresh display: Must be continuously refreshed. Such systems produce moving line drawings, dynamic pictures, with very high resolution. The systems are fairly expensive, highly interactive, and can be used as stand-alone devices.

TABLE IV

GRAPHIC DISPLAY TECHNOLOGIES SUMMARY (63)

	Raster Scan	Storage Tube	Refresh
Cost	$3K - $20K	$8K - $15K	$15K - $350K
Resolution	low to high	high	very high
Drawing type	areas, realistic	line	line
Motion	dynamic	static	dynamic
Color	lots	green on green	mono or four color
Data Content w/out flicker	unlimited	unlimited	limited
Selective Erasure	Yes (limited)	Optional	Yes
Interactive-ness	high	low	very high
Use	intelligent terminal	dumb terminal	stand alone systems

3.2.1.2. The Text Display Unit

A second workstation component of many workstations is a text display unit, dedicated to alphanumerics only. The unit displays text while it is being typed by the operator, prompts the user for input, notifies him of mistakes, and keeps the user informed of the system's status. Most systems use a second CRT for this function, but some manufacturers prefer a single-line flat panel display. Other suppliers believe that combining text with the graphics on one display is a superior, more cost effective approach, and do not include an alphanumeric display.

3.2.1.3. The Display Hard Copy Unit

Display hard copy units serve many purposes:

- -allow the engineer to continue working on a problem away from the workstation,
- -allow the engineer to plan for the next workstation session,
- -provide hard copy required for a project notebook,
- -hard copy is often useful in tracing a design's evolution,
- -allow the communication of current designs to other departments and locations which do not have remote workstations,
- -hard copy may be useful as an exhibit attached to a design progress report,
- -allow access to quickly-produced up-to-date information for hastily arranged design reviews or client meetings.

3.2.1.4. CRT Copiers

CRT copiers are low-cost, table-top devices which produce small, medium quality copies with a minimum of effort and time. They cost about $4500 to $10,000. Copy size varies amoung models, and depends on the CRT type and dimensions. Most copies fit inside an 8-1/2 X 11 inch border.

CRT copiers use either an electrostatic writing technique, a dry-silver paper image transfer system, or a thermal printing process for output.

3.2.1.5. Keyboards

Alphanumeric keyboards are the primary input devices system control commands and entering textual data. In most systems, the alphanumeric keyboard can be used to enter almost every kind of command and data type that the system will handle. Thus it is the universal, if rudimentary, input device.

While many workstations use a standard computer terminal keyboard, others have a custom layout which reduces keying effort. For example, auxiliary alphanumeric keygroups in calculator-type layout are often provided to facilitate numeric entry. Some keyboards have special function key groups for specialized control functions.

3.2.1.6. Function Menus

Function menus were developed to provide a simple pushbutton way of making a CAD/CAM system work. They may be mechanized in many different ways:

-pushbutton function menus: May be pushbuttons packaged in a separate mobile table-top housing, or pressure-sensitive contact elements mounted in a thin, portable tablet, or a pushbutton array which is part of the workstation console or keyboard.

Individual pushbuttons are assigned to specific menu items, and functions are invoked by pushing the appropriate buttons. Since different menus can be assigned to a single pushbutton array, an unlimited number of functions can be handled by an array. Overlays with menu fuction identifiers are fitted over the pushbutton panels to indicate their current function assignments. Only the functions of a single menu are operative on a given array at one time. Knowing which menu is operative at a given time can be a problem. Often it is left to the operator to remember to switch overlays at each function reassignment, although some systems provide this information on the display screen or otherwise.

Most pushbuttons provide the user with some sort of feedback to let him know that the system has recorded his keystroke.

-digitizer function menus: Digitizer tablets may also be used to mechanize function menus. Usually 11 X 11 inch tablets, these instruments can automatically detect the coordinates of any point on their surface which is selected with a cursor, a pen-like or puck-shaped device.

Digitizer function menus have a substantial software dimension. A common implementation consists of a Mylar sheet on which a grid has been drawn. When a point inside a square is selected with the cursor, the software detects which square was selected from the coordinates of the digitized point.

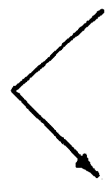
Usually, as with pushbutton function menus, different function menus are known to the software, and the system must be informed which menu is operative, usually by a keboard menu identifier or via a menu function.

-display function menus: Sometimes a function menu is implemented directly on the graphics or alphanumeric

CRT screen. Usually this is done by displaying a short list of functions that can be selected either by a single keystroke on the keyboard or by a display-cursor positioning device such as a light pen or a joystick. Once a function is chosen, the system will execute the request and display a new set of choices predicated on the previous selection.

Display function menus can be extremely powerful interactive elements because they are selectable by the system on the basis of the context of what the user is trying to accomplish, and there is never any doubt about which is the currently operative menu. However, the number of items in each menu is limited, the menu tends to clutter the display, and a great deal of software is needed to take full advantage of their potential.

-character recognition function menus: Another way of implementing function menus is the character recognition approach. In this scheme, simple symbols are traced by the operator, freehand, on a digitizer tablet. These symbols are recognized by the graphics processor software and interpreted as menu items. Symbols may be drawn on the tablet so that a command can naturally be combined with location data by drawing the command symbol in a corresponding place. An example of a character symbol which represents a command to repaint the CRT screen is shown below.



To enter a menu function symbol, the operator moves the display cursor to the desired position by means of the digitizer's cursor unit (usually a pen-like device called a stylus) then traces the symbol on the tablet.

As with other function menu implementations, the operator is given feedback that the system has received the function request, as the function symbol is traced on the graphics screen. Once the symbol entry is completed and the stylus is lifted off the tablet, the system will display the symbol meaning in English and execute the function.

A standard set of function menu symbol definitions are supplied with the system. The user is also able to teach the system to recognize other symbols.

This implementation of the function menu can be an extremely efficient method of data entry and system control for experienced operators. However, for operators who use the system infrequently, it can be difficult to remember all of the various symbols, and looking them up is very disruptive.

-voice recognition function menus: One supplier employs a function menu which utilizes voice data entry (VDE) units that enable users to enter items verbally by speaking into a microphone. the vocabulary of words which correspond to particular menus are defined by the user, who "trains" the unit to recognize his utterances and associate them with menu functions. The command issued is displayed on the CRT before being executed.

Physically, the VDE unit consists of a noise-cancelling microphone and headset interfaced via an analog/digital converter to a dedicated microprocessor which is connected to the graphics processor via a conventional data link. Pattern recognition software in the microprocessor recognizes the unique speech patterns in the VDE's vocabulary.

This method of interaction is very efficient in that it allows the operator to enter functions in a very natural way while keeping his hands free to manipulate other devices. However, the VDE cannot recognize the voice commands if anything happens to the user's voice such as a cold or allergic reaction. Also, if the operator were not a frequent user, it would be difficult to remember the vocabulary and disruptive to have to look it up.

3.2.1.7. Digitizers or Tablets

Digitizers are one of the most commonly used, purely graphical input devices. They are an indispensable component of any CAD/CAM system as a primary interactive workstation device for:

-mechanizing function menus,
-display-cursor positioning,
-inputting drawing information.

Digitizers have three associated elements:

-an instrumented tablet on which points can be located,
-a cursor unit with which to select the points,
-instrumentation to convert the selected locations to

digital form for transmission to a computer.

Physically, digitizers are available in many different sizes. The smaller units are portable. Some larger units have opaque back-lighted tops to avoid annoying shadows, and may be mounted on motorized, fully articulating stands.

The cursor unit associated with digitizers may be a pen-like device called a stylus, but the larger tablets generally have a puck-like cursor with a glass section inscribed with a reticle (and usually a magnifying glass).

One type of digitizer is fitted with a pen holder and X- and Y-axis drive mechanisms to make it into a hybrid device called a digitizer/plotter. These are very versatile interactive devices.

Applications of digitizers:

-large digitizers as primary input devices: Some workstations are digitizer-centered, and consist of a large digitizer, a graphics display, an alphanumeric keyboard, a small pushbutton panel, and occasionally, an alphanumeric CRT. The digitizer comes with a puck-style cursor that has four to ten function pushbuttons for requesting operations such as X-hold, Y-hold, snap-to-gid, and so forth that provide computer assistance for indicating a desired or relative cursor position.

The starting point for entering the graphical data into the computer is the drawing or sketch. The sketch is mounted on the tablet and the operator then digitizes it using the cursor and function menu to input drawing elements and create an idealized form of the sketch, checking his work on the graphics CRT as necessary. This mode of operation is minimally threatening to people with a drawing office background who feel uncomfortable working at a workstation that looks like a computer terminal. If the main task is to input already existing drawings into a CAD/CAM system, digitizing is a generally accepted, speedy way of doing it.

-digitizer/plotters as primary interactive devices: Digitizer/plotters are hybrid units that are both locator devices and graphics plotters. Looking like a large drawing board, a digitizer/plotter is often equipped with such features as power tilt, backlighting, and electrostatic hold-down. These units are versatile, interactive graphics terminals that can be used alone or in combination with other workstation devices.

Usually a workstation with a digitizer/plotter will include:

-a medium size pushbutten panel, usually the primary means of communicating commands to the system,

-a digital display of the X,Y coordinates, used to help position the cursor precisely, and determine the coordinates of any point.

-an alphanumeric keyboard,

-a graphics CRT (sometimes) to provide interactive feedback and provide additional views to aid in the creative process.

As in conventional digitizing, the sketch is mounted and is digitized using the cursor and function menu to input drawing elements. But instead of manually moving the cursor into position to input specific points, the cursor is positioned with the aid of the unit's power-drive using a joystick-type control. Using this technique, it is possible to position the head very precisely to within the limit of the plotter's resolution.

Extremely useful is the plot-back capability of the digitizer/plotter, which allows the operator to immediately plot what has just been input directly over the original, thereby helping him detect errors quickly and easily.

Digitizer/plotters can be used in almost all CAD/CAM applications, but are not as common as other interactive workstation devices. Because of their unique plot-back capability, they are more versatile than a conventional digitizer for entering drawing data, but are more expensive. To justify the additional expense, users look for payback in the unit's plot-back, error-check feature and in its ability to pinch hit as a production plotter.

3.2.1.8. Cursor Controls

Introduction to cursor positioning:

When constructing or manipulating graphics while viewing them on a display screen, an operator must frequently refer to the location coordinates, geometric objects, or specific regions on the screen. For example, in order to insert a line between two points, the designer must identify each point to the system. Almost all graphics functions have one or more operands that specify coordinates or refer to a geometric entity. Thus CAD/CAM suppliers have made an effort to develop devices and methods to do this quickly and conveniently.

It is important that the cursor positioning device as well as all other input and feedback devices be will suited to the user, as the quality of the interaction between the computer and the operator is dependent on the choice. To the extent that an input device satisfies the user's natural modes of expression in a particular activity, he will view the interaction as being more natural, and will adapt more easily to the CAD environment while thinking and reacting in terms of the application environment (20).

What makes the process of choosing input devices difficult is that what feels natural to one group of individuals may be very awkward for another group. It seems that there is no inherently superior method: It's what feels good that works best. Recognizing this, some suppliers offer a variety of devices and leave the choice up to the user.

The Light Pen

Physically, the light pen is a photoelectric, pen-shaped sensor that generates a signal when light is detected at its tip. This signal is fed back to the display processor software which then determines what display element was being output when the light pen signal was generated. Light pens, due to their use of software to determine locations or objects, incur a considerable amount of processing overhead.

The light pen can be used in a pointing mode, to point at information on the screen or to designate the location at which elements are to appear; or in the drawing mode, for direct information entry. Since the light pen's operation depends on time dependent functions, this tool can not be used with storage tube displays.

Digitizer-Tablet Cursor Controls

This scheme of referencing the display relies on the operator's sense of relative position to locate points on the screen in an indirect method. An equivalence is established by software between an area of the digitizer and the CRT screen. Screen references are made with the stylus by digitizing points on the digitizer tablet that correspond to the desired points on the screen. Visual feedback is provided by a cursor symbol displayed on the screen. This is a very popular and successful method and is characterized by good resolution and a moderate software overhead.

Thumbwheel Cursor Controls

Thumbwheels provide an indirect method of positioning the cursor.

Joysticks

A joystick is a lever that can be moved in at least two degrees of freedom which is coupled to potentiometers. An advantage of joysticks is their easily realized three-dimensional (3-D) capability. Joysticks are reliable, fun, and convenient to use.

Trackball Cursor Controls

A trackball consists of a ball mounted in a bearing that allows it to spin freely in all directions. The user positions the cursor by spinning the ball in the appropriate direction, then stopping the ball when the cursor is in position. Some authorities assert that trackballs are better than joysticks because of the superior tactile feedback provided by the ball's momentum during rapid movement. Also, it is said that the trackball makes it easier to position the cursor mosre precisely than is possible with a joystick.

Pushbutton Cursor Controls

Pushbutton controls utilize four motion buttons arranged in a diamond shaped pattern, each button moving the cursor in one of four directions: up, down, left, or right. Pushbutton controls are inexpensive and are very common in alphanumeric displays where they provide adequate performance. They are not used to any significant degree in CAD/CAM graphics because they are harder to manipulate than other techniques, and significantly slow the operator down.

3.2.2. THE PRODUCTION STATION

The output of a CAD/CAM system includes drawings, geometric model data, numerical control (NC) tapes, bills-of materials printouts, and digital data files. The most common CAD/CAM production devices are plotters, line printers, perforated tape punches, and magnetic tape drives.

3.2.2.1. Hard-Copy Graphics Plotters

Plotters are devices that convert the digital graphics data in a CAD/CAM system into conventional hard-copy graphics as a means of documenting work or to provide data for reports. The output of plotters consists of:

-detail drawings,
-assembly drawings,
-schematics,
-flow charts,

-project control charts,

-technical illustration masters.

Plotters and graphics displays complement one another very nicely in CAD/CAM systems. While the CRT can display a low accuracy picture very rapidly for fast manipulation and graphics creation, the plotter produces large, high accuracy permanent copy for documentation but at a very slow rate.

Plotters can go beyond producing images of a product on paper. In some CAD/CAM applications they actually participate in the manufacturing process. Artwork masters for printed circuit boards are sometimes cut directly by a plotter fitted with a strippable-film cutting accessory in place of drawing pens. Some plotters scribe complex patterns directly onto metal-plate work pieces. Others are fitted with miniature milling heads to cut intricate shapes and patterns in sheet metal.

The plotters used in CAD/CAM production stations fall into four broad categories: pen plotters, electrostatic plotters, photoplotters, and computer-output-microfilm (COM) systems. Table V provides a summary and Appendix D provides a detaileddescription of the systems.

TABLE V

SUMMARY OF MAIN PLOTTER TYPES USED FOR ENGINEERING OUTPUT (21)

Plotter type	Drum	Flatbed	Microfilm (COM)	Electrostatic
Line quality	Good, but requires attention	As Drum plotter	Good, Consistent	Consistent, but limited by dot matrix size
Typical Addressable Points	22,000	44,000	16,000	8,500
Output medium	Paper or plastic opaque (translucent)	As Drum plotter	Various microfilm	Special coated paper
Characters	Single line	As Drum plotter	Versatile fonting possible	Versatile fonting, but limited by dot matrix size
Typical drawing speed	3 sec	10 sec	4 ms	---
Cost ratio	1	4.2	8.3	1.7

3.2.2.2. Line Printers

Line printers are often used to print out listings of various attributes such as coordinate information, and summary listings.

3.2.2.3. Perforated Tape Subsystems

Paper Tape Punches

Punched tape is presently the predominating means of transmitting digital control data to programmable automated production equipment such as numerical control (NC) or computer numerical control (CNC) machine tools. Other uses of punched tape includes off-line plotting, microfilm preparation, and software storage.

Tape punches are generally purchased with a CAD/CAM system and can be configured as part of a workstation in some systems. High speed punch installations usually add about $5000 to the cost of a turnkey system.

Perforated Tape Readers

Tape readers are needed to read tapes for verification before releasing them to the machine, because tape punching is not particularly reliable. Tape readers also help with utility functions such as duplicating previously punched tapes and for reformatting tapes to make them compatible with various NC or CNC machines.

Readers come in electromechanical or photoelectric versions, the latter being less "hard" on the tape. Purchased as part of a turnkey CAD/CAM system, readers cost around $5,000.

Although rugged and inexpensive, punched tape is difficult to handle and a great length of it is needed for complex machining jobs. With advances in CNC and the availability of rugged, low-cost memory and magnetic data-transfer media, punched tape will probably be replaced by diskettes or hard-wired links in the near future.

3.2.2.4. Magnetic Tape Subsystems

Magnetic tape is a low cost, portable medium on which large amounts of digital data can be stored very compactly. In addition to its role as a storage medium, tape has become a means of interchanging data between all kinds of very different data processing systems because recording formats have been able to be very standardized in this medium.

In CAD/CAM operations, this interchange tends to integrate the CAD/CAM systems with other engineering, production and business computers used by an establishment, thereby allowing many of the indirect benefits of CAD/CAM to be realized. While data transfer can be accomplished via telecommunications links, much of it continues to be done manually by transporting mangnetic tape reels from one system to another. Typically, data may be interchanged with large mainframe processors, other CAD/CAM systems (although this may require special software to reformat digital data), off-line production systems, and with their manufacturer's support and development organizations. Most CAD/CAM suppliers use magnetic tape as a distribution medium for new software and for software upgrades. In addition, software debugging is often performed off-site by sending a memory dump on tape to the system manufacturer.

Short-term storage of vital data and software on magnetic tape provides security and backup for on-line storage data, thus rendering it immune to operator error or hardware or software failures. Long-time archival storage of large quantities of data is another common use for magnetic tape. Its long-term stability, low cost (about one-tenth the cost of disk storage), convenient shape and small size make it ideal for this application.

Tape drives add from $16,000 to $32,000 to the cost of a system. The tape can be purchased in quantity at a unit cost of about $15 per 2400-foot reel.

3.2.3. THE SYSTEM PROCESSOR

The GRAPHICS PROCESSOR or system processor is the main computational facility of a CAD/CAM system. Most of today's systems use distributed computing and consist of more than a single processor. Minicomputers and microprocessors are often utilized for such processing tasks which include:

-a dedicated computer in each workstation to control the display and analyze digitizer/tablet input,
-a dedicated computer to convert vector graphics to raster form for electrostatic plotting,
-a dedicated computer for database management and for controlling communication to a network of workstations or to other computers.

The system processor coordinates the activities of these other computers, controls access to the database, executes user-written software, and does the major portion of the geometric and analytic computations performed by the system.

As a rule, the system processor is a general purpose minicomputer made by one of the major minicomputer manufacturers such as Digital Equipment Corporation, Sperry-Univac, Hewlett Packard, Prime Computer, or Data General. But some turnkey CAD/CAM system manufacturers have developed proprietary special-purpose "graphics" computers, and use these as system processors. There is no straightforward answer to whether a special-purpose processor or a general-purpose minicomputer is better for

CAD/CAM applications. A user must evaluate the advantages of each approach in the light of his own unique situation and objectives. Appendix E lists some of the advantages of each configuration.

Processor Features and Characteristics

Basically, graphics processors consist of a processing unit, memory, and a data bus. The processing unit executes program instructions stored sequentially in memory. These instructions serve to direct the performance of arithmetic or logical operations on data stored in the memory, the transfer of control to different programs and subroutines, and the initiation of operations to transfer data between the memory and peripheral devices.

Program instructions and other data stored in the memory are transferrable to designated peripheral devices as well as to the processor and can be accessed by these units more or less directly.

Data and control signals flow between the memory, the processor and the peripherals along controlled DATA BUSES, which can be thought of highways along which data travel. Today's high performance minicomputers have multiple processors, memories and data buses all working together to provide greater throughput capacity.

Features and characteristics commonly associated with contemporary mini- and midicomputers used as CAD/CAM processors are listed in Appendix F.

3.2.3.1. Data Storage

On-Line Storage

On-line storage contains data needed for the current interactive operation of a CAD/CAM system. This includes user information and programs. On-line storage refers to the total amount of memory to which the system processor has immediate (less than a second) access. Disc storage accounts for more than 99% of the total on-line memory in most of today's CAD/CAM systems, the rest being made up of the computer control store, cache and main memory. Most on-line storage systems are based on 14-inch rigid disc drives.

An emerging disc storage medium which may soon be offered by CAD/CAM system manufacturers is the 8-inch Winchester rigid disc. The units are compact, very high density, non-removable pack drives with large storage capacities and very fast access times. Winchester disc prices are very competitive with small to medium sized 14-inch disc storage systems.

Off-Line Storage

Off-line storage provides an inexpensive way to retain a virtually unlimited amount of data and is invaluable as a back-up to more volatile data held on on-line storage systems. CAD/CAM systems use reels of magnetic tape and removeable disc packs for short-term and long-term off-line storage.

Back-up short-term storage is prudent because of the fallibility of human operators. Some installations create copies of vital on-line data on a removable medium on a daily basis and always have a week's worth of data on hand in case data recovery should be necessary. In addition, an end-of-the- month tape or disc pack is kept for up to one year to help recover from errors not discovered for longer periods of time. These back-up tapes are frequently kept in off-site, fire-proof vaults.

Long-term archival storage of large quantities of data are generally stored on magnetic tape reels. For shorter-term, more frequently needed off-line storage, disc packs are generally used. It is not justifiable to have drawing or other infrequently accessed data occupying expensive on-line storage space. Off-line storage provides a low-cost temporary storage medium from which it can be readily restored to on-line storage whenever it is needed.

3.3 CAD/CAM SYSTEM INTERCONNECTIONS

As discussed earlier, networking is widely accepted in the CAD/CAM industry. CAD/CAM system networks are multiple, interconnected basic CAD/CAM systems that are intended for multi-plant, or multi-department applications that exchange data on a regular basis.

All but the most basic CAD/CAM systems are made to support more than one workstation. This allows data storage, processing and output facilities to be shared. As more workstations are added to the system the load on the database processing and output facilities increases unitl the entire system is saturated with work. this results in long delays at each work station which breaks the rhythm of interaction between the operation and the system, thereby reducing the operator's productivity. Thus there is a limit to the number of workstations which can be supported by a single graphics processor. As a rule, minicomputer based CAD/CAM systems can interface up to 16 workstations. However, they can operate no more than three or four simultaneously while maintaining full operator productivity. Networks are also used in situations where the number of workstations required is greater than that which can be accommodated by a single system.

In these applications it is necessary for portions of the database to be shared by all the systems in the network. In each individual case, the relationship between the systems comprising the network and the nature of the data flow that can occur between them is governed by the network configuration, its philosophy, and the details of the software used to implement that philosophy.

3.4 SOFTWARE FOR CAD/CAM

3.4.1. SYSTEM SOFTWARE

Although software is the least tangible part of a CAD/CAM system, it is by far the most important. Software provides a body of techniques to help the user get the performance he desires from the computer hardware.

A CAD/CAM system contains many different categories of software:

- Firmware: Microprograms used in the processing unit and in most intelligent input and output devices. MICROPROGRAMMING is a technique for the design and implementation of hardware control structures. It introduces software aspects into the development of computer hardware, thereby providing for specialization of the hardware (22).
- Operating software: Used to control the computer's work flow, organize its data, and perform housekeeping functions.
- Application programs: For data entry, design, drafting, and manufacturing functions.
- Programming support: Software which enables the user to implement custom applications or modify the system

to satisfy specialized requirements.

3.4.1.1. The Operating System

The operating system consists of a set of programs that assist the user in obtaining better operating performance from the computer, facilitates the preparation of programs, and aids in the management of the computer's time scheduling. Thus the major function of the operating system is to allocate the resources of a computer to the various tasks needing them. Access to peripheral input and output units and data storage space in on-line storage devices are also controlled and allocated by the operating system.

The allocation scheme may encourage keeping all the computer's equipment working at full capacity to maximize throughput, or it may give priority to more urgent tasks to minimize response time at the expense of throughput. Thus, most resource allocation schemes are a compromise between response and throughput objectives.

In addition to providing resource allocation functions, operating systems often:

-impose a beneficial structure on applications programs and their data files,

- provide a number of interfaces (for text editors, programming language compilers and debugging aids) and services (such as arithmetic and timing routines, inter-task communications facilities, specialized aids for programming input and output operations) that simplify application program implementation.
- detect programming errors and provide orderly recovery or restart when one an error is encountered.
- keep track of the system's hardware status,
- provide a common interface between the operator and each of the application tasks.
- keep an account of the system's utilization,
- activate an orderly shutdown in the case of a power failure.

Most CAD/CAM vendors use general-purpose operating systems developed by their hardware vendors. Some leading vendors, however, have developed their own operating systems that are specifically tailored to the needs of their CAD/CAM systems. This approach, although superior, does limit the amount of purchased general-purpose software that can be run on a system (because the software purchased must be compatible with the operating system) and makes in-house software development by the user more difficult. General-purpose, widely-distributed operating systems support much of the commercially available CAD/CAM software without modification. The special-purpose operating systems tend to be more efficient and usually provide better response times, while occupying less space in main memory and in on-line storage. Most users sooner or later want to customize their system's capabilities, and therefore, should carefully examine the difficulty of integrating purchased software and the facilities provided by the operating system for software development.

3.4.1.2. Software for a Distributed Processing Environment

Application software for CAD is currently directed at the single machine environment. A consideration which emerges when dealing with software designed for operation in a distributed environment is the problem of on-line communication between computers. This includes the choice of synchrononous or asynchronous and serial or parallel communications, depending on the distance between the communicating equipment and the required speed of transmission. More important from a software point of view is the development of communication PROTOCOLS which attempt to standardise the control mechanism for handling communication signals. On top of this, some manufacturers of computers have provided an advanced language for controlling communications between their own machines and sometimes those of another manufacturer, e.g. DECNET, PRIMENET, etc. (23).

3.4.1.3. Database Management

Database management is an informal matrix of software and data formatting rules within which the system's data are organized. Database management software is often considered to be a component of the operating system, although in some minicomputer-based CAD/CAM systems, a considerable amount of this software is implemented outside the operating system.

The Need for a Data Management System

Typically, the systems of data collection, storage and manipulation found in today's corporations have evolved over many years, stemming from a host of unrelated user requests. These systems were initiated individually and independently of one another. The end result is a conglomeration of independent systems serving a multitude of different users, none of whom are aware of what data is being used where, by whom, or for what purpose. For the most part, the concept of using data as a resource has been overlooked. It is the effective utilization of database management concepts that emphasizes the utility of data as a corporate resource, to be shared among all users. These concepts stress a consistent and coordinated effort to organize the corporation's applications in a way that deals with the totality of information requirements in an orderly fashion.

The Company Database

A DATABASE is a collection of data and INFORMATION (structured and associated data) which is stored on a direct storage device and has the following characteristics:

- -It can be shared by several programs,
- -It is organized in logical records which take into account the data's logical characteristics as opposed to merely their physical locations on a storage device.
- -It permits the addition, deletion, manipulation, and modification of both individual records and groups of logically related records.

A conceptual representation of a database is shown in Figure V.

There is a saying: "Disc files do not a database make". The concept that any file or set of files stored on a direct storage device comprises a database is one of the most common misconceptions in the data processing industry.

A database requires logical access concepts as well as physical access techniques. Thus groups of logically related records may be accessed where the group may consist of different record types located in different physical files. A database also differs from a group of disc files in that the content of the database records and the structuring of the database are independent of the applications programs which use the database.

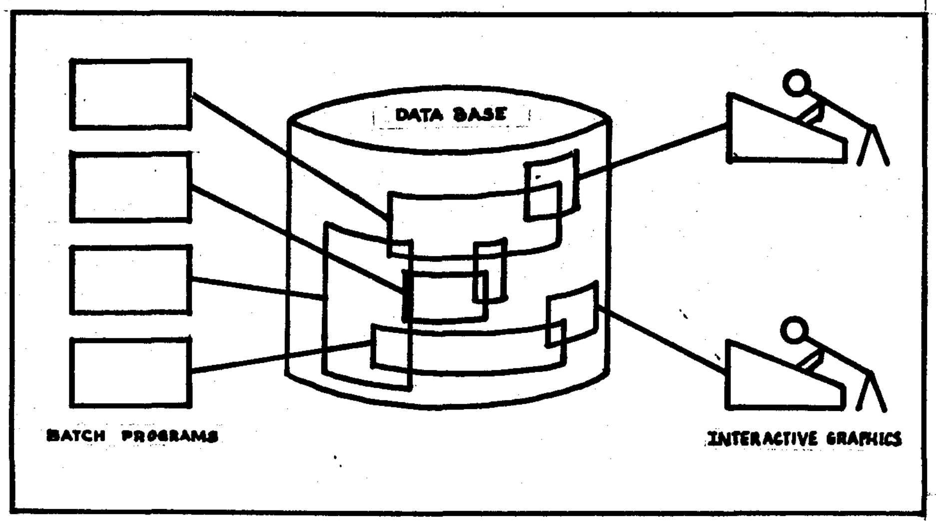


FIGURE V

THE SHARED DATABASE (64)

The primary objective of the database management system (DBMS) is to organize the system's data in a way that makes it efficient to retrieve and, at the same time, to make effective use of physical storage space. there is a fundamental trade-off between the needs of fast retrieval and effective storage utilization: the requirements of speed usually incur a penalty of space and vice-versa. This is because data-retrieval aids take up extra space. Without such aids, however, the entire database must be searched item-by-item to retrieve a specified piece of information. Another compromise that must be made with a database scheme is that of simplicity; the overall scheme is rather complicated and requires mastery of a number of new procedures and concepts.

DBMS's provide the structure for a database in which geometric data, graphic data, mathematical/statistical data, organizational data, and general design data and design standards are stored in a logical fashion, thereby allowing the user to access stored data in an associative manner.

To the advanced CAD/CAM user, this is the one of the most important attributes of CAD/CAM systems--ASSOCIATIVITY, i.e., the degree to which the data management scheme can associate a specific data element, such as the geometric model of a certain part, with all other related data elements such as drawing files, bills-of-materials, revisions, textual reports and all the assemblies in which it occurs. If information such as material type, manufacturing cost, manufacturing resources and other related data is associated with the model, it is possible to price subassemblies, produce material take-offs, and generate data for scheduling manufacturing facilities automatically. In fact, without crosslinking of information, many of the more advanced applications of CAD/CAM are not possible.

An example of associativity is the linking of drawing geometry to the model data from which it derives. With this association, minor changes in the model will automatically be reflected in the drawing. This linkage is permanently maintained because the drawing data contains parameter rather than absolute values. Similarly, other entities such as groups, symbols, or figures can be parametrically linked so that when a group is inserted into a model or drawing, the model or drawing will contain a reference to the inserted entity, rather than a copy of the entity data as it existed at the time the entity was added. Thus every time the model or drawing is displayed or plotted, the most recent version of the entity is used to generate the plot or display. This is an extrememly powerful feature since an indefinite number of models, drawings, and other data can automatically be kept up to date.

Advantages of Adopting a Database Approach

-Minimizes data redundancy and duplication. This can mean cost savings in terms of decreased rental for data storage devices and less expense incurred in updating data.

-Minimizes software redundancies: The software functions of data collection, verification, storage, retrieval and maintenance account for 40 to 60 percent of the programming effort required to implement an applications program. By utilizing DBM concepts, these functions are treated as system UTILITIES (software routines) and are shared by all application programs. Thus there is no need to duplicate the software for each such program, minimizing not only coding and logic specifications, but also testing, debugging, and program storage, plus concrete savings in terms of manpower for systems development.

-Minimizes reprogramming effort due to data changes: The DBM approach clearly separates application program procedural logic and data specification, so that a change to a collection of data elements in an application program requires only a change to the data specifications without need for reprogramming.

-Minimizes data collection: Pre-existence of data, exactly as required or in a derivable form, is more easily recognizable since information relative to data is more centrally available.

-Provides tighter control over contents and access which is inherent in the database. If management chooses to exercise this control, the danger of unauthorized access to senitive data is greatly lowered.

-Facilitates the creation and accessibility of information by utilizing advanced techniques to extract information in support of the management decision process. Often, the raw data necessary for an unanticipated corporate decision exists within the database; the information must be available within a short time period and without the significant effort required to write a usually required special-purpose program. What is needed is the facility to retrieve and operate on the data to produce the specified information.

3.4.1.5. Utility Software

System utilities aid in all phases of a computer system's operation. They include programs and routines which:

- -help during the genesis of the system, during the everyday operation, and also if the system should fail.
- -perform hardware conversions which configure the operating system and the CAD/CAM application programs to the hardware
- -make copies of discs and tapes
- -interchange data between dissimilar storage media
- -make copies of main storage or disc packs (memory dumps) following software failures for subsequent analysis.
- -aid hardware engineers in isolating hardware malfunctions.

These programs contribute to indirectly to the CAD/CAM capability of the system by affecting its performance and making it more convenient to use.

3.4.2. CAD/CAM SOFTWARE

CAD/CAM software embodies the main difference between turnkey systems on the market today. This software contains the general-purpose functional capabilities that are of primary interest to most users. Programmed into the CAD/CAM software, these capabilities include:

-modes and means of data entry,

-the relationships that can be set up between data,

-the facilities for viewing data,

-the useful productions,

-the analytical capabilities.

CAD/CAM software includes a set of independent special-purpose applications packages which provide additional, customized capabilities to the system.

Most vendors market their CAD/CAM software in individually priced packages linked to a hardware purchase. Typically there is a standard set of software identified as the base system, with additions and extensions available as separate optional packages. The standard software generally contains facilities for:

-data entry,

-data storage,

-data display,

-data retrieval,

-drawing production.

Optional support software support provides facilities for:

-additional graphical building blocks,

-enhanced facilities for derivative and parametric graphics creation,

-enhanced graphical analysis,

-special engineering applications.

The following section will describe the capability and significance of the standard and optional software. Note that there is disparity among the vendors concerning what is standard and what is optional.

3.4.2.1. Basic Standard Graphics Software

Standard CAD/CAM software supports the general-purpose capabilities of the system and provides the basis for most of the more advanced system functions. Following is a description of the software facilities provided by standard graphics software.

Data Entry

Graphics entry facilities provided by software consist of a number of geometric building blocks and a set of tools to enter, position and modify them. Complex geometric entities are built by combining the basic elements with the positioning and editing tools interactively at the workstation. A representative set of basic building blocks include:

- points,
- lines,
- circular arcs,
- parabolas,
- ellipses,
- splines,
- planes,
- surfaces of revolution.

Tools provided for geometric construction include those used to enter, position and edit elementary blocks to create the desired geometry, and those used to direct the system to computer derivative geometries from constructions that already exist. It is this set of tools that gives CG data entry the power responsible for much of the productivity gains achieved in computer-aided- drafting. Appendix G provides a listing of a representative set of basic input facilities.

Data Display Software

Because the operator's ability to add to or modify a design interactively depends so much on being able to see and point out particular geometric features, the facilities provided for viewing graphics has a big impact on an interactive graphics system's effectiveness.

From the user's standpoint, the more significant features of the display capabilities are:

-flexibility and control provided for the creation of various views: Helps to manipulate the graphics and to visualize the 3-D entities. Can also show interferences in assemblies.

-the number of views that can be "active" simultaneously: Refers to whether the view can actually be manipulated by the operator via input devices or only serves as a visual reference to data.

-the response time: Important because long delays interrupt a smooth work flow and disrupt logical thought progression.

Display facilities are listed in Appendix G.

Data Management Software

Data management facilities provide the means to classify and associate graphics data so that it can subsequently be retrieved according to these associations. Data management functions included in basic software packages are listed in Appendix G.

Analysis Software

Analysis software provides a basic set of functions to calculate geometric properties of the stored graphical data for example length, area, volume, and moment of area. A minimal set of analysis functions is provided with most standarad CAD/CAM systems. See Appendix G for a listing of basic analysis functions.

Drawing Production Software

Almost all standard turnkey CAD/CAM systems have the ability to generate hard copy plots of the graphics data in their database. The software provided with the basic system is often a minimal package that drives the vendor's preferred plotter, although some basic systems have more advanced software that produces a faster plot. Most vendors supply a good optional selection of advanced plotting software for different brands of graphics output systems. Figures VI and VII show typical drawings produced by CAD/CAM software.

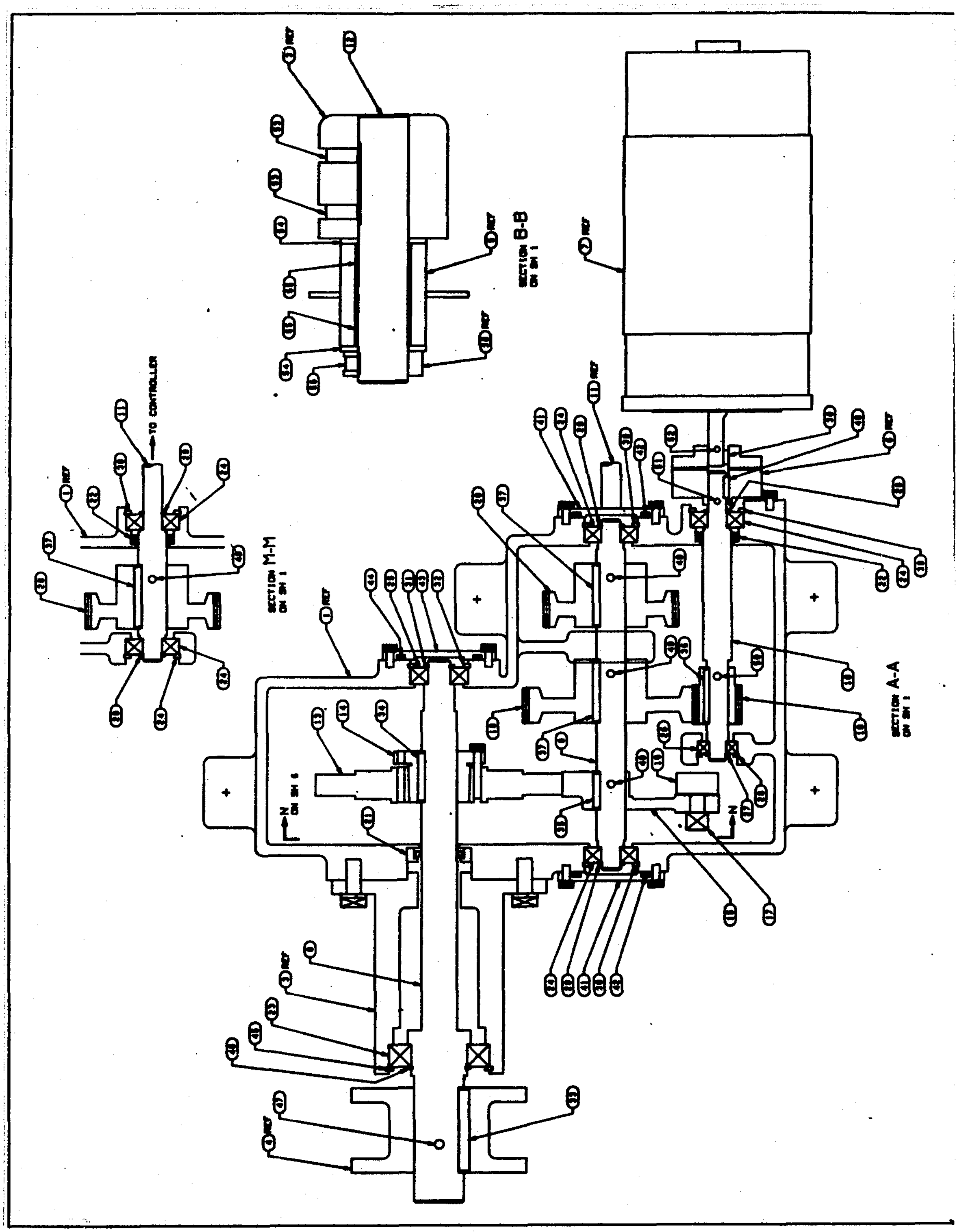


FIGURE VI

TYPICAL MECHANICAL DESIGN (65)

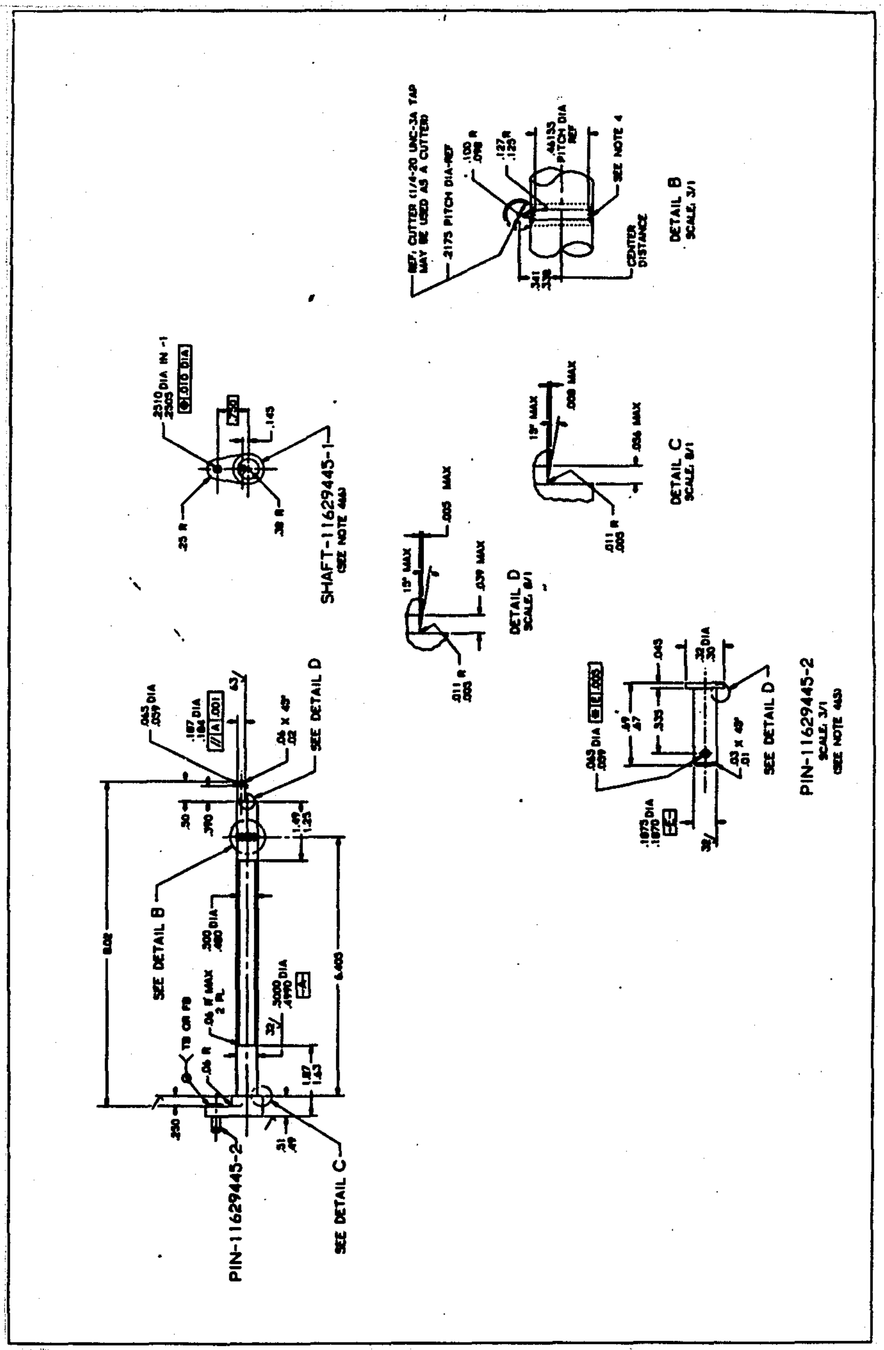


FIGURE VII

TYPICAL PIECE PART WITH DIMENSIONS (66)

3.4.2.2. Software Enhancements

Software enhancements to the basic graphics facilities of standard systems are provided by most of the turnkey system vendors. They can provide for incremental extensions of the general-purpose capabilities of the standard software. Listings of the additional facilities provided by enhancements can be found in Appendix G.

3.4.2.3. Applications Software

One of the greatest promises of CAD/CAM is the unity it can bring to the diverse activities of a manufacturing enterprise. The coordination of the engineering, purchasing, manufacturing, quality control, marketing and accounting functions eliminates costly duplication of effort and improves cooperation. But ready-to-use software to support large-scale, total integration of product data still seems a long way off.

A major problem with the ideal of completely integrated corporations has been the difficulty of bringing together the different data formats used by the large number of existing applications programs currently in use. In the CAD and CAM fields themselves, there is a large amount of disjoint application software which turnkey vendors are just beginning to bring together. Thus, what we have today are

CAD/CAM systems with a limited amount of ready-to-use capabilities, and the programming tools with which to build the bridges to other data processing systems and create additional capabilities.

Broadly speaking, CAD/CAM application packages fall into three categories:

-design synthesis,

-design analysis,

-manufacturing.

Initally, most application software had to be developed in-house by individual users, but today, an increasing amount of application software is being offered either by turnkey system vendors or through vendor organizations by other users. At present, few independent software houses sell CAD/CAM packages that can be fully integrated with turnkey systems but it is anticipated that more will enter the market as the number of installations increase. Information on software is available through trade and professional journals, trade shows, CAD/CAM seminars and user group organizations. Appendix H provides listings of trade journals and professional organizations.

Design Synthesis Application Programs

DESIGN SYNTHESIS may be defined as the combining of separate material and abstract entities into a unified entity for a particular purpose. It is supported by the general-purpose interactive graphics capabilities of a CAD/CAM system. Recording the engineering concepts, creating individual parts, fitting them together into subassemblies and subassemblies into products is all within the scope of most base-system capabilities. However, these base capabilities may be further particularized for certain types of design work. Vendors offer applications software packages that deal with a specialized selection of graphics which more efficiently automate specific areas. In plastics and mechanical design, these include structural design synthesis and piping design synthesis for example. Application software will be discussed in greater detail in the upcoming discussion of plastics product design.

Analysis Application Software

Analysis is a vitally important part of any design process. Specialized software is available for analysis of electrical control circuits, civil and mechanical engineering structures and parts and sheet metal development.

Some users desire to develop their own software in-house. However, so much engineering software already exists, it is likely unwise for users to expend their resources recreating it. Instead, users are better off seeking out existing software and spending their efforts integrating it with their systems so both input and output is compatible with their CAD/CAM database.

Production software

Many CAD/CAM system vendors have available interactive software to aid in the preparation and verification of particular programs for may types of numerically controlled (NC) machines including drills, lathes, punches, mills, turrets and flame cutters. Since this software is usually integrated with the systems database, the geometry of the finished part can be extracted and used as a starting point for developing the NC program as well as other tooling. Thus, the same geometric model is used for analysis, documentation and production. Some systems generate tool paths automatically; and some systems have graphic path verification that tends to minimize machining errors and tool crashes.

3.4.2.4. Programming Support Software

The amount of programming CAD/CAM users undertake after purchasing a CAD/CAM systems is really dependent on their attitude toward programming. some feel apprehensive and even overwhelmed at the thought of software development, while others are fascinated and excited by the possibilities it opens up. About 70% of users do undertake software development projects with a year or two of purchasing a system.

Programming a CAD/CAM system can achieve very beneficial results, especially because this particularizes its general-purpose capabilities, allowing the user to create his own unique, special-purpose problem-solving tools.

There are three kinds of programming undertaken by CAD/CAM users:

- -Macro function-menu programming,
- -Special-purpose "graphics" or "design language" programming,
- -Conventional computer programming using general-purpose computer languages.

Function-Menu Programming

As previously described, most CAD/CAM systems are sold with a basic set of function menus to facilitate data entry and to control the workstation. These menus are designed to have general applicability to specific areas of engineering, but even these tend to be too broad and inefficient for most users. Thus most vendors provide the user with the tools to modify standard products to customize menus. Menu items may be made up of simple combinations of other functions called MACROS. Many systems allow their menu facilities to be used to activate and pass parameters to user-created programs written in HIGH LEVEL LANGUAGES. These are computer languages that allow the programmer to write programs using natural English commands, rather than demanding machine language. Each instruction corresponds to several machine instructions, thus programs are easier to write, read and understand. Common high level languages are FORTRAN, BASIC, COBOL, and Pascal (24). Most menu building and macro creating procedures are easily learned and require only a very rudimentary level of programming skill to use.

The extension of capabilities that can be obtained with macro programming is quite limited. It is often necessary to look to more comprehensive programming languages in order to utilize fully the system's resources.

"Graphics" or "Design" Advanced Procedure-Defining Language Programming

The simple macros described above are a method of combining a group of frequently used commands into a single one to save time and reduce entry errors. In recent years, the capabilities of macro facilities have grown so that many now include provisions for expressing conditional branching, arithmetic and logical calculations, database references and even analytical procedures. Thus the more advanced macro facilities have developed into formal special-purpose languages with complete ability to express procedures and sequences of operation.

While the increased power of the more advanced languages give the user a greater potential, they also require additional training and more sophisticated programming skills to take advantage of the added potential.

Conventional Programming Using General-Purpose Languages

While the above techniques give greater potential power to the CAD/CAM system user, they are only of limited value because they do not support advanced engineering computations, decision making and access to the data in the system's database. Engineering tasks which require more sophisticated computing techniques such as these require a comprehensive data and procedure defining facility. The facilities required are provided by many of the well-established high-level languages, as well as in machine language. Some vendors adopt this approach. However, there are some drawbacks to using general-purpose languages. First, these require programming skills and internal systems knowledge well beyond what a typical CAD/CAM user should be expected to develop. One of the attractive features of CAD/CAM turnkey systems is that the user can take a black box approach to computer usage. Second, hiring progessional programmers is not always effective because engineers have traditionally experienced great difficulty in expressing their needs to programmers.

Thus some suppliers have developed specialized programming languages to put the necessary capability into the hands of users without necessitating that they become computer experts.

3.4.2.5. Programming Interfaces

Programming interfaces are used to programmatically access and manipulate a system's data, and are often provided in place of a special-purpose programming language, or to augment the capabilities of such languages. Using programming interfaces, users can write application programs in a general-purpose, high level language to carry out a wide range of CAD/CAM functions.

Programming interfaces normally consist of a library of subroutines that do such things as access the system's data base, perform graphical transformations, or perform calculations to determine areas or volumes of graphical entities. The object is to eliminate the need for application programmers to be concerned with the physical structure of the data, and eliminate the specialized application programming required to manipulate and analyze graphical structures, except at the highest level. In addition, the application programs are somehwat immune to changes in the format of the database since these changes will normally only require a change in the interface subroutines.

3.4.2.6. Programming support utilities

A sizeable portion of software development consists of tedious mechanical activities which can be considerably speeded up with the aid of programming support utilities.

Program development tools used in entering program text into the computer are called text editors. They generally support interactive entry of program text at a work-station or keyboard. Editors support SEARCH, INSERT, DELETE, and SUBSTITUTE capabilites, and are able to create, edit, and delete program text files.

Other utility software aids the programmer during the process of program compiling by pointing out the location and nature of statement format errors, language grammar and syntax errors, and other errors.

Once the compilation of the text is complete and error free, some systems go through a second level of processing to link individually compiled modules with one another and the rest of the system. The software performing this process is called a linker. Like compilers, linkers detect programming errors; linkers with more explicit error flagging facilities aid software development more effectively.

During software testing and verification, software debugging tools can be invaluable. The more powerful these tools, the more quickly the software is made operational.

3.6 SUMMARY AND CONCLUSION

In summary, a commercial turnkey CAD/CAM system customarily includes four components. One vital aspect of a successful turnkey system which, due to preoccupation with hardware and software, is often overlooked, is that of on-going system support.

-An integrated set of hardware

Work stations

A system processor

Output stations

Interfaces & interconnecting cables

-Software

All of the general purpose programs needed to operate the system

-Vendor services

Installation & maintenance

Software maintenance (fixing bugs)

Management education and training for operators

Help with application & special-purpose applications programming

-A commitment, by the seller, to make the system work.

There are variations on this theme, of course, and some vendors supply more or less of these components with their turnkey offerings. It is, therefore, important that a buyer examine the nature of each turnkey package and carefully evaluate its system, service, and commitment in the light of his particular needs.

Software supplied by the vendor is, as a rule, tailored to the application. That is, the vendor supplies a limited set of software selected jointly by the buyer and seller prior to the purchase of the system. Typically, the vendor supplies the following kinds of software:

-Operating software
- Control store microcode
- Operating system
- Device drivers
- Data management
- Power fail and restart software

-Operating software (optional)
- Communications drivers
- Network support programs
- Interfaces
- System use accounting software

-Utility software
- Copy programs
- Programming debugging aids

-CAD graphics software (standard)
- Basic graphics

- CAD graphics software (optional)
  - Advanced graphics
  - Advanced graphics editors
  - Drafting software
  - Hidden line removal
  - Finite element model creation
  - Bill of material extraction
  - Mass and volume extraction
  - Area extraction

- CAM graphics software (optional)
  - APT Interface
  - NC basic software
  - NC drilling, flame-cutting or machine-center support
  - Sheet metal pattern layout

- Special application software
  - e.g., special purpose analysis programs

- Manuals and logs
  - System operator's manual
  - System superviors's manual
  - Tutorial manuals
  - System maintenance manuals
  - System log
  - Work station logs

This is not an all-inclusive list, but it does show the way software is packaged and distributed by CAD/CAM vendors.

Services supplied by the vendor

The comprehensive expertise and services provided by the vendor are an important part of the turnkey package. A key advantage of having a single source for all services is that there is a single unambiguous focus of responsiblity for hardware, software, and its applications.

-Hardware maintenance: Seller provides remedial and preventative maintenance for a designated period of time. Various guarantees are offered by indiviual vendors.

-Software maintenance: The seller undertakes to locate and correct bugs, usually on a "best-effort" basis. The amount of responsibility assumed by individual vendors for this service varies greatly, and is very important because of the great impact this can have on the success of the system. Most sellers also provide the buyer with assistance on how to get the most out of their system, i.e., applications assistance.

-Management assistance: The seller provides advice on matters such as access control, scheduling, and personnel selection, start-up planning, etc.

-Education: Training for all levels of personnel is provided by most of the established vendors. Some vendors provide courses on special software packages, programming, and other specialized training. Courses are usually structured one- or two-week affairs and consist of laboratory and class work. Training will be discussed further in a discussion dedicated to this topic.

IV. THE DESIGN PROCESS

The plastics industry has not been left untouched by CAD/CAM technology. In the following section, the process of mechanical design of plastics parts, and how CAD techniques have fit into the process will be discussed.

In order to appreciate fully the systematic use of computers in design, one must have an understanding of the design process itself. In the broadest sense, there are four basic elements in every design project involving plastics:

1) Part or product design itself--A set of activities leading from the establishment of product requirements to the generation of information necessary for manufacturing the product. This set of activities can be broken down into four general overlapping phases:

   a) The conceptual phase: Involves the specification of product requirements from end-use and market considerations, and a design-analysis-redesign cycle in which a qualified designer gets a feel for the problem.

b) The analysis phase: Involves explicit or simulative analysis of the proposed product. This may be considered the solution phase. The designer may choose to use an iterative, or trial-and-error approach, or a direct approach in which the design is produced directly by analysis. Evaluations are made on a virtual model which is simulated on a computer or on a real prototype.

c) The detail phase: The aspect of design in which all component assemblies required for manufacture of the product are designed. This is usually performed by engineering technicians or draftspersons.

d) The documentation phase: Comprised by the communication of the results of the previous activities.

2) Selection of specific material from which the part is to be made.
3) The mold or tool design and construction.
4) The processing, finishing and assembly of the product.

4.1. TRADITIONAL DESIGN

In order for maximum benefit from any kind of mechanical design activity to be realized, the design of the component parts must be organized at the earliest conceptual phase of design. Traditionally in the paper-and-pencil environment, this has been done through what is called the "master layout" wherein all of the main components are shown on a single drawing. Paper master layouts are created at the initial project stages to permit gross sizings. They are relatively easy to update at this stage, since they are simple, there are few people involved, and schedule pressures are typically not yet felt. However, paper layouts have limited function and are difficult to update and to use. As a result, designers have never been able to fully exploit them.

There are also difficulties in using a paper layout even if it is accurate and up to date. Paper layout function is limited by the line accuracy and the number of key dimensions that can be fitted into the available space. The profusion of overlapping lines creates confusion. The fine pencil lines required for layouts reproduce poorly and result in difficult overlay checking. Paper opacity limits the number of overlays to two or more to be able to retain any sembalnce of clarity. Furthermore, the entire layout is in one scale: too large for some areas and too small for others (25).

V. THE APPLICATION OF COMPUTING TECHNOLOGY TO THE DESIGN PROCESS

In essence, there are three basic areas in which CAD is applied to the design process:

- serves as an extension of the designer's memory, providing a database and an information structure. One American company quotes 95% of a designer's time is spent in searching for information, only 5% in making actual design decisions.

- enhances the analytical and logic power of the designer by serving as a calculator during specification and synthesis.

- relieves the designer from routine, repetitive tasks. The introduction of computer automation can intensify decision making by over 1900%.

The designer, then, is left to control the design process, organize the information, and contribute his ingenuity, creativity, and experience.

For many years the application of computing methods to the design and manufacture of mechanical components and assemblies had proceeded piecemeal with the development of programs aimed at particular aspects of the process, particularly drafting, finite-element analysis and numerical control. Because of their separate development and specialized purposes, these systems often coexisted with difficulty, requiring considerable duplication of human effort in data preparation and transformation.

Perhaps the most important development in CAD/CAM was the realization that maximum benefits from applying CAD techniques are obtained when graphics is a part of an integrated system which encompasses design and manufacturing. An integrated system of this type is shown in Figure VIII. The full significance of such a total approach to interactive CAD/CAM technology is that it makes possible the integration of all the diverse-yet-related applications of computing technology and, consequently, the full realization of their potential benefits in cost, labor, and lead time reduction. Design, design analysis, drafting/detailing, process planning, NC programming, tool design, DNC, robotics, and inspection are all interconnected within the total system and supported by the communication capability by which it is characterized.

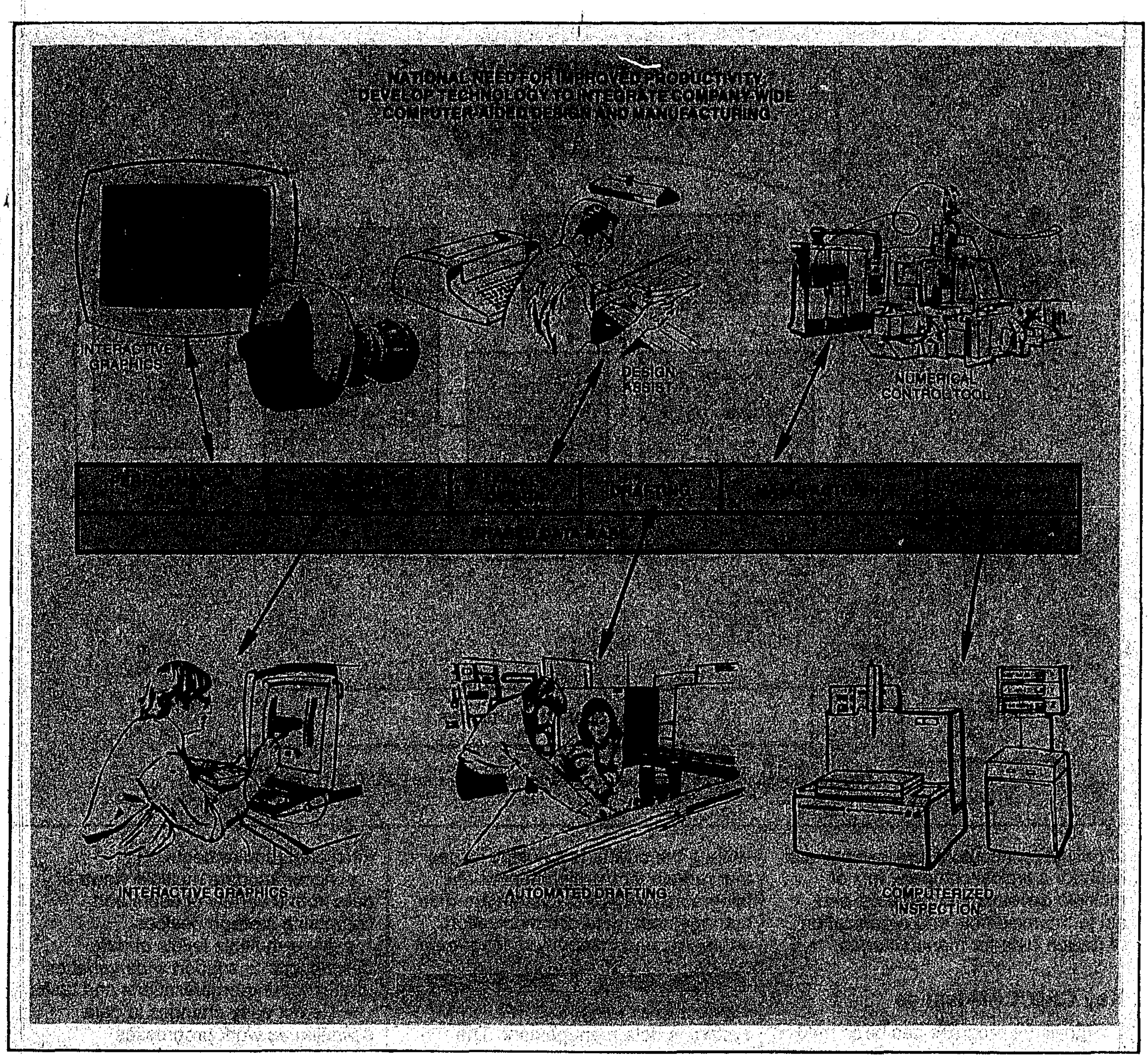


FIGURE VIII

INTEGRATED COMPUTER AIDED DESIGN AND MANUFACTURING (67)

Communication with and among the various activites by means of an integrated computing system permits part descriptions and properties to flow downstream from design to manufacturing, and machinability and manufacturing information to flow upstream. This affords the designer to anticipate manufacturing problems and the process planner to review the design in its early stages, while it can still be modified easily. It also eliminates the handling, transcribing, and manual processing of vast quantities of data with its commonly attendant errors.

When these aspects of technical CAD/CAM systems are extended to encompass all management information, such as cost estimating, purchasing, accounting, payroll, inventory control, work scheduling, bills of materials, packaging, maintenance, product support, experimental and production tests, etc., the value of the system increases even more dramatically.

In attempting to utilize computers to integrate design and manufacturing processes and improve their efficiency, the primary requirement is the ability to communicate design information in a timely, complete, and unambiguous manner. The value of the information issued by the designer as the end product of his activities is measured by the ease with which parties downstream can extract from it the information they require.

Design details are traditionally recorded on drawings as geometric descriptions of the part together with other relevant information, for example materials and manufacturing data. The three-dimensional (3-D) part geometry is normally recorded as 2-D sketches of the principal edges, profiles, feature curves and key cross-sections, together with dimensional data defining the parts' shapes and positions. To overcome the difficulty of the drawing being two dimensional, several different views of the object are shown. The designer has to be extremely careful that the information on each view is compatible. The representations are then reconstructed into 3-D concepts by the downstream parties, for example the manufacturing process planner and mold designer. With all this translation and encoding, errors are easily made. To complicate matters further, the projections laid out by the designer sometimes do not clearly represent what he had in mind. Some representations, furthermore, are ambiguous, and may represent two or more different solid parts. No information, moreover, is recorded about the faces of the components.

It is clear that the benefits of CG techniques in CAD are not only related to the faster deposition of ink lines on sheets of paper. Although there exist systems for computer-aided drafting and first generation CAD systems drawn from such principles, the primary benefit of second generation CAD systems is the provision for the designer to construct in computer memory a representation of the project or assembly, in numeric form. This representation can best be considered as a model which can be manipulated by computer programs, thus often eliminating the need for physical prototypes. The recording of design information in the form of a numeric model rather than a master drawing is the fundamental difference between CAD and traditional methods. Extraction of information may, of course, take the form of automatic production of drawings so that communication is still in the drawn form. However, the possibility of more sophisticated ways of extracting and presenting information is open.

5.1. THE INTERNAL DIGITAL REPRESENTATION

In the design of mechanical assemblies using CAD systems, users typically create geometric models by drawing pictures on interactive graphics CRT terminals. In this way, no knowledge of computers or computer programming is required. Another technique for model generation is the use of input materials such as drawings, sketches, and any other kind of dimensioned data (for e.g., vendor drawings, stress analysis results, freehand sketches). All drawings related to the project are used to build the model, and can be utilized in any order.

The model is generally full size and contains information in 2-D, 2-1/2-D, or 3-D, depending on the capabilities of the CAD system and user requirements. 2-D models represent flat parts or planar views of 3-D parts; 2-1/2-D types represent a part of constant section with no side-wall details; and 3-D models represent fully developed 3D parts or assemblies. A 2-D object representation is incomplete in precisely the same way as a drawing representation. The responsibility to ensure unambiguity and correctness of the master record still lies with the designer. There is still no explicit information about faces and calculations involving them, e.g., cross-sections and profile lines cannot be done properly. In the 3-D case, the advantage is obtained that, via a simple coordinate transformation, any projection or perspective view of the geometry may be obtained with no possibility of incompatible information being shown on different views.

The model describes the assembly or project in great detail. Every part is entered into the model as a separate object with its proper size, shape, and location in 3-D space, plus all of its attributes (shape, material, treatment, the drawing on which the part occurred, etc., for example).

Advantages of the Digital Model (26)

The prototype 3-D model is the single source for all computer drawings and schedules, and thereby provides:

-Coordination between scales: The model contains full size dimensions so that all drawings are produced by scaling down. It is no longer necessary to make the distinction between detail drawings and assembly drawings; the model may contain full detailing information throughout. The amount of detail appearing on a drawing at any scale remains under the full control of the user at all times.

-Coordination between disciplines: The model contains information for all disciplines of engineering and other consultants. Certain areas of the model become so congested that they would be unreadable when drawn to small scale if the user were unable to suppress unwanted detail. However, each component is assigned a category number when first introduced to the system which defines its generic group and remains associated with it when it is assembled into the model. The user is therefore able to call for any combination of categories for display or hard-copy output. Users of the model are able to refer to drawings which show only required items.

-Coordination between components: The three dimensional nature of the model means that alterations in the model are automatically reflected in all projections.

-Speed of Production: Provides a means of producing drawings and schedules which is faster than manual methods.

-Cost and Staffing: Significantly fewer man hours are required for a project. This can represent substantial labor savings. In addition, project teams can be reduced in size, offering a positive solution to worsening staffing shortages, saving labor costs, and requiring less control and coordination.

-Revisions: Using a high speed plotter, a typical drawing can be produced within an hour. Therefore, the final issue drawings need not be produced until very much later in the design phase than manual methods allow. The final drawings can therefore incorporate the very latest revisions, avoiding costly addenda and errata.

-Programming of work: The model allows management to make substantial alterations in scheduling methods.

-Competition: The integration of computer-aided methods will undoubtdely increase the competitive edge of companies which use it and of industries in the face of international competition.

5.2 MODELING TECHNIQUES

The field of work concerned with the comprehensive collection of concepts and procedures used for the description of mechanical components (non-geometric information essential to the production process as well as shape, position, and dimensional data) has become known as GEOMETRIC MODELING (27).

Most modeling today is done with "wire frames" which represent part shapes with interconnected line elements. Also called stick-figures, wire frames are generally the simplest to create, expending relatively little computer time and memory. They provide precise information about the location of surface discontinuities on the part. However, wire frames contain no information about surfaces nor do they differentiate between the inside and the outside of objects. The computer defines the whole object at once without regard to one perspective, showing all the object's surfaces, angles, and curves, regardless of whether they are located on the side facing the viewer or on the back, which the eye cannot see. Thus, wire frames tend to be cluttered, confusing, and ambiguous in representing complex physical structures and often leave much interpretation to users. Moreover, wireframe representations are verbose and as a consequence are tedious to create and expensive to store and transmit.

Many of the ambiguities of wire frame models are overcome with surface models. Developed in the early sixties for the design of the outside skin shapes in the ship, aircraft, and motor industries, surface models define outside part geometries precisely. However, surface models represent only an envelope of part geometry, even though features such as automatic hidden-line removal easily make the part appear to be solid. Such features permit the computer to depict an object from a specific viewpoint just as the eye would see it. The inability to represent the solid nature of parts leads to difficulties in calculating parameters such as weight, volume, and moments of inertia. User interpretation is often required to determine, for example, if the model represents a solid object, or a thin-walled hollow structure. Surface models find application where the requirement is to represent the geometric complexity of a small number of freeform surface faces rather than a complete description of the component. Surface models can also be useful for producing NC machining instructions where definition of structure boundaries is critical.

The highest level of sophistication in geometric modeling overcomes this ambiguity by an approach which uses combinations of elementary cubes, spheres, and other solid "primitives" or other techniques to create complex models. Called 3-D solid models, these advanced representations allow the solid nature of an object to be realized, facilitating computations of parameters such as weights and moments, and cross-sections to expose internal details. Furthermore, it is possible to asssociate non-geometric information--such as surface finish, material, and hardness--to faces, edges and components. Solid modeling techniques, only recently developed, are presently very expensive, relatively slow, and require extensive user expertise and computer time. Most turnkey CAD system vendors, however, are developing more practical solid modeling features which are expected to be available in the mid-1980's. Figure IX compares a wire-frame and a solids model.

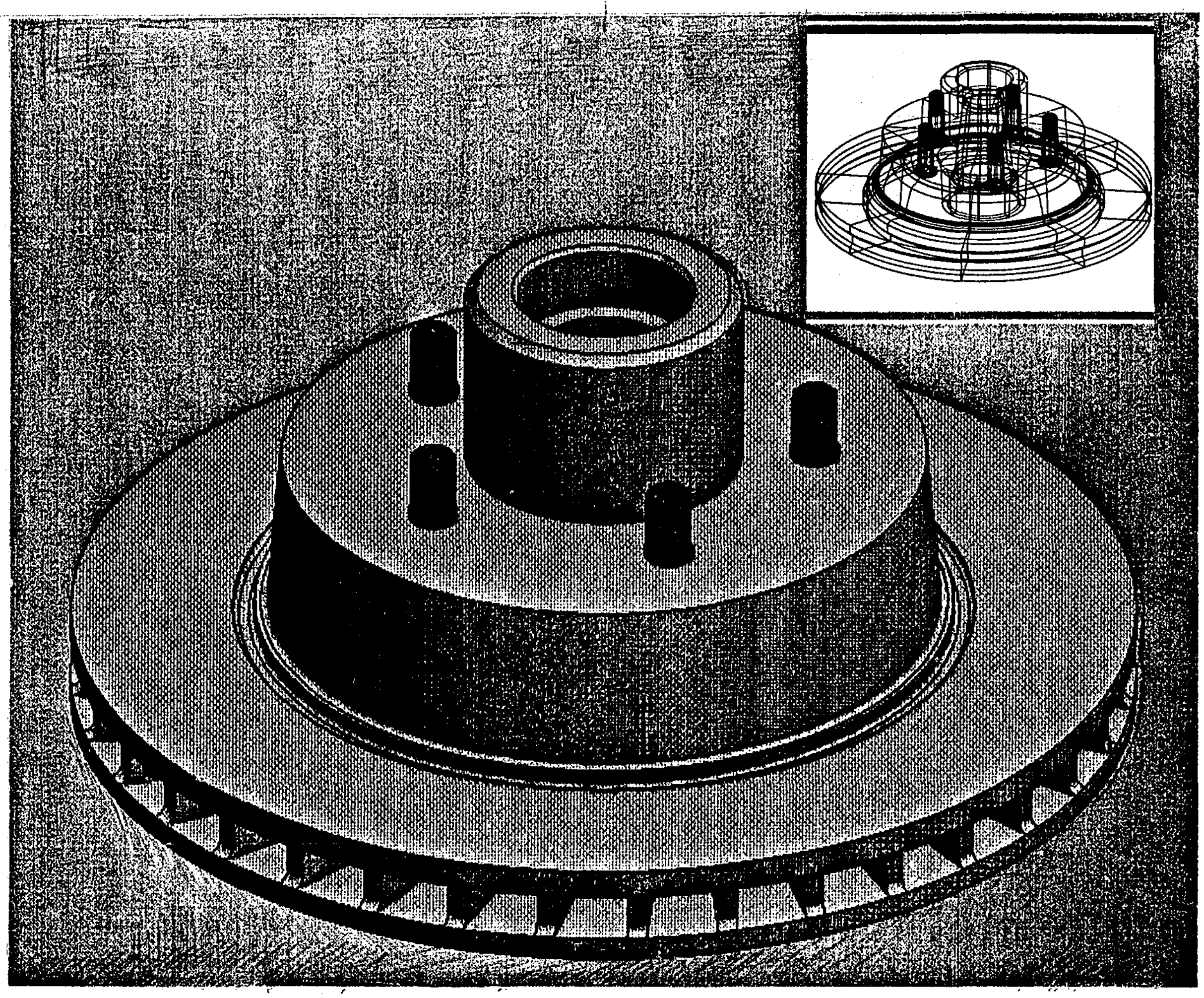


FIGURE IX

THE WIRE FRAME AND THE SOLID MODEL (68)

Substantial progress is also being made in the effort to produce more realistic images (28).

-Highlights due to mirror-like reflection can be computed.

-Shadows generated by one or more point light sources may be calculated.

-Transparent objects can be displayed by accounting for light reflected by objects behind the transparent ones.

-The effects of light refraction can be included.

-Texture can be added to the surfaces of images.

5.3 HOW THE MODELS ARE CREATED

Wire frame models are created by specifying points and lines in space. The designer uses the CRT screen in much the same manner as a drawing board to create top, bottom, side, isometric, and other views of the model. CAD systems provide many automatic features to aid the designer in this process. For example, CAD systems use up to 40 techniques for the generation of straight- line elements. Similar automatic features can produce circles, CONICS, complex curves such as ellipses, hyperbolas, and parabolas, and SPLINES, smooth coninuous curves fit through a series of arbitrary points specified by the user. Other features of the systems include automatic projection of lines created in one view into other views, feature duplication at multiple locations, selective deletions, picture scaling, and many others.

Surface models are created by connecting various types of surface elements to user-specified lines. The entire model may be comprised of different types of interconnected surfaces. CAD systems provide extensive surface menus (see Figure X) from which to model, including:

a) PLANES: the most basic surface type curves
b) TABULATED CYLINDERS: projections of free-form courves into the third dimension
c) RULED SURFACES: produced between two different edge curves

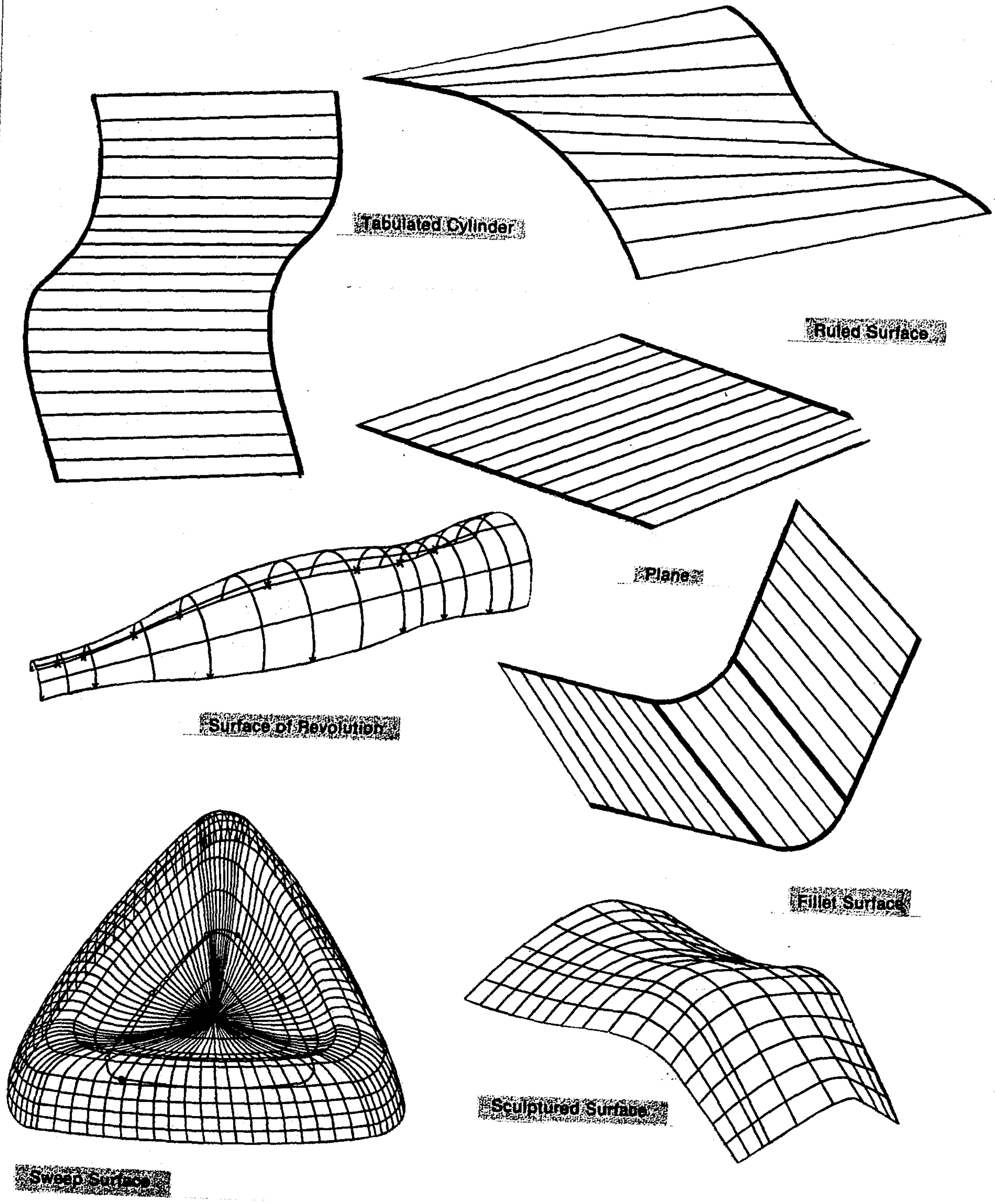


FIGURE X

MENU OF SURFACES (69)

d) SURFACES OF REVOLUTION: created by revolving an arbitrary curve in a circle about an axis
e) SWEEP: an extension of the surface of revolution; revolve an arbitrary curve through an another arbitrary curve instead of a circle
f) FILLET SURFACE: a cylindrical surface connecting two other surfaces with a smooth transition. CAD systems quickly solve the problem of blending surfaces, a tedious operation when done manually, with precise mathematical continuity.
g) SCULPTURED SURFACES (also called CURVE-MESH SURFACES, FREE-FORM SURFACES, B-SURFACES, and CUBIC-HATCH SURFACES): a differential surface created from two families of curves which need not be orthogonal, fixed, or parallel. These are complex contours that cannot be described with the usual lines and curves of conventional modeling. Typical structures containing such contours include helicopter blades and automobiles.

Solid models are formed by adding and subtracting solid primitives-basic geometric shapes such as spheres, cylinders, cones, ellipsoids, parallelpipeds, wedges, and toruses. In addition to combining primitives, some solid modeling systems can also produce sweep solids by projecting 2-D areas into the third dimension. This allows complex structures to be more easily modeled and also speeds simple part-shape modeling.

Two other approaches to solid modeling have recently been developed and are beginning to become available in commercial systems (29).

5.4 CAD/CAM IN THE DESIGN AND MANUFACTURE OF PLASTICS PRODUCTS

COMPUTER-AIDED DESIGN

After the components of any given preliminary design are modeled using the CAD system, they are transferred to the central computing facility where the model of the whole project takes shape. The model is thus available to a worldwide designer community via teleprocessing and satellite networks.

Since all the data for the design is contained in a single data base, a global coordinate system is practical, and multiple coordinate systems can be easily referenced to one another. Part dimensions may be omitted since they clutter up the picture and are stored internally in the data base for instant recall if required. A date associated with each part indicates the current design version. The designer himself retains control of which version is accessible to project personnel so that he can experiment with alternate designs in private. He releases a version to designer community only when he feels the design is sufficient. The process of engineering change can be dramatically improved since all changes are made against the single data base.

Once the model data from each of the designers involved in a particular project is stored in the central database, it can be accessed by several different design application software packages for:

- -interference checking
- -tolerance checking
- -summary lists
- -automatic drawing production
- -conceptual evalution
- -design evaluation
- -material and process selection
- -design analysis
- -material property modeling

Interference Checking

A computer program compares each object in the model against all other objects to see if any two are occupying the same space. Since the global coordinate system has already been agreed upon, no designer communication is required to check interferences. Only when a problem is identified does communication become necessary for resolution. In that case, the program generates a simple report which is distributed to the appropriate departments for correction. When the drawings have been duly modified, they are again sent to the CAD system where the digital model is modified accordingly. Such programs have been found to be a much more reliable means of finding interferences than either interdisciplinary checking or the use of composite drawings, and at no greater expense.

Tolerance Checking

Each line in the digital model is geometrically linked to every other line in the design. Component parts can be moved by the designer within their tolerance ranges and resulting spatial relationships examined at large magnification on the screen to 5 to 10 place accuracy dependent on the graphics system. Whole assemblies can be moved slightly by the designer to simulate abnormal conditions and again the spatial relationships can be easily examined at high magnification. These types of tolerance analyses which would have been time-consuming and difficult with paper and pencil are very simple with computer graphics. As a result of this simplicity, it has been found that designers are more willing to undertake such analyses which in turn results in a higher quality product.

Summary lists

Another program uses data in the digital model to find quantities and to produce lists of such information as cubic inches of plastic in a given part, shrinkage factors, material requirements, etc. Quantity summaries from digital models have two advantages. First, the model is usually current, so that quantities taken from it are up-to-date. Second, the cost of producing summaries is so nominal that they can be requested frequently and used in ways which were impractical in the past.

Automatic Drawing Production

Another application program using the model produces drawings directly from the model. Any view can be chosen, so that the user can request isometric, axiometric, and orthographic drawings. This technique opens the door to making it possible to have both system and composite drawings for a project, (currently expensive and error prone) for a small incremental cost.

Software techniques such as mirroring, rotating, copying, and use of component libraries help to insure cost effective delineation of the piece parts. Scaling routines accommodate the production of exploded views. Sectioning routines provide for interior details of the parts, as shown in Figure XI. Automated dimensioning routines save time and assure that the drawings accurately reflect the design dimensional data. Detail parts may be extracted, dimensioned, and prepared for transmission to a plotter for hard copy record. The model may also be mathematically "illuminated" and shading patterns may be generated for each visible surface. The results are realistic, photographic-like images of the model which may be very useful for client presentations or product promotion. Surface coloring may be a system capability.

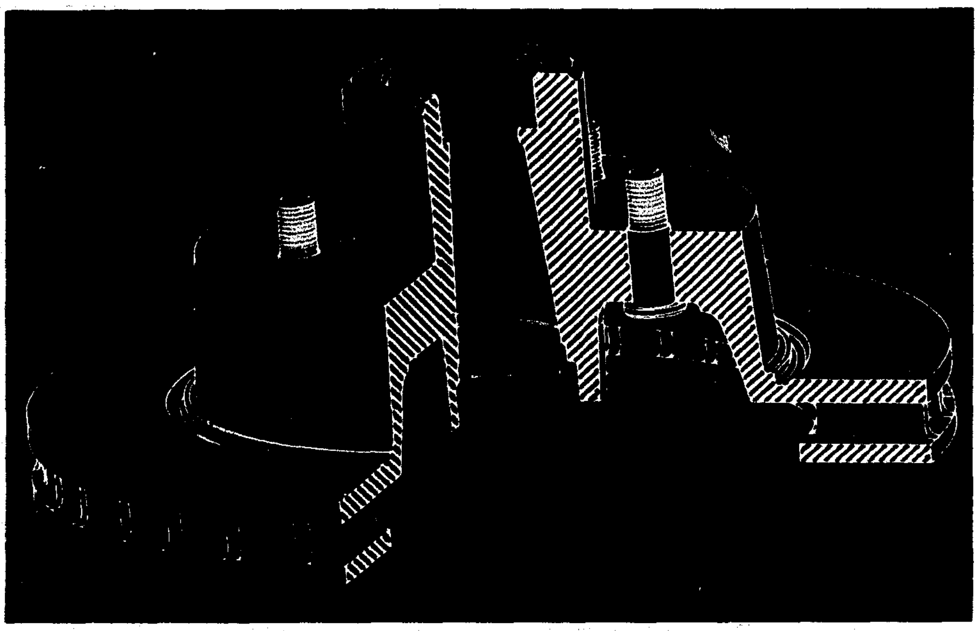


FIGURE XI

INTERIOR DETAILS REVEALED BY SECTIONING ROUTINE (70)

Conceptual Evaluation

It is in the area of conceptual evaluation and trade-offs that Computer Graphics methods can produce tremendous pay-offs. Since valuable time is no longer spent by designers pushing pencils over paper, full effort can be devoted to discussing designs and evaluating alternate concepts. In this way, the designer's energies can be more directly focused on creative problem-solving.

The workstation graphics screen serves as a window through which the designer sees the virtual model of his design which is as realistic as possible. An intuitive approach to design is encouraged by continuous visual feedback of the current status of the design.

The designer can pull his drawings apart, enlarge details, apply colors, change shapes, test the parts under mathematically simulated conditions, and immediately adjust parameters to achieve proper shapes, configurations, weights, strengths, etc. While designing, he can easily extract geometric information at any time without using mathematical formulae or doing any computer programming. Data such as volume, first moment about the axis, center of mass, radius of gyration, polar moments, and surface areas may be ascertained.

A unique software product is available which may come into play at this concept stage. SAMMIE, a human factors evaluation tool, allows the designer to consider the interaction of the human figure with a product or an environment which may range from a kitchen to an aircraft cockpit. SAMMIE, shown in Figure XII, may be animated to achieve different overall body activities, thereby aiding in anthropometric studies and kinesiology. Special emphasis is given to bio-stereometrics as a primary database from which applications may be prepared. After many years of development and evaluation, SAMMIE is now being used for a wide range of design problems (30, 31, 32).

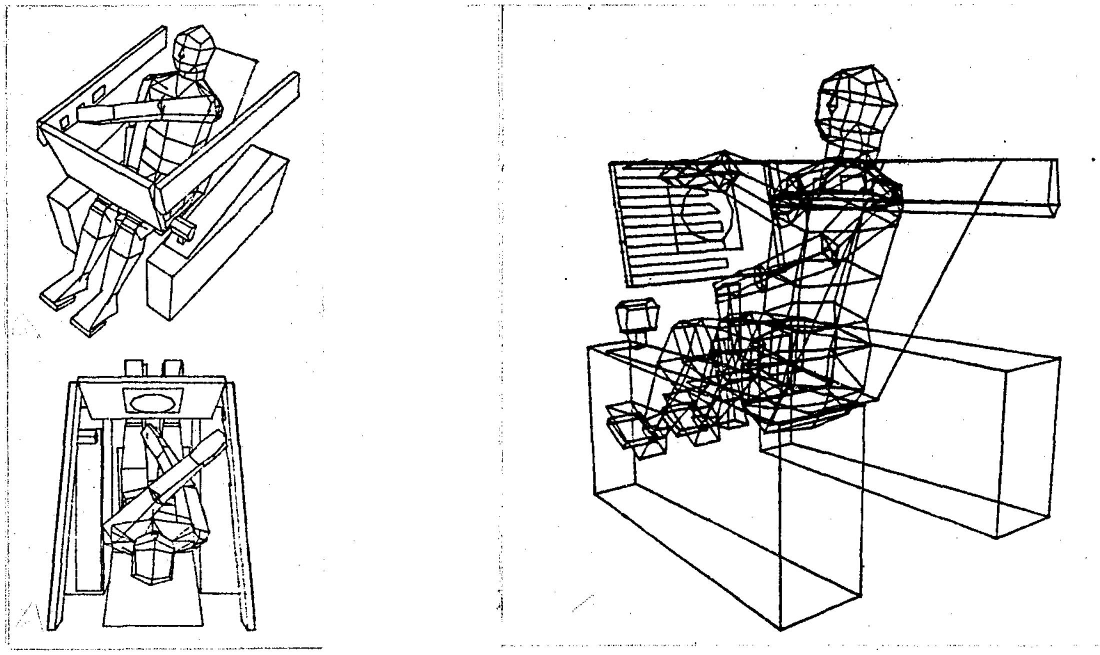


FIGURE XII

SAMMIE PERFORMING REACHING EVALUATION TESTS (71)

Design Evaluation

Once the designer has defined a particular configuration, programs are available which will analyze the design and present performance evaluation data back to the designer. An example of a "design evaluator" program is one which can be used for the process of manually assembling small parts. The program evaluates a given assembly in terms of the relative ease or difficulty of manual assembly associated with a given design configuration. The program is a valuable design aid, particularly in those situations where assembly costs are a major portion of total product cost.

Quantitative analysis requires a coding scheme which will be applied in some consistent manner. One such coding scheme describes the total process in terms of individual operations. To code an assembly operation, the designer must assign appropriate numerical values, based on the level of difficulty of the operation, for each of seven identifiers which describe it, in accordance with prescribed coding rules. The designer is given the option of feeding the codes directly or electing to enter an interactive mode. The basic premise of the analysis is that each basic operation has an associated level of difficulty and attendant execution time. It is assumed that there is a direct correlation between difficulty level and execution time. The relationship utilized by the program implies that the minimum time required to accomplish one basic operation is one second and that very complicated assembly operations can require up to nine seconds to accomplish. The results of the analysis are available in three forms:

-gives an overall figure of merit for the assembly characteristics of the design configuration.

-gives a line by line accounting for each subassembly selected by the user, and points out any individual inefficient operations.

-gives a part summary listing which includes each part identification number and corresponding part type (33).

Material and Process Selection

An area where the memory capabilites and computational power of the computer can result in substantial reduction in manufacturing costs is in the selection of materials and manufacturing processes during the early stages of design. The designer may make use of computer programs which aid him in identifying candidate material and process combinations for further study. One such program, MAPS-2, interactively generates a twelve digit classification code to express important characteristics of the part. Each digit represents a particular characteristic. For example, the first digit is an indication of how many parts are to be made, the second an indication of how large the parts are, and so on as shown in Figure XIII. The program then uses the code to eliminate unsuitable processes and materials from consideration. The first five digits (batch size, bulk, shape, tolerance, and surface roughness) are used to eliminate processes while the next three digits (service temperature, corrosion rate, and corrosive medium) are used to eliminate materials from consideration. The program also eliminates incompatible process and material combinations. After the eliminations are completed the program indicates how many combinations remain and on request will provide a list of them broken down into two categories: usual practice and unusual, costly practice. If the number of combinations were small, the user could elect to investigate either relaxing some of the design requirements or manufacturing the part in more than one step. On the other hand, if the number of combinations were large, the user could direct the program to rank the combinations.

The ranking system is based on the use of figures of merit, quantitative measures of how well a particular material and process combination satisfy a qualitative criterion of excellence set by the designer. The program first defines the appropriate figure of merit and then ranks the different combinations by calculating the figure of merit for each combination, and arranging them in order of decreasing figure of merit.

The use of the figure of merit is complicated by the fact that, in general, the appropriate figure of merit depends not only on the criterion of excellence, but also on the loading mode. Moreover, the design stress values to be used in calculating the figure of merit depend on the loading schedule as well as the service temperature. For example, if the part were subjected to long-term loading at elevated temperature, then it would be more appropriate to use a creep strength than a conventional yield strength or ultimate strength. Thus additional figures represent the characteristics that decide the appropriate definition of the figure of merit and the type of strength data to be used in its calculation. The program thus proceeds by interactively generating these digits and then uses them to calculate the figure of merit (34).

Digit no.		
1	Batch size	Process related
2	Bulk	
3	Shape	
4	Tolerance	
5	Surface Roughness	
6	Service temperature	Material Related
7	Corrosion resistance	
8	Corrosive medium	
9	Loading mode	Ranking Related
10	Structural geometry	
11	Loading schedule	
12	Criterion of excellence	

FIGURE XIII

ARRANGEMENT OF DIGITS IN PART CLASSIFICATION SYSTEM

A similar materials-selection program is being built by Paul Kusy, the manager of Organic Materials Research at

John Deere & Co., in Moline, Ill. His current system requires that the designer know what properties are required for a particular application before the program can determine material suitabilities. Kusy is working on an update, however, which would quiz the designer on the application and environment in order to narrow the material choice. Help routines will coach the designer should he or she need them (35).

Current parallel efforts to develop materials databanks are being conducted by The Plastics Technical Evaluation Center of the U.S. Army Armament R&D Command in Dover, N.J., The International Plastics Selector, several materials producers such as Celanese (36), and DTSS Inc., which offers interactive access to a database called POLYPROBE. The database contains detailed information from 150 manufacturers on the engineering properties, sources and prices of more than 7,900 commercially available plastics. A typical search for a plastic that meets four or five design criteria costs about $15 through this "dial-a-plastic" service (37).

Design Analysis

The analyzing of mechanical designs is very important and usually occurs at a critical time in the design cycle, namely after the conceptual designs have been created and production designers and detailers are ready to move into the cycle. Over-designing of parts can be very costly from both a material and labor standpoint. Under-designing can be disastrous from a functional and safety standpoint. The engineer of today is faced with solving structural and analytical problems of more complexity than ever before, placing a heavy burden on his skilled time. Analysis which can be performed quickly and accurately is a major benefit. In a company with an integrated CAD system, this is the case since analysis personnel are able to access the design geometries in the database in order to perform stress and heat transfer analysis necessary to verify the design criteria.

CAD Analysis software provides an effective tool for the construction, modification, and viewing of models for FINITE ELEMENT ANALSYSIS (FEA). This technique involves breaking the shape of the component into thousands of small, simpler geometrical shapes, or elements. Considering just one of these elements, its performance under certain conditions can be defined by a few equations. The displacements at the element's boundaries or at those points can be expressed mathematically. The determination of how each element behaves under the conditions specified can provide an assessment of how the whole component will behave. Finite element analysis is used to study statics, vibration analysis, linear and non-linear transient dynamics, heat transfer and more.

In the past, such an analysis consumed a great deal of time and was prone to costly input errors. Generation of all geometrical input is accomplished much more rapidly with CAD by keyboarding into the terminal a relatively small amount of data concerning key points and properties. Software aids the process with 2- and 3-D automatic mesh generators comprised by trigonometric routines. The finite element model can be viewed on the CRT terminal, usually superimposed on the component. The mesh can be viewed from any angle, and may be greatly magnified for detailed examination. Finding an error, the engineer can keyboard in changes, the corrections automatically being made in the data stored in memory. An error in input can easily waste $1000's in analysis computing costs. Yet a CRT check only costs about $4.

Also an aid during finite element analyses is the graphical portrayal of the deflected shape of the geometry as a result of the loads and forces applied, as shown in Figure XIV.Rather than being buried under pages and pages of bewildering numerical data, the CRT allows the engineer to condense the paperwork to a simple graph or sketch, displayed nearly instanteously and at little cost, providing vital design feedback.

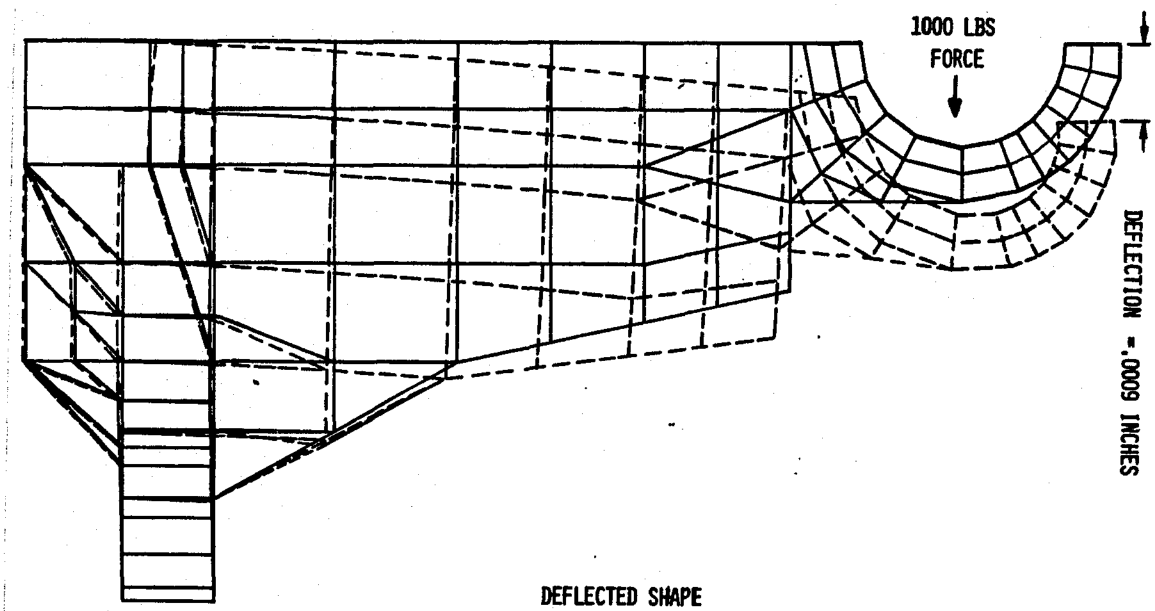


FIGURE XIV

FINITE ELEMENT ANALYSIS MODEL (72)

Generally FEA programs run on midi or large minicomputers because they require extensive computational resources not available on most interactive graphics systems simultaneously with interactive graphics functions. Thus, the approach taken by many CAD/CAM vendors is to provide tools for constructing the input models just described (the finite element model) on the CAD/CAM system and transmitting the model to independent mainframes or stand-alone minicomputers. There various parameters are added to the graphical data (e.g., forces, temperatures, material properties, etc.), and the structure is analyzed. There are also powerful interactive graphics finite element modeling software available for mainframes. FEA capabilities can also be purchased as stand-alone turnkey systems.

Material Property Modeling

The use of complex materials such as composites for structural component design exacts a price of increased complexity in design and analysis procedures. The heterogeneic and anisotropic nature of these materials create mechanical, thermal, electrical and transport properties which vary with the constituent composition and the internal geometry of the mircostructure developed during fabrication. Before a finite element technique can be applied to such materials, they must be preprocessed to generate a position-dependent anisotropic material property data base. CAD techniques are valuable for modeling the point-to-point effective material properties, the distribution of which is controlled by the mold geometry, processing conditions, and rheological properties of the molding material. The CAD routines calculate the properties by manipulating large amounts of data on disk storage devices. Characterization of a complex part requires a complete description of constituent properties and constants for each point throughout the structure. The problem quickly becomes unwieldy if the effective properties for large databases are calculated by hand. The output of the CAD routine is a complete set of material orientation, volume fractions and geometry parameters of each element in the mesh. At this point, the data can be passed to other codes which provide effective material property calculations for the finite element analysis (38, 39).

COMPUTER AIDED MANUFACTURING

The use of the digital model and global coordinate system has implications beyond the design phase of a program. Once the design is approved, the part geometry in the CAD/CAM database is released by Design so that it can be accessed for a number of activities which were not of prime concern during the design phase:

-CAD for mold design

-CAM for mold cutting

-Molding the part, processing & cost optimization

-Molding the part, CAD/CAM process control

-Automatic inspection

-Robotics and assembly routines

-Costing and scheduling

Display screens in the manufacturing areas permit engineers to apply all of the graphical functions to the database so that studies pertaining specifically to manufacturing can be more readily carried out.

CAD for Mold Design

One thing that is clear about CAD/CAM: it's not just an aid for toolmakers to help them cut steel faster. Rather, it is an extremely powerful tool for speeding and simplifying mold design.

A sizeable group of molders and toolmakers are harnessing computer power to integrate efficiently part and mold designs, supply more accurate and productive tooling than conventionally possible, and accelerating the entire tool design and manufacturing process. The most conservative estimates by current or prospective CAD/CAM users are:

-tool design tasks are speeded up by a factor of from three to ten,

-overall moldmaking productivity increases by 20-30%.

More commonly, moldmakers are expecting at least 50% lead time reductions for design and delivery. Toolmakers believe CAD/CAM to be the single most important advance in toolmaking in a generation; they feel it is one that will expand opportunities for plastics in sophisticated metal-replacement applications (40).

A major reason that CAD/CAM is gaining swift acceptance by moldmakers is that intricate cavity and core details, complex undercuts, and other demanding design details can be visualized on a CRT screen more easily than on stacks of blueprints. The ability to rotate and section the part to be molded, to quickly and effortlessly modify shapes and dimensions, and to quickly convert a part design into a cavity by turning the part shape "inside out" is an inestimable aid to the designer.

The growing incorporation of CAD/CAM tools in mold design is also related to what industry souces see as an approaching toolmaker manpower shortage. The Bureau of Labor Statistics indicates that employment in the moldmaking field is declining about 8% annually, and that the average age of a toolmaker is now in the late 50's (41). No extensive apprenticeship programs exist to remedy the situation. A combination of this worsening skills shortage, pressure throughout industry for improved accuracy and quality, and market demand for shorter product introduction cycles will drive even more companies to take advantage of the increased productivity and quality afforded by CAD/CAM systems.

Another significant advantage of CAD/CAM over conventional technology is accuracy. CAD/CAM helps the molder parallel the growing sophistication which is visible in part design. Parts demanding tolerances as tight as +-0.001-inch require optimized molding conditions.

In developing a mold, designers must make decisions involving the layout of runners, the type of runner system, runner and gate locations, and the number of gates required for each cavity; and arrangement of the cooling system. Such capabilities require a full understanding of the molding process and software tools for simulating the process for making predictions. Specialized CAD software has been refined to optimize melt flow in the tool as well as mold cooling.

The first example of such software is the MOLDFLOW system, developed in Australia. Readily available via telephone through a remote access network, this is a collection of programs which analyze flow of plastic into a cold mold by considering both heat transfer and fluid flow to predict pressure, temperature, stress, etc. It provides a scientific approach to balancing and sizing runners and gates, preventing overpacking or underfilling, predicting the location of weld lines, and spotting potential molded-in stresses and excessive shear heating (42).

The computer system simulates the molding of the part and analyzes the path of the melt, stage by stage, from sprue through runners and gates, into the extremities of the cavity or cavities. This may be done before metal is cut, thereby circumventing some expensive mistakes, or it can troubleshoot a mold that is not performing adequately.

In addition to the programs, the other major element of the MOLDFLOW System is a library of resins characterized rheologically throughout the temperature/pressure spectrum encountered during molding (43).

The user communicates interactively with the system via telephone, describing the part, identifying the resin, indicating which molding parameters are fixed and which are to be optimized, and selects the programs needed, depending on how much information is required.

The cost for running a specific job ranges from $500 to $750, depending on how much information is needed and thus how many programs. If the resin of choice were not in the library, it costs $250 to have that resin tested for the rheological data needed, and entered into the datafile. These costs can be recovered by reducing part and runner weight, reducing cycle time, and most important, preventing problems. As one automotive engineer remarked, "It's a lot less expensive to change a line on a drawing than to recut metal" (44).

The MOLDFLOW System's complement is an interactive program for designing cooling systems. The software utilizes a mathematical model which simulates the heat transfer dynamics of a mold. Based on rigorous thermodynamic principles, this approach eliminates best-guess intuition, thereby resulting in increased cooling efficiency and, because approximately 80% of a typical molding cycle is required for cooling the part, a large potential in cycle reduction (45, 46).

In the past, there has been no practical way for the mold designer to predict accurately heat-transfer efficiency. The first time cooling performance could be checked was after the mold was built, usually too late to do any real optimizing in cooling-channel layout. With the use of cooling analysis programs, it is now possible to predict the cooling performance before releasing the design to the machine shop.

Until recently, mold-cooling software was available only through time sharing from a host computer and only in two dimensions, through a program called MOLDCOOL, available from Application Engineering Corp., Elk Grove Village, Ill. The use of the program did not come cheaply. After the one-time initiation fee of $2000, the time charge for for designing and optimizing a new mold ranged from about $800 to $2000, depending on the mold's complexity and the part requirements (46). However, such software is now a standard feature of the Calma turnkey system geared for Injection mold design. Calma's Mold Cooling Analysis Program (MCAP), moreover, permits 3-D modeling (48).

Minimizing material consumption by shortening runners and sprues, simplifying debugging of difficult molds, providing greater accuracy and trimming mold cooling times are the primary benefits provided by flow and cooling analysis software.

Another set of programs for the design of injection molds using interactive computer graphics is being developed at Cornell University. The program MoLD ASSembly (MLDASS) includes a subroutine for the design of simple cooling systems. Once cooling parameters are determined, the required thickness, width, and length of the mold plates can be selected. This selection is made by an algorithm which uses a special coding scheme to describe mold components and their assembly, from several data files based on standard mold component catalogues. The program generates a complete parts list including the name, quantity, catalogue numbers, and dimensions of each component, and calculates the cost of the assembly. Through an interface routine with the Parts and Assembly Description Language (PADL), drawings with dimensions and tolerances can be generated for each of the components and the assembly. A program to generate NC machining data based on PADL is also being generated (49, 50).

Another area where CAD/CAM has the potential for major impact is in part designer/mold designer communication. The designer's responsibilities in tool design never have been clear-cut; often the designer and the toolmaker end up as adversaries instead of partners. As noted previously, the part designer has in the past had to translate his 3-D concepts into 2-D drawings in order to communicate his design to the moldmaker. In advanced integrated CAD/CAM systems, the 3-D digital model is accessed directly by the mold designer, so that no ambiguity exists and much time is saved. CAD/CAM also accommodates maintaining models at current revision levels--a tedious manual task, considering that twenty revision-level changes on one tool are not uncommon before a mold design is finalized.

CAD/CAM is also changing the moldmaking field in the standardization of mold components. Digitized graphic representations of components and companion cutter paths for their manufacture can be stored in memory so that mold bases, spares, cores, pins and other components can be quickly called up from memory and rapidly fabricated when required.

Noting this trend, National Tool & Manufacturing Co., Kenilworth, N.J., is now offering software for CNC milling of standard designs. In addition, graphics and cutter-path software for mold bases from D-M-E Co., Madison Heights, Mich., have been incorporated into a turnkey CAD/CAM system from GE Calma Co., Sunnyvale, CA.

CAM for Mold Cutting

On the CAM side of moldmaking, computerized numerical control (CNC) of milling machines is quickly becoming commonplace and permits far more accurate tolerances than with manual milling. Programmed through a punched tape, CNC machines follow machining paths such as that shown in Figure XV, with up to five-axis milling and automatic cutter-changing capabilities. Punched tapes may be eliminated by Direct Numerical Control (DNC) in which the machine is controlled directly from the computer's memory via cable (51). DNC is a fundamental element in the implementation of integrated interactive CAD/CAM.

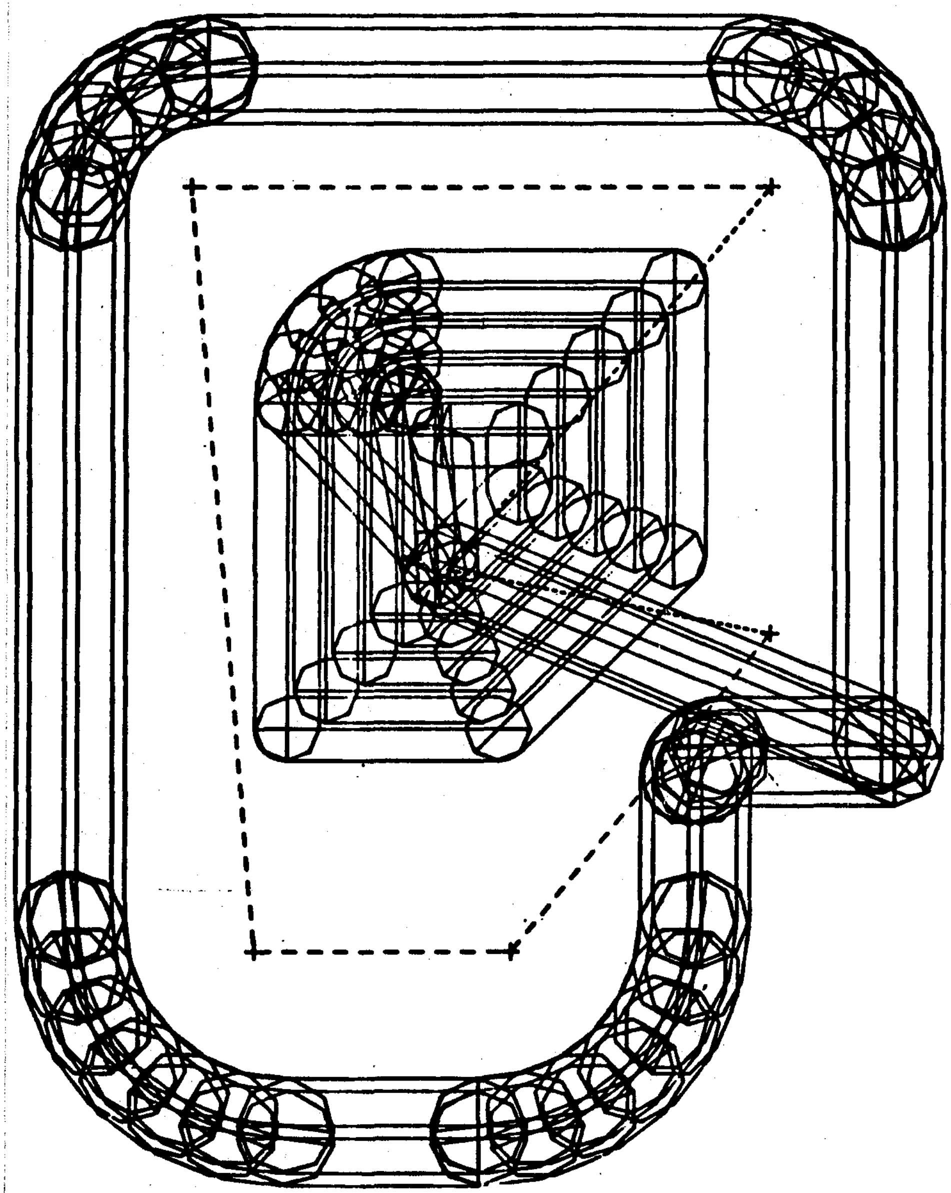


FIGURE XV

TYPICAL NC TOOL PATH (73)

Standardized cutter-path instructions ensure uniform mold cavities and allow perfect duplication of tooling components or entire molds. Additionally, cutter paths can now be verified right on the CRT screen before any metal is cut, ensuring in advance that the cutter head won't strike holding fixtures or other obstructions, and saving considerable time spent manually checking cutter paths by the mill operator.

Computer-controlled electrical-discharge machining (EDM) is another growing technology, which many feel may eventually replace most of the common methods of die manufacture, most of which involve highly skilled time consuming manual operations such as die sinking and/or pattern making. EDM is a particularly attractive process because it can be employed for intricate shapes in hard metals and is very suitable for the reworking of worn die cavities. When EDM is used, copy milling from a suitable pattern is the most frequently employed method of electrode manufacture. Consequently, the use of NC machining for EDM electrode manufacture for dies and molds has substantial benefits.

The process of generating an NC tape involves three stages (52). First, the part or surface must be described; then the path of the cutter must be traced. The NC software package initiates a prompting routine for the designer to select his tool sizes, machine speed and feed rates, coolants and other unique manufacturing-related criteria. Finally, the cutter path information is converted into machine-control commands.

Describing the surfaces and cavities of the mold is the most difficult task. If the part were designed using a computer internal representation, then the geometric description already resides in the database. Thus, the geometric description of the mold cores and cavities can be generated, and the tool paths developed in an integrated manner. Mirror images with exact tolerances can be produced with CAD's assistance, eliminating hours of engineering time. Once dimensions for a cavity are stored in the computer's memory, the geometry can be duplicated for multicavity tool designs. Moreover, dies are made oversize in general to allow for the shrinkage upon cooling of the plastic part after processing. The usual allowance can be made automatically by entering a parameter at the start of the particular job. All of the dimensions are then multiplied by an appropriate amount to allow for this estimated shrinkage. The default value is zero. Using the MODular CONstruction System (MODCON) (53), which is an example of a geometric modelling system with such capabilities, a typical part generally requires the order of 30 minutes data preparation time and 2-3 minutes computing time for generation of the necessary NC tape to machine the final electrode.

To assure that the NC control tape is error free when it arrives at the production machine, it is first passed through a tape verification system. The system consists of a large computer, a drum plotter, and software which converts the NC tape into a plot command file. Various codes are used to show feed motions, direction, tool changes, hole sizes, etc. A pictorial representation of the output enables gross errors to be spotted. The system has editing capabilites which allow correction of any tape errors discovered and the means to punch a revised tape (54).

Molding the part, Processing and Cost Optimization

Another area in which CAD/CAM may be applied to the manufacture of plastics parts is in the optimization of processing conditions. TMC Plastics Processing and Cost Optimization is an interactive engineering and management system which is available as part of Computer-Aided Engineering (CAE)-In Plastics, a set of software tools which is part of the General Electric Engineering System. This system also includes MOLDFLOW and MCAP which have been discussed above. The GE-CAE International software products are offered by the GE Information Services Company, Milford Ohio. Appendix K details GE's involvement with CAE.

By considering both the technical AND economic variables, TMC aids the user in the transition from a design concept to a rational molding operation. The program can be used to solve existing processing problems, or to plan the entire manufacturing process. It identifies major processing difficulties and machine limitations, thus enabling the user to opimize the process. The system also aids the user in projecting unit costs of alternate designs. Mold designers can use TMC to identify potential molding problems, and molders can select the optimum equipment and prepare cost estimates. The program may also be used for evaluating plastics material alternatives.

The TMC database incorporates actual production data from a library of more than 1000 industrial moldings. The database includes the principal variables of material, part design, mold design, processing, machine, and cost, for each molding.

<u>Molding the part, CAD/CAM Process Control (PC)</u>

Since 1959 the technology for the application of computers to the real time control of industrial processes has been under continuous development. Dramatic reductions in the cost of computers have taken place and today there is a much greater capability worldwide for the implementation of such systems. Today process computer control is a widely accepted and used technology for process monitoring, remote adjustment of processing variables, diagnosing malfunctions, and collecting data for production reports. Some systems combine display technology with controllers, so that the CRT can actually display an animated image of for example, an injection molding clamp going through its operating sequence (55).

CAD/CAM systems have many similarities, and embrace many of the same technologies as real time process computer control systems, but they also contain important differences in technological emphasis. Both are real time computer implemented systems and both are EMBEDDED, the computer is not employed in a stand alone configuration, but is employed within a system configuration that involves other types of equipment as well.

Both systems use sensor based inputs, but these account for a greater percentage of the input information processed in PC applications than in CAD/CAM. In CAD systems much of the initial input information is of human origin. However, as the information handled progresses through the various stages of the design process, there is an expanding database to be handled, in which more and more information has been computer generated in previous phases. Consequently a declining percentage can be attributed to the inital statement of requirements and human input that initiated the process. Thus database design is much more important in CAD/CAM, and a much more severe system design problem, than in process control.

A significant difference exists in that application of process control computer systems, at least in the development period, were almost exclusively restricted to large scale plants and processes. CAD/CAM systems are now reaching the discrete parts manufacturing industry and other sectors which are much less capital intensive. Because of this, the socio-economic impact of CAD/CAM can be expected to be much greater than has been the case for process control. Appendix I provides a table of the similarities and differences between CAD/CAM and PC (56).

Automatic Inspection

Once the parts for the product have been manufactured, automated and interactive inspection can occur, utilizing the database for automated input to inspection tools such as coordinate measuring machines. This provides the necessary dimensions and shapes and make possible the on-line comparison of inspection data from fabricated parts against the basic descriptions and specifications in the design data base.

New information is required to supplement the existing database for the planning and controlling of the inspection process. This can range from the programming of coordinate measuring machines where the prime objective may be to position a probe relative to the part to verify its dimensions, to sophisticated surface inspection machines which may automatically scan the part with the scanner kept approximately normal to the surface and at some distance offset from it as it looks for surface flaws. In the future, additional new capabilities will be required to accommodate new automation technology such as x-ray scanners which will use computerized tomography techniques to verify internal geometry or look for flaws in the materials.

Manufacturing stores information concerning part fabrication and the qualitative results of inspection in the CAD/CAM data base. This closes the data loop, so that design engineers have access to data which is used to evaluate their designs.

Robotics and Assembly Routines

The final step in the design process is to extend the information required to assemble the part or series of parts into a final assembly or subassembly. This could simply provide information in a graphical form to guide manual assembly or it could provide directions to robots. Robot arm and hand positions can be shown graphically in their various positions to assure that there is sufficient clearance to permit them to operate within the confines of the assembly. In applications involving robotic assembly, the basic geometric description of the part is then merged with additional command sequences to place the part in the proper orientation and initiate the sequences required to perform the assembly.

Costing and Scheduling

Once a design is complete, the primary concerns are costs and schedules as a function of production volume. Integration and compatiblity with product design are not crucial but may be desirable in later phases of system integration.

VI. CAD/CAM EDUCATION IN THE U.S. AND CANADA

6.1 INTRODUCTION TO CAD/CAM TRAINING

Psychologically, the majority of engineers and draftsmen look forward to CAD/CAM training. As a rule, technical people are turned on by computer graphics and can't wait to get their hands on a system. Some look at the training as an opportunity to find out more about computers and learn a new skill. Some see it as a professional step-up and a way to avoid technical obsolescence. Others are excited by the possibility that the drudgery will go out of their work. And then there are those who feel it is just plain fun. But a few, typically older professionals who grew up before the push-button age, feel insecure and harbor doubts about their ability to learn new ways of doing things.

Daratech's poll (57) of vendors and users indicates that most people develop adequate proficiency in three months and become skilled operators in only six months. Most of the people with a moderate amount of aptitude go on to become expert operators after nine months of experience.

6.2. TRAINING OFFERED BY VENDORS

The training offered by turnkey vendors varies widely, both in quality and quantity. Some offer courses at the buyer's site only and use the newly purchased equipment in the course. Other vendors hold a regularly scheduled series of coordinated courses on their own premises in well-equipped classrooms and laboratories.

The better courses are structured affairs given by full-time professional instructors. Class size is usually limited to ten people or fewer, and the better laboratories have enough equipment so that no more than two or three students have to share a terminal. Off-site learning facilities are preferable because of the interruptions and distractions that invariably occur at the user's plant. Typically, half the time is taken in class work, and the rest, hands-on, in the lab.

The poorer courses are typically given informally by instructors unfamiliar with engineering practices and design office procedures. There is usually insufficient working equipment for hands-on training and the curriculum often covers too little in far too much detail, or covers too much in too little detail.

Scheduling the training sessions can be important. The best time to undergo training is immediately before the system is installed. This is because newly learned skills are quickly forgotten if not put into practice.

Usually, there are separate courses for managers, programmers, and operators. Courses designed for operators generally take one or two weeks to complete and are aimed at two or three levels of students, entry level and courses for people with two to six months experience. Programming courses also take from one to two weeks and are aimed at FORTRAN programmers or advanced operators. Management courses are tailored to individual needs, but are usually given prior to installation planning. In addition, management seminars are held from time to time for more advanced users and deal with topical issues.

Some representative course titles and their subject matters are outlined below:

BASIC OPERATOR'S COURSE: An entry level course designed to teach basic skills: turning the system on and off; operating the workstation components; command structure; graphics creation and editing commands; use of on-line storage; use of magnetic tape; elementary dimensioning; text insertion; function menu design.

ADVANCED OPERATOR'S COURSE: A course designed to teach operators with about three-months experience advanced commands and techniques: data structures; data extraction for bill-of-material and other reports; generating N/C manufacturing tapes; 3-D operations; parts properties extraction; building models for finite element analysis.

APPLICATIONS COURSE: A course designed to teach engineers how to use specialized analysis, report generating, or other design or manufacturing applications software packages.

APPLICATIONS PROGRAMMING COURSE: A course designed to teach programmers and advanced operators to design, code, debug, and install special-purpose programs in a graphics design language: language structure, statement format, vocabulary; operating system interface; entering a program; editing a program; compiling a program; installing and executing a program; debugging a program; saving a program on tape.

MANAGEMENT COURSE: Designed to teach the elements that go into pre- installation planning and system management: work station layout, lighting, and access scheduling; personnel selection; personnel training; hiring; wage scales; labor/management relations; career paths in CAD/CAM; establishing a high-productivity environment.

6.3. SEMINARS AND SHORT COURSES

The following is a sampling of the intensive workshops which are being offerred throughout the country.

CAD/CAM Seminars

CAD/CAM SEMINAR

Sponsored by the Society of Plastics Engineers
Fee: $345, Two days

Objectives: To show that computer assistance in the injection molding industry is a reality today and will be a necessity tomorrow. To explain and demonstrate the hardware and software which is available today and to tell how to use them.

Description: The Program covers four major topics wherein the use of computers brings increased productivity and profitability to the industry. These are plastics part design, injection mold design, mold making and injection molding process control. Exhibitions of hardware and software.

CAD/CAM FOR MANAGERS

Sponsored by the University of Detroit
Fee: $455.00, Two days

Objective: To expose executives and mangers to CAD/CAM technology, applications, and available systems with emphasis on their strengths and limitations.

Description: Introduction to CAD/CAM as a system which includes design, drafting, analysis, production, tool design, process planning, scheduling, inspection and materials handling. Exploration of available CAD/CAM systems employing main frame computers and dedicated turnkey systems. Discussion of the fundamentals of CG, CAD, and CAM. Justification, implementation, and training requirements. Trends. Demonstration of applications.

CAD/CAM FOR ENGINEERS

Sponsored by The University of Detroit
Fee: $755, Five days

Objective: To study applications of digital computers in design and manufacturing environments and to aid CAD/CAM system users in implementing a fully automated factory.

Description: Introduction in detail of the fundamentals of CAD/CAM systems and their applications. Discussion of available CAD/CAM systems: evaluation, implementation, and management and training. Examination of networking, communication, programmable controllers, data base management, computer-aided engineering analysis, and future trends. Demonstrations.

CAD/CAM FOR DESIGNERS/DRAFTERS

Sponsored by The University of Detroit
Fee: $700, Twelve evenings

Objectives: To teach operators of Interactive Graphics systems and designers the basic operation of the CADDS3 operating system software utilized to create mechanical designs.

Description: Introduction to CG, and to ComputerVision's Designer System. Basics of part creation. Filing. Commands. Documentation. Coordinate systems. Data input and error-correcting procedures. Dimensioning and text commands. Intro to views, 3-D construction, surfaces. Paramenter management, grids and layers.

<u>CAD Seminars</u>

INTRODUCTION TO COMPUTER AIDED ENGINEERING DESIGN

Sponsored by Virginia Polytechnic Inst. & State University
Fee: $530, Three days

Objective: To introdue the participant to a practical involvement with finite element stress analysis, dynamic system simulation, transfer matrix methods, and related mechanical design topics.

Description: Emphasis of course is on effective model-building techniques and evaluation of results from computer programs. Theoretical foundations are presented to aid physical understanding. Hands-on use of computers provide immediate involvement in practical applications.

COMPUTER GRAPHICS: CAD/CAM AND MANAGEMENT APPLICATIONS

Sponsored by Worcester Polytechnic Institue
Fee: $495, Two days

Description: Subject matter includes: The essentials of CG, Basics of graphics technology, understanding complex systems, overviewing successful applications, selecting the best system, handling key management courses, managing system installation and use, planning for the future of graphics.

INTERACTIVE COMPUTER GRAPHICS AND COMPUTER-AIDED DESIGN

Sponsored by Cornell University
Fee: $725, Five days

Objective: To provide a comprehensive presentation of recent advances in interactive CG and CAD techniques for engineers and managers.

Description: Intro to CG problems and difficulties. Physical principles of display hardware. 2-D vector graphics, input methods, 3-D graphics. Geometric modeling, surface descriptions. Engineering applications. 2- and 3-D finite element analysis. Post-processing display routines. Hands-on experience in sophisticated state-of-the-art CAD laboratory.

COMPUTER-AIDED DESIGN OF DYNAMIC SYSTEMS

Sponsored by Michigan State University
One week

Objective: To provide engineers who wish to improve their productivity an opportunity to use modern, computer-based approaches to modeling, analyzing and simulating dynamic behavior of engineering components and systems.

Description: The course provides an introduction to structured modeling of mechanical, electrical, hydraulic/pneumatic, and thermal effects and demonstrates how interactive computing with graphics greatly improves the overall design process. It also provides a solid basis for subsequent study of computer-aided automatic control systems, vibration phenomena, and optimization methods. No prior computing experience required.

CAM Seminars

COMPUTER-AIDED MANUFACTURING

Sponsored by Lehigh University
Fee: $545, Three days

Objective: To help persons involved in the design or operation of manufacturing systems acquire an understanding of the techniques and technologies associated with CAM.

Description: Educators will be present for instruction in the engineering technology underlying the hardware, software and systems; experienced users will present case studies and examples for CAM technology implementation; and vendor technical experts will discuss new developments and the assembly of programs. Topics will include: Computer Systems overview. CAM technologies for improving productivity. Planning, scheduling, & controling manufacturing activities. Group technology. Integrated CAD/CAM systems. Implementing CAM technology. Projected developments.

COMPUTERS IN MANUFACTURING: THE NEW REVOLUTION

Sponsored by Worcester Polytechnic Institute
Fee:$495, Two days

Objective: To teach the manager, engineer, and user the practicalities and economics of industrial computerization.

Description: Topics include: Understanding the Uses of mini and micro system, small computer technology: what's in the tool kit, application cases and examples, designing computer-based industrial systems, handling managerial and human aspects of computer-based industrial systems more effectively, successful implementation, operational management, understanding future growth that impacts current plans.

DESIGN ANALYSIS AND MANUFACTURING

Sponsored by The University of Missouri-Rolla
Fee:$595, Five days

Objective: To provide the participant with a foundation in the theory and practice of computer-aided design, analysis and manufacturing.

Description: The design and manufacture of mechanical parts and structures employing a computer system that blends the various steps into an integrated whole is considered. All steps are carried out or controlled interactively at the computer terminal, which is capable of drawing pictures as well as transmitting alphanumerics. The engineer communicates with the computer using engineering terminology and working methods, rather than by writing programs. The speed and convenience of the approach ensure that only highly refined designs need ever reach the prototype stage. Computer-assisted analysis of the prototype permits further refinement and verification, followed by automated manufacture and assembly.

COMPUTER METHODS FOR MODAL ANALYSIS

Sponsored by Michigan State University
Five days

Objective: Instruction in empirical and analytical techniques.

Description: The uses of finite element software. Discussion and demonstration of SUPERTAB and ANSYS. Explanation and demonstrations of modal testing. Hands-on experience with FEM software and test equipment.

AUTOMATION AND MANUFACTURING SYSTEMS

Sponsored by Lehigh University
Fee: $545, Three days

Objective: To instruct participants in the principles and practical applications of automation and CAM systems used in modern manufacturing systems.

Description: Emphasis will be on techniques appropriate for discrete parts manufacture, and practical application of techniques to solve production problems. Topics Include: Numerical Contol. Industrial robots. Tour of Ingersoll-Rand's modern NC manufacturing facilities. New tooling systems. Flow line production systems. Flexible manufacturing systems. Integrated CAD/CAM systems. Group Technology. Economic justification. The future automated factory.

MICROCOMPUTERS IN CONTROL SYSTEMS

Sponsored by The George Washington University
Fee: $915, Five days

Objectives:
- Assess the applicability of microcomputers for control problems, with emphasis on single component microcomputers,
- Select the optimum system for particular applications,
- Configure systems for particular applications,
- Gain hands-on experience in developing software for control systems,
- Gain in-depth understanding of interfacing and factors in machine selection.

Description: Participants are familiarized with the capabilities of microcomputers to replace discrete digital, analog, and electromechanical control elements in control applications. They are shown the current state of microcomputer technology and become familiar with both the economic and technical aspects of the use of such systems as replacements for more conventional control methods. Emphasis is on practical applications. Presents basic techniques in interfacing microcomputers with external devices.

Other seminars and short courses include:

APPLIED INTERACTIVE COMPUTER GRAPHICS
PRACTICAL CAD/CAM CONSIDERATIONS
MANAGEMENT OF CAD/CAM SYSTEMS

Sponsored by the University of California at Los Angeles

REAL-TIME COMPUTER APPLICATIONS MODERN COMPUTERS IN MECHANICAL DESIGN: A MANAGER'S WORKSHOP CAD IN MECHANICAL ENGINEERING

Sponsored by Digital Equipment Corporation

UTILIZING CAE, CAD, CAM AND COMPUTER GRAPHICS FOR BETTER DESIGN

Sponsored by American Management Associations R & D Division.

6.4. CAD/CAM TRAINING BY EDUCATIONAL INSTITUTIONS

This section represents a summary of the results of a survey conducted by the author of 350 advanced educational institutions in the United States and Canada. The survey was a request for information concerning:

- The facilities for Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM) and Computer Graphics (CG) owned by the institution or accessable to the student population.
- Mechanical CAD/CAM training available through the institution.

Institutions were contacted which had majors or concentrations in the following fields:

- Aerospace Engineering
- Computer Aided Design
- Design and Drafting Technology
- Engineering
- Engineering Analysis and Design
- Engineering Design
- Engineering Design Technology
- Engineering Technology
- Mechanical Analysis & Design
- Mechanical Design
- Mechanical Engineering

The target institutions were chosen with the aid of the following reference materials:

- The College Blue Book, 17th Edition, Degrees Offered by College and Subject, (New York: Macmillan, 1979),

Edited by David B. Biesel et. al.

-The Guide to Independent Study through Correspondence Instruction 1980-1982, Joan Hunter, ed. (Washington, DC: National University Extension Association, 1980).

-Peterson's Guides to Graduate Study, 1980. Edited by Margaret G. Butt (Princeton, N.J.: Peterson's Guides, 1980).

Appendix J is a compilation of information concerning educational facilities and programs within the United States and Canada which include theoretical and/or practical training in the use of Computer-Aided Design/Computer-Aided Manufacturing (CAD/CAM).

It is almost invariably the case that there is a considerable time lag between the widespread industrial acceptance of a new product or technology and the time that it is incorporated into educational programs. And so it is with CAD/CAM.

Of the 350 educational institutions contacted for the survey included in this thesis, only 98 (28%) responded. Of those from whom the author received replies, 29 (8.3%) had no facilities nor courses which covered CAD/CAM topics. Approximately 16 (55%) of those who did not support CAD/CAM did have plans for, or were in the process of CAD/CAM equipment acquisitions and curriculum development. Of the institutions which reported to offer facilities and/or courses, most could at best be described as severly limited.

Analysis of the survey results beyond this preliminary information was rendered difficult due to several factors:

1. There exists a great disparity in that which is considered to be encompassed by the term CAD/CAM. While some institutions could boast of ownership of complete, turnkey systems or mainframe systems with extensive satellite graphics processing stations, others considered CAD/CAM to include collections of microcomputers or data acquisition minicomputers with random software capabilities.

Without an extensive investigation of the specific hardware and software capabilities of each school, it is difficult to differentiate between institutions which offer "true" CAD/CAM capabilities and those with facilities which can only be loosely associated with the technology. To expand on this, if one were to examine a listing of all the automotive parts owned by a well-stocked parts store, one might conclude that the shop housed an automobile. Unless the parts were combined in a proper, integrated manner, this obviously would not be an accurate conclusion.

A related disparity may exist between the sophistication and capability of the facilities owned by a given institution and the comprehensiveness of its course offerings. For example, many CAD courses are dedicated solely to teaching the student techniques for computer-aided drafting. This is undoubtedly a fundamental aspect of CAD/CAM education. It is, however, only a segment of the knowledge required to implement a development project. The author contends that a course in computer-aided drafting, finite element modeling, or other CAD/CAM aspect does not make a CAD/CAM program.

2. It would be an error to conclude that an institution is inadequate in CAD/CAM education because it does not offer any courses particularly dedicated to the technology. CAD/CAM may be utilized in the completion of assignments and projects so extensively throughout the engineering curriculum, that the potential for theoretical understanding and technical proficiency is as strong as in a school which does offer specialized CAD/CAM courses. This may even be a superior route because of its potential for preventing the tendency for the engineer to become so enamored with CAD/CAM itself that he loses sight of the fact that it is merely a tool which must be thoroughly integrated into all other aspects of engineering processes. On the other hand, it would be difficult to become well-versed in engineering techniques such as differential equations, transforms, and

heat transfer principles if these subjects were not considered separately and in-depth before attempting to incorporate them into applications.

3. A third factor which adds to the difficulty of drawing conclusions is that courses listed as official departmental offerings may in essence be "phantom courses" which appear in catalogues but are actually scheduled only periodically over the course of a student's matriculation.

4. A final factor is that survey respondents were not consistent in reporting the facts. For example, not all colleges denoted the departments which sponsored courses or their graduate vs. undergraduate status.

Keeping these points in mind, the following observations have been made:

1. The schools which appeared to be most actively involved in CAD/CAM training included:

The University of Akron
The University of Alabama at University
The University of California at Los Angeles
Colorado State University
Cornell University
The University of Delaware
The University of Detroit
George Washington University
The University of Iowa

Louisiana State University
The University of Lowell
Michigan State University
Michigan Technological University
The University of Missouri at Rolla
The University of Nebraska at Lincoln
Ohio State University
Purdue University
The University of Rochester
The U.S. Naval Academy
Virginia Polytechnic Institute and State University

2. There appeared to be no strong geographical concentration or pattern of institutions which were reported to support CAD/CAM involvement. In fact, it was quite surprising that Massachusetts, considered a leading center of technological education, constituted only a minor force in CAD/CAM training. One would expect strong curricula from such universities as Massachusetts Institute of Technology, Tufts University, Wentworth Institute, University of Massachusetts, Boston College, And Franklin Institute. It may well be, however, that the state's poor showing stemmed more from busy department personnel than from lack of CAD/CAM support.

3. Most of the schools supporting CAD/CAM are relatively large engineering universities, as would be expected in view of the capital investment required for equipment acquisition. Only one community college and two technical intstitutes responded positively. Courses were concentrated in Mechanical Engineering departments, although others were

listed under Aerospace, Civil, Electrical, and Industrial and Systems Engineering, Computer Science, Informational Science, and Engineering Graphics. Had the survey requested information about CAD/CAM in general, response would undoubtely have been more dramatic, since CAD/CAM systems for mechanical applications constitute less than half of those marketed.

4. Courses tended to be offered at the junior and senior undergraduate or the graduate level. Only one college offered a Doctor of Science degree, Michigan State University, while three offered Master of Science degrees in CAD/CAM, George Washington University, Michigan State University and Ohio State University. George Washington State University also offered a professional degree in CAD. Two institutions offered technical options in CAD/CAM at the baccalaureate level, namely Michigan State University and Ohio State University.

VII. RECOMMENDATIONS

This thesis has presented CAD/CAM from a decidely positive viewpoint, listing its advantages and benefits, extolling its virtues, and stressing its potential. Although the author has perceived from the literature that most users are indeed satisfied with their systems, the technology is young and still requires some debugging. It would be interesting and beneficial to conduct an investigation of the problems and weaknesses that have affected CAD/CAM acceptance. Such an investigation might include a literature survey and a series of carefully designed questionnaires and personal interviews with current industrial users.

Considering her own educational background in CAD/CAM from the University of Lowell and from extensive literature coverage, and the offerings of the institutions surveyed, the author has designed a CAD/CAM core which could be incorporated by educational programs involved with the preparation of students for product engineering (design or manufacturing) careers. Such a set of courses would be in addition to the integrated use of CAD/CAM throughout the program, for the completion of projects and assignments, and for research endeavors. Although the expense of CAD/CAM systems prohibits major extended acquisitions by most institutions, it is the author's recommendation that equipment purchase should be an important priority for engineering departments, supplemented by cooperative agreements with local industrial concerns and/or consortia of other area universities and colleges.

While the author is inclined to recommend that facilities be provided by all technologically-oriented institutions which would enable hands-on training for all sophomore or junior engineering students, simple mathematics demonstrates the impracticality of such a suggestion. However, the author recommends that a short course or introductory seminar be presented. For such a course, the author finds the topic selections of the courses which are currently offered throughout the country, as listed in section 6.3, quite satisfactory.

RECOMMENDED SAMPLE CAD/CAM COURSE DESCRIPTIONS

2 to 5 Semester CAD/CAM Core for Design-Oriented Students

Introduction to Engineering Computer Graphics:

This course provides an introduction to Computer Graphics and addresses the objectives and problems of interactive graphics. The course is augmented by substantial programming and user experience with graphics devices and software. Case studies, examples, and displays from actual systems are an integral part of the course.

Topics include:

Drawing and display hardware and systems
Input and output devices
Graphics software
Graphic data structures
Interactive techniques
Algorithms for the display and transformations of 2- and 3-D objects
2- and 3-D graphic data in various representation systems
Graphic standards
Visible surface algorithms
Shading
Hidden line removal
Color
Graphics high level languages
Animation techniques
Image processing
Considerations in interactive graphics and future trends

-Computer Aided Design and Manufacturing

(a two or three semester course):

Prerequisites: Introduction to Computer Programming
Introduction to Engineering Computer Graphics

A two or three semester user-oriented project/lecture course concentrating on the applications of computer modelling, computer-aided design, and computer graphics to the design and manufacture of discrete mechanical parts and assemblies. The course is designed to be compatible with industrial practices, equipment, and procedures.

Topics Include:

Components of CAD/CAM systems
Commercially available application software
Real-time computer acquisition of experimental data
Computer representations of objects
3-D curves, 3-D surfaces
Advanced geometric modelling
Iteration, parametric studies, and optimization of mechanical designs
Static and dynamic analyis
Graphical simulation of dynamic mechanisms
Analytical data preparation techniques
Finite Element methods
Empirical methods for modal analysis
Reliability analysis techniques
Manufacturing process planning
Manufacturing data processing
Numerical Control machining
APT machining language
Fundamental control theory
Control problems relevant to the computerized manufacturing system
Software requirements for computerized control
Digital interface considerations
Introduction to process control
Computer-aided process control
Robotics
Robot programming languages
Robot control algorithms,
Robot sensor development

VIII. CONCLUSION

The integrated computer-aided design and manufacturing process allows entire design jobs, from the first stages of preliminary and conceptual design to the production of smoothly running molds manufactured by DNC or NC tapes, to take place primarily at one location and with one set of data. No interpretation of hard copy drawings is required to analyze the parts, construct the mold or plan the machining processes; no keypunching of data is required, and manual inputs have been reduced to the absolute minimum. The interface between the engineers and the computer is a friendly one, supported by interactive dialogue which prompts the user for the required input, gives him or her the information he or she needs, and keeps everyone involved with the project up-to-date. It should be quite clear that design, manufacture, inspection and assembly applications have many common data requirements. They all primarily require a good description of the part, the ability to orient additional geometric elements around this part, and the use of graphics to verify fits, clearances, tool paths, flow paths, etc. The full significance of such a total interactive CAD/CAM system is that it makes possible the integration of all these applications of computing technology and, consequently, the full realization of their potential benefits in cost, labor, and lead time reduction to do a specific task.

Reductions in the price/performance ratio of computers have kept improving every year by 32% for memory costs, 23% for logic and 11% for communications. A ten-fold cost reduction every ten years means that a calculation costing $1000 in the early days of computing would cost only $10 in 1972, $1 in 1982, and $.1 in 1992. Economic changes such as this keep opening up new waves of applications as long as the organization and development of applications know-how and the labor cost of programming can keep up.

The greatest resistance to the use of CAD/CAM and Computer Graphics is due to the high expense in buying and using the systems. CAD/CAM does carry a hefty price tag. Initial cost of commercial turnkey systems can run from $100,000 to $800,000, epending on supplied options and number of workstations involved. The more extensive systems can sell for more than $1 million. Installation costs, operating costs, software development expenditure, maintenance contracts, and other additional expenses add up rapidly.

Other complaints include the lack of development of flexible, easy to use software, and the complexity of the hardware. Particularly interesting are the potential dangers that trade unions anticipate. They foresee a continuing fragmentation of jobs and a higher degree of specilaization resulting in less job satisfaction because fewer will be able to see the panoramic picture of the complete job. They think that the employers will wish to expoit their workers more as high capital cost equipment is used in design and manufacture. Probably the most dangerous aspect of CAD/CAM is the high burn-up rate in staff which they due to fear the intensive use of CAD facilities. Since Computer Graphics can eliminate much of the routine reference work and greatly intensify decision making, the stress put on the man can become very great. Because the job requires a greater intensity, only personnel within a certain age bracket will be recruited for those jobs. As staff grow older they may be "scrapped" along with the machine, or at least subjected to career de-escalation. The unions also point out that CAD may make employers more vulnerable to strikes from a few members of staff. However, union members are becoming aware of the tends and advantages offered by automation, and it is being realized that new techniques in design and production must be accepted in the long term, otherwise jobs will disappear to overseas competitors.

In direct contrast with the attitute of the trade union, may companies believe that the use of CAD/CAM helps avoid specialization because a designer with a good all around training can call on specialist programs, such as FEA, which can be built into the CAD system. They also assert that the introduction of Computer Graphics has been welcomed due to the reduction of tedious tasks, leaving more time for designers and engineers to think and plan (58).

CAD/CAM has established itself as an important technological tool in the industrial sector.

The fully integrated CAD/CAM environment, the "fully automated factory", may at present be realized only in large, high-technology industries such as the aerospace and automotive fields. However, the technology does exist, and has been available since the early sixties. On a narrower front, the marriage of computer operated design and prodution equiment with computer programmed industrial robots and other materials handling equipment into sub-systems are very likely to become a widespread reality in the very near future.

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XI. APPENDICES

APPENDIX A

BASIC CONCEPTS OF COMPUTER ORGANIZATION

The computer takes in data in the form of symbols which represent real-world situations, events, or conditions, performs manipulations (subtractions, alterations, insertions, deletions, rearrangements, tests, and logic and arithmetic operations) upon the symbols, and outputs processed data to the user.

In order to accomplish these fuctions, two computer elements are required:

-Hardware: The machinery,
-Software: The instructions which direct the machinery (programs), and instruct humans in the use of the hardware and software (documentation).

The hardware of a data processing system is of two types:

-The Central Processing Unit: The heart of the system responsible for the processing function. It is comprised of:

a) The main memory (stores instructions and data),
b) The control unit (integrates and coordinates the operations of the input and output units, storage devices, and the arithmetic and logic unit),
c) The arithmetic and logic unit (performs computations and comparisons),
d) External or mass memory (optional; stores additional data and information).

-The peripheral units: for input and output functions.

Input data describes conditions, tells of events, or pictures actions. Because input is the most costly part of the operation of a computer system, the selection, collection, and preparation of input data is vitally important.

Output data consists of symbols which represent events and conditions which have been processed by the computer. Output data can be characterized by the way it is presented. It can be viewed in the following formats:

-linear (serial): Single lines of data,
-tabular: A set of linear formats in vertical pattern, usually with the same format used on each line,
-narrative: Blocks or paragraphs in free style,
-graphic format: Condensed into simple geometric relationships and patterns.

APPENDIX B

SUPPLIERS OF COMMERCIAL TURNKEY CAD/CAM SYSTEMS

Adage
One Fortune Drive
Billerica, MA 01821
(617)-667-7070

Applicon, Inc. (1969)
154 Middlesex Turnpike
Burlington, MA 01803
(617)-272-7070

Auto-Trol Technology
12500 N. Washington St.
Denver, CO 80223
(303)-452-4919

California Computer Products, Inc.
3320 E. LaPalma Ave.
P.O. Box 4407
Anaheim, CA 92803
(714)-821-2011

Calma Interactive Graphic Systems (1968)
527 Lakeside Drive
Sunnyvale, CA 94086

Computervision Corporation (1969)
201 Burlington Rd.
Bedford, MA 01730
(617)-275-1800

Data Technology
4 Gill St.
Woburn, MA 01801
(617)-935-8820

Digital Equipment Corporation
146 Main St.
Maynard, MA 01754
(617)-897-5111

Evans and Sutherland Computer Corp
580 Arapeen Dr.
Salt Lake City, Utah 84408
(801)-582-5847

Gerber Scientific
83 Gerber Rd. West
South Windsor, Conn. 06074
(203)-664-1551

GTCO Corp.
1055 First St.
Rockville, MD 20850
(301)-279-9550

Information Displays, Inc.
150 Clearbrook Road
Elmsford, NY 10523
(914)-592-2025

Imlac Corp.
150 A Street
Needham, MA
(617)-449-4600

Intergraph Corp.
One Madison Industrial Park
Huntsville, AL 35807

International Business Machines Corp.
1133 Westchester Ave.
White Plains, NY 10604
(914)-765-1900

M & S Computing, Inc.
P.O. Box 5183
Huntsville, AL 35805
(205)-772-3411

McDonnell Douglas Automation Co
Dept. KBP-500
Box 516
St. Louis, MO 63166

Nicolet Zeta Corp.
2300 Stanwell Dr.
Concord, CA 94520

Prime Computer, Inc.
Prime Park, MS15-60
Natick, MA 01760
(617)-655-8000

Summagraphics Corp
35 Brentwood Ave.
Fairfield, CT 06430
(203)-384-1344

Synercom Technology Inc.
500 Corporate Drive
P.O. Box 27
Sugarland, TX 77478
(713)-491-5000

Vector General, Inc.
21300 Oxnard St.
Woodland Hills, CA 91367
(213)-346-3410

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A Survey of Commercial Turnkey CAD/CAM Systems. 2nd Ed. (Dallas, Texas: Productivity International, Inc., 1981).

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APPENDIX C

GRAPHIC DISPLAY TECHNOLOGIES

A. REFRESH TECHNOLOGY

A graphic display unit which uses refresh technology, also known as VECTOR REFRESH, DIRECTED BEAM, RANDOM SCAN, or STROKE REFRESH technology, utilizes a phosphor which emits light for only a few milliseconds. Because of this, the screen must be repainted 10-40 times per second in order for the eye to perceive the image as flicker-free. A major drawback to this type of display is that only a limited number of flicker-free graphic characters can be displayed at one time.

However, because of the highly interactive nature of the technology, the user does not need to display high-density pictures. He can bring in the information as needed, rather than try to display all of it at once. In addition, refresh systems, because of their short-persistence phosphors, allow the user to selectively erase graphic elements from the display screen without repainting the whole picture. These characteristics make refresh technology very well suited to anything that requires dynamic motion, such as simulations, mathematical modeling or animations. It is also well suited to any application such as three-dimensional engineering design which requires a high degree of interactiveness. A three-dimensional picture can be displayed in perspective and then rotated in essentially real time, so that the user can easily visualize the object the data is describing.

Refresh technology is also well suited for complex engineering applications because it uses a continuous line technique to generate characters and graphic elements. Other systems use point-by-point methods which can result in jagged diagonal lines. Another advantage of refresh graphics is the flexibility it provides concerning the types of input devices with which it may be used. The light pen, which will be discussed later, is an example of such a device which can not be used with other graphics systems.

The main advantage of this technology is its highly interactive nature, which enables the user to explore a number of various alternatives quickly before committing himself to a specific choice. As you might guess, the user must pay for all this flexibility; refresh systems cost between $15,000 and $350,000. Limited color is available with the system.

Refresh displays also require a considerable amount of random access memory to store an image while it is being displayed. In some early systems, the host computer served to refresh the display with repeated outputs from its memory, requiring a large number of data words every second. However, in the last several years the price of computer power has decreased dramatically, so that a minicomputer or microcomputer may be used as a DISPLAY FILE MEMORY so that the computer merely loads the this memory with a single frame of data, then recycles the data as often as necessary. The computer is required only when a change in the display takes place.

B. DIGITAL TV TECHNOLOGY

The second type of display technology is the digital TV system, which uses techniques similar to those employed in a television set. The electron beam always follows a fixed pattern of horizontal scans across the tube rather than moving to random X,Y locations as in the previously discussed system. The picture is formed by intensifying the beam in appropriate places, illuminating each picture element into which the screen is divided into one of 64 intensity levels.

The system accepts digital definitions of graphic elements and converts them within the system into a DISPLAY BIT MAP MEMORY FILE which is used to refresh the short-persistence phosphor. The conversion may be done either by hardware or with a dedicated microcomputer.

THE ADVANTAGES AND DISADVANTAGES OF THE DIGITAL TV SYSTEM

Advantages:

-high availability of low cost monitors,
-ability to display a large amount of information without flicker,
-capability of low cost color displays,
-ability with some systems to mix the output of conventional TV cameras with the digitally generated information,
-ability for selective erase and moderate dynamic capability.

Disadvantages:

-usually has poorer resolution than the refresh or storage tube systems,
-poor diagonal line quality characterized by "jaggies",
-more difficult to use some input techniques such as the light pen,

- requires an order of magnitude more memory for picture storage than does a refresh system for equal resolution and even more if the picture incorporates color or gray levels,
- because the display is only updated at about 10 times per second, as opposed to 30 times per second for the refresh tube, dynamic capability is not as advanced with this technology.

C. TV/SCAN CONVERTER DISPLAY TECHNOLOGY

An alternative to the digital TV display which is very similar is the TV/scan converter. In this technology, the display memory is replaced by a scan converter, which is essentially an analog storage device. First, the picture is drawn in a conventional random fashion and stored in the mechanism of the screen. TV is obtained by scanning the storage surface and showing the output on the TV monitor. This system combines the advantages of both the refresh display and the storage tube technologies. Because beam movement is not affected by picture content, the picture described in the display file can be modified while the picture is being displayed, thereby providing selective erasure capability and the resultant ability to display motion. Because picture complexity does not affect beam movement, there is no flicker problem.

Other advantages include:

- low cost TV monitors,
- gray level capability,
- modest dynamic ability,
- relatively low cost ($10,000 - $15,000),
- full color capability,
- bright picture.

Disadvantages of the technology are:

- poorer contrast and resolution than characteristic jagged diagonal lines,
- inability to use light pens as input devices with this system,
- poor dynamic ability.

D. STORAGE TUBE DISPLAYS

Storage tube displays operate similarly to refresh displays. The picture is initially generated by a directed electron beam, causing the image to be traced on an extremely long-persistence phosphor inside the CRT. However the beam writes on a fine mesh grid mounted just behind the phosphor-coated screen, not on the phosphor itself. The charges deposited on the grid are transferred to the phosphor by a flood of electrons from a flood gun. Hence the picture is stored on the grid and, as a result, needs to be traced only once. The image traced by the writing beam can be illuminated for a long time.

A great feature of recent models of the storage tube, also known as a direct view storage tube (DVST) which is very important in CAD/CAM applications, is that the image can be illuminated with the writing beam without triggering the storage mechanism. The unstored image must be refreshed by the writing beam about 10 times per second in order to keep it illuminated. the refreshed image can be overlayed over a stored image without destroying the latter. By utilizing the refresh approach with a DVST, the designer can now work on segments of the picture displayed in the refresh mode and then freeze the segment in CRT storage when work on it is complete. This feature overcomes the major problem which plagued the traditional storage tube, i.e., no selective erasure capability.

Advantages of the DVST are:

-no flicker problems with high density drawings,
-because there is no display file memory, the cost of the system is reduced by an order of magnitude ($8,000 - $35,000),
-low cost hard copy accessories are available,
-storage tubes tend to have large screens and high resolution.

Disadvantages include:

-relatively low brighness and contrast, which makes it difficult to see in a normally lit room, and contributes to eye strain and fatigue,
-no selective erase unless system has refresh option; hence entire screen must be erased and modified and the picture completely redrawn in order to delete one item. Erasure is accompanied by an intense flash,
-A high degree of dynamic motion is not possible since changing a displayed image requires erasing the entire image and redrawing it.
-not well suited for highly interactive applications such as three dimensional engineering drawings,
-no gray level,
-no color capability,
-no technique for color display,
-small display, marginal for engineering applications,
-no light pen capability,

-slow writing speed; a complex picture can take several minutes to draw.

APPENDIX D

PRODUCTION HARD-COPY PLOTTER TECHNOLOGIES

Pen Plotters

Generally, pen plotters use ink pens to draw graphics on a variety of materials. Some pen plotters can be fitted with alternate heads for other purposes as well.

Of the pen plotters, the most widely used is that in which the paper is wrapped around a drum which, in turn, is rotated by a digital stepping motor. The pen is mounted on a gantry across the drum so that when the pen is lowered to the surface of the paper, a line is drawn in either the vertical or horizontal direction as dictated by the two motions. Drum plotters are fairly fast, very convenient to use, require little operator intervention, provide unlimited length plots, and take up little floor space. On the other hand, they are difficult, if not impossible to read as they are executing the drawing and the less expensive models have, in the past, displayed the same loss of definition due to "jaggies" as do raster scan terminals, rendering them inadequate for most engineering drawing applications. However, recent developments have enabled drum plotters to produce good-looking, accurate drawings at speeds comparable to bed types, and their prices have risen to match. However, good quality drum units are available at lower prices and are a good choice for many low cost operations. Drum plotters are available in many sizes and may operate on-line or via remote magnetic tape stations.

The other type of pen plotter is the flatbed version in which the paper is held flat while the pen is moved on a gantry being driven in a direction perpendicular to the motion of the pen. Plotting speeds for the drum plotter are around 100 to 300 mm/second while the flat bed is capable of speeds ranging from 100 - 1000 mm/sec. The latter produces better quality copies suitable for the most exacting engineering requirements. An advantage of the stationary bed is that the drawing can be examined as the plot progresses, allowing the operator to monitor the line quality and terminate the plot should any defects be observed. The stationery bed also contributes to accuracy when drawing with wet ink on a non-absorbent material such as Mylar. This is because the slow-drying inked lines are not offset by rapid movements of the bed. Another advantage of the flatbed is that plots can be made on heavy or thick materials that need not be flexible. These units handle pre-cut sheets of drawing material and are charcterized by superior quality of construction and a higher price tag than other designs. Despite the greater expense and amount of floor space required for a flatbed plotter, they are preferred by two-thirds of the CAD/CAM sites surveyed in a recent study of components.

With advances in plotter technology, such as the advent of servo drives, more sophisticated control circuitry, and microprocessors, new approaches have emerged to improve the performance of plotters. Some experimental units are now able to join any two points lying on the plotter's resolution grid with a truly straight line or regular curve which need not pass through intervening grid points.

Pen Plotter Controllers

Pen plotters are relatively dumb devices that can only carry out a small number of basic commands. A very large number of these commands must be used to generate a typical engineering drawing. The commands are very sensitive to timing in order to create accurate drawings while achieving the plotter's throughput potential.

Microprocessor-based controllers have considerably improved plotter performance by taking direct control of the unit's electromechanical mechanisms, thereby relieving the graphics processor from having to provide timing information. Because they are dedicated devices, they are also able to insure that the plotter will always be driven at its rated speed. By having resident character sets and a vector capability, controllers significantly reduce the amount of plotting data that must be generated by the graphics processor.

Apart from other obvious contributions to improved CAD/CAM system and plotter throughput, plotter controllers also provide a flexible interface that can match a plotter's attribute to the requirements of different CAD/CAM systems. Their data buffering, re-formatting and programmability make them ideal as interfaces to telecommunication networks. Note however, that electrical compatibility, data compatibility and data rate compatibility must exist to ensure that a plotter will work with a particular system. If a telecommunication protocol is used, it must also be supported by the controller.

Plotters equipped with any but the most rudimentary control are called smart because they do much of the computation that would otherwise have to be performed by the computer generating the plot data. Typical smart plotter features include:

-vector generation,
-circular arc generation,
-linear interpolation,
-circular interpolation,
-data scaling,
-compressed plot data,
-telecommunication protocol support.

Electrostatic Plotters

Electrostatic plotters can produce drawings at a rate of up to 100 times faster than electromechanical plotters but at the expense of quality. Electrostatic plotter reliability is also much better because of its simpler mechanical design. They are very serviceable and quick to repair. Finally, the versatility of these plotters, their ability to function as CRT hard-copy units while doubling as high-speed printers with printing rates as high as 2000 lines per minute, make them an ideal choice for installations that need both high-speed graphics and large volumes of printed output.

The actual plot is performed in a raster format by a head which comprises a number of wire styli spaced from 100 to 200 to the inch. One axis of deflection is provided by moving the paper while the other is provided by depression of the styli to place a dot on the paper according to the information presented as the trace is scanned. This technique affects the appearance of the image and requires completely different hardware and software than is used with pen plotters.

Conventional computer graphics is generated in a pen-plotter- compatible vector format, that is as a series of line segment start and end coordinates. This data, 10 to 100 times more compact than raster data, must be transformed into raster data before it can be plotted, requiring a substantial amount of computer time. This can impact overall CAD/CAM system performance as well as plotter throughput. Typical conversions of mechanical drawings may take five minutes to one hour of conversion time. Thus, when additional time is taken into account for conversion when computing throughput rates, the electrostatic plotter's speed advantages vis-a-vis the pen plotter drops off to about 5:1, still an impressive improvement.

From the telecommunications standpoint, raster and compressed transmissions are more costly than vector transmission because there are many more of them to transmit. This does not apply when dedicated data lines are used.

Today, electrostatic plotter accuracy is quite limited. Another drawback of the plotters is that they are restricted to rolled or Z-folded electrographic paper, which is not as dimensionally stable as film or triacetate and has a shorter storage life. The electrostatic plotter is also more expensive than pen plotters, and if the cost of the additional on-line computation for vector-to-raster conversion is considered, the price is even higher.

While electrostatic plotters draw only in one color, they make up for this limitation by using as many as 25 different shading patterns to highlight areas or distinguish one type of one from another. This shading technique is actually considered an advantage by some users.

Where throughput is the primary selection criterion, an electrostatic plotter is the natural choice because of the vastly superior cost per unit of throughput that can be realized.

Photoplotters

Photoplotters are very high-precision, incremental, digital plotters mainly used by CAD/CAM systems for the production of PC artwork masters. They are very similar to flatbed plotters but have a laser-light beam projector in place of a pen with which to expose photosensitive materials.

Computer Output Microfilm (COM) Systems

COM Systems are used to produce graphics and printed page microfilm directly from a CAD/CAM system's digital plot and print files. The systems are characterized by high throughput, high quality, and flexibility, and are particulary effective when compared to other less direct methods of producing microfilm such as photographing printed or plotted hard copy. In fact, when high-volume production is involved, COM systems are the only reasonable approach.

COM systems may be on-line devices, but generally receive digital plot data and print files manually by magnetic tape. Options include telecommunications and plotter interfaces. Most systems need an operator to monitor their operation closely, are relatively high-priced, and provide adequate accuracy and resolution.

A typical COM system consists of a minicomputer controller, a reformatting unit and a microfilm recorder. The reformatter is usually a general purpose minicomputer or microprocessor equipped with a tape deck. The formatter reads the digital data from the magnetic tape, converts this data into the form required by the microfilm recorder unit, then transfers it to the recorder at the proper rate. The recorder unit consists of a high-precision CRT, a microfilm camera, and associated electronic and electromechanical controls.

APPENDIX E

CONFIGURATIONS OF GRAPHICS PROCESSORS

The advantages of general purpose minicomputers:

- minicomputer manufacturers are larger than CAD/CAM manufacturers, hence they generally have better R & D, manufacturing, and testing facilities.

- minicomputers are members of a family of compatible products, allowing upgrading at a later time.

- a great deal of CAD/CAM and business software is available for general-purpose minis.

- maintenance and spare parts are generally more available.

- The resale market for a general-purpose machine is larger and more broadly based.

The special-purpose processor has the following advantages:

- It has all of the instructions of the general-purpose minicomputer from which it was derived as well as all those features that were missing from the mini.

- It can be optimized fro graphics applications and so provide better performance.

- Since the CAD/CAM system supplier built the machine, he is better qualified to service it. This also eliminates questions of responsibility for services.

There is currently a trend among manufacturers toward the larger minicomputers and in some cases midicomputers and mainframes. This trend will likely get stronger as the cost of these more powerful machines continues to decrease, and the capability and computational requirements of CAD/CAM systems increase.

APPENDIX E

FEATURES OF CAD/CAM SYSTEM PROCESSORS

-Microprogramming capability: This means that the processor is itself implemented as a small special-purpose computer. This computer consists of a limited function processor and a control store containing a microprogram for fetching, decoding and executing the program instruction set of the main processor. This scheme allows the addition of micro-code to the instructions in the control store, thereby enabling the computer to be tailored to particular applications. This scheme also provides additional diagnostic tools for hardware and software problems.

-Floating-point hardware: This refers to special-purpose hardware that performs floating-point arithmetic at a much higher speed than is possible with software. The capability may be due to an extended microprogram in a microprogrammmed computer, or may be an entirely separate processor that operates in parallel with the main processor. Because of the large volume of floating-point arithmetic required for graphics manipulations and creations, these units are especially important in CAD/CAM applications.

-Main memory: Minicomputers are available which have a memory size of from 64K words to large memories of up to a million words. Larger 32-bit minis and midicomputers are designed to support more than two million words of main storage. There are basically two types of memory used in minicomputers:

-Magnetic core memory: Relatively slow with the advantage that it retains its data form any weeks without electrical power.

-Solid state memory: Considerably faster than core but it is more expensive and requires power to retain the data within.

-Battery backup (optional): These units preserve the contents of a solid state memory during a power failure.

-Memory mapping: This is a scheme which makes it possible for a computer to access additional amounts of main memory while providing protection to data access. The mapping mechanism results in significant overall gains in throughput.

-Virtual memory: A scheme that simplifies the writing of large programs by making it appear to the user that the computer has a large memory when it in fact does not. It is implemented using special memory mapping hardware and disk storage.

-Cache memory: A small high-speed memory used to store frequently accessed portions of main memory. Typically, a computer equipped with a cache will need to refer to main memory less than 30% of the time, thereby gaining a substantial speed advantage.

-Parity memory: Enhances system integrity and allows the system to detect and locate memory errors.

-Error correcting codes: Another scheme to check and correct memory bit errors, resulting in a prolonged effective mean time between failures.

-Memory interleaving: A feature which tends to speed up the effective memory access rate.

-Multi-port memory: also serves to speed up the effective memory access time by allowing some data transfer operations to proceed in parallel.

APPENDIX G

FACILITIES PROVIDED BY CAD/CAM SOFTWARE

Basic input facilities

-Actions
- -set scale
- -insert
- -delete
- -trim
- -join

-specification of indicated position location as indicated

-coordinates
- -cartesian
- -polar
- -spherical
- -cylindrical

-relative to existing elements
- -parallel
- -perpendicular
- -tangential
- -at a specified angle
- -on a surface
- -at the origin
- -at the center
- -at the end
- -at an intersection

-specification of distance
- -in scale units
- -between specified points

-specification of direction
- -with unit vectors
- -clockwise, counterclockwise
- -up, down, left, right

Basic facilities for computing derivative geometries:

-group actions
- -insert
- -delete
- -resize
- -copy

- move
- rotate
- mirror
- stretch

-specification of geometric groupings
- create an array
- create a group

-pre-defined groups
- crosshatch

-interactive linkage to the display and digitizer

- specification of location relative to the indicated position
- relative to existing elements
- specification of distance
- specification of direction
- specification of geometric groupings

Facilities for entry of associated non-graphical data are also provided. Examples of such data include notes, labels, dimensions and formatted texts. These facilities also provide for the creation of various classes of data elements associated with geometric groups that can later be identified and processed by other software to create summary reports such as bills-of-material, cost analyses, and parts-utilization analyses.

Facilities for the entry of "semi-graphics"

-specification of actions
- insert
- delete

-semi-graphic data types
- spatially located text
- dimensioning entities
- line types

-facilities for associating semi-graphics or text data
- associative groupings

-facilities for creating derivative semi-graphics
- numeric text variables
- alphabetic text variables
- automatic scaling of text
- automatic orientation of text
- macro language link to graphics analysis functions

Display Facilities

-display capabilities
- -view definition
- -line weights

-display control
- -simultaneous displays
- -display of motion
- -dynamic view control
- -scale control
- -echo
- -selective display control

-interactive linkages
- -number of active views
- -type of active views
- -restrict model edit

Data Management Functions

-definition and edit functions
- -create
- -modify
- -delete

-access functions
- -store
- -fetch

-control functions
- -transfer off-line
- -transfer on-line

-housekeeping
- -manual
- -directory listings
- -space utilization summary

Typical Basic Analysis Functions

-verify functions
-calculator functions
-point coordinates
-angles
-axis
-2-D section analysis of closed figures

Software Enhancements for CAD/CAM

1. Extended graphics and graphics analysis: Provides the user with additional graphical building blocks and some additonal functions with which to analyze graphics.

   -additional building blocks: Generally 2- and 3-D compound entities that increase the user's ability to create curved shapes.

   Curves:
   -splines
   -offset splines
   -space curves
   -composite curves
   -draft curves
   -freehand curves
   -surface intersection curves
   -surface edge curves

   Surfaces:
   -ruled surfaces
   -developable surfaces
   -warped surfaces
   -tabulated cylinders
   -composite surfaces
   -fillet surfaces
   -curved meshes
   -surfaces of revolution
   -offest surfaces

   -additional analysis capabilities:

   -extract perimeters
   -extract volumes
   -extract centroids
   -extract moments of area
   -extract radii of gyration
   -spline analysis

2. Extended semi-graphics and non-graphic entry: Gives the user additional tools with which to produce engineering documentation.

   -extended drafting functions
   -standard dimensioning
   -metric conversion
   -extended drafting facilities
   -automatic perspective views
   -manual perspective views

   -extended text/graphics functions
   -text extract (for summary reports)

- text linkage
- text to graphics transfer
- text sort/merge
- bills-of-material

3. User programming support:

    - language support options:
        - macros
        - special-purpose language compilers
        - programming interfaces
        - data management extensions

4. System interface and management support

    - management support options:
        - security features
        - documentation control systems
        - system audit and usage accounting software

    - system interface software:
        - communications and network support
        - device interface support

APPENDIX H

TRADE JOURNALS AND PROFESSIONAL ORGANIZATIONS DEALING WITH CAD/CAM

JOURNALS

CAD/CAM ALERT
Reservoir Executive Park
824 Bolyston Street
Chestnut Hill, MA 02167
(617) 232-8080

Monthly user news and information service: CAD/CAM hardware, software, and system reviews; user case studies; tips on feasibility studes, applications studies, implementation planning, measuring productivity, and quality circles.

COMPUTERS IN MECHANICAL ENGINEERING
The Computer Engineering Division, ASME
United Engineering Center
345 E. 47th St.
New York, NY 10017
Published quarterly

COMPUTER AIDED DESIGN
A. Pipes, Managing Ed.
IPC Science and Technology Press Ltd.
32 High Street
Guildford, Surrey, England GU1 3EW
Published bimonthly

CAD/CAM DIGEST
P.O. Box 8100
Dallas, Texas 75205

ENGINEERING GRAPHICS
226 Pasqual Ave.
Ventura, CA 93003

COMPUTER GRAPHICS
P.O. Box 10922
Eugene, Oregon, 97440

COMPUTER GRAPHICS & IMAGE PROCESSING
A. Rosenfeld, et al., Eds.
Academic Press
New York, NY
Published monthly

SOFTWARE--PRACTICE AND EXPERIENCE
D. Barron, et al., Eds.
Wiley & Sons
Baffins Lane
Chichester, Sussex, UK
Published monthly

IBM SYSTEMS JOURNAL
C.A. Thiel, Ed.
International Business Corporation
Armonk
New York, NY 10504
Published quarterly

PROCEEDINGS OF THE SOCIETY FOR INFORMATION DISPLAY
S. Sherr, Ed.
Society for Information display
654 North Sepulveda
Los Angeles, CA 90049

COMPUTER GRAPHICS, A QUARTERLY REPORT OF SIGGRAPH-ACM
(See below)

COMPUTERS & GRAPHICS,
Pergamon Press, Inc.,
Maxwell House, Fairview Park
Elmsford, NY 10523
Published quarterly

Other journals that often contain articles relevant to CAD

ACM Transactions on Graphics Computer Graphics Forum
Computer Graphics Software News
Simulation
Engineering
Machine Design
Engineering Materials and Design

PROFESSIONAL SOCIETIES

Computer Aided Manufacturing-Internationl, Inc. (CAM-I)
611 Ryan Plaza Dr.
Suite 1107
Arlington, TX 76011

American Institute of Design and Drafting (AIDD)
3119 Price Road
Bartlesville, OK 74003

National Computer Graphics Association (NCGA)
2033 M St. N.W., Suite 330
Washington DC 20001

Society for Information Displays (SID)
654 North Sepulveda Blvd.
Los Angeles, CA 90049

ACM/SIGGRAPH
1133 Avenue of the Americas
New York, NY 10036

Society for Computer Simulation
1010 Pearl st.
P.O. Box 2228
La Jolla, CA 92038

Design & Drafting Management Council (DDMC)
P.O. Box 11811
Santa Ana, CA 92711

American Engineering Model Society (AEMS)
400 Commonwealth Dr.
Warrendale, PA 15096

Numerical Control Society (NCS)
519 Zenith Drive
Glenview, IL 60025

SERVICE ORGANIZATIONS

General Electric-CAE International Inc.
300 TechneCenter Drive
Milford, OH 45150
(513) 576-3800

General Electric-CAE-in-Plastics offers software which will save time and costs in virtually every phase of a plastic part development-from product design through manufacturing. Software tools, discussed in the text, include MOLDFLOW, MCAP, and TMC. In addition to software availability, GE-CAE offers a full range of services to support plastics technology. Key among these are: a strong education program, walkin access to computers at CAE Productivity Centers, located around the world, complete mold design and manufacture, and consulting expertise. The staff stands ready to offer assistance in the areas of software training and awareness, problem solving, and technical consulting.The company also offers computer timesharing services.

APPENDIX I

COMPARISON OF CAD/CAM AND PROCESS CONTROL (74)

Attribute	Process Control	CAD/CAM
Computer implemented	yes	yes
Real Time system	yes	yes
Embedded System	yes	yes
Sensor based inputs	Main source for input in system	Minor portion of input
Input of human origin	Minor portion of input	Major source of input
Expanding database	No	Yes
Process Control	Major purpose is feedback or feed forward control in classic sense. Major process units included within these loops; process gains and dynamics important.	Orientation is more towards the mere handling, timing, release, etc. of large volumes of information.
Output interfaces	Set point stations, valves, etc.	Plotters, machine tools, wiring machines, flame cutters, robotics, automatic test equipment.
Predominant user industries	Chemical, petroleum, steel, pulp and paper	Discrete parts manufactring (transportation equipment, machinery, etc.
Socio-economic impact	Modest	Much larger
Main period of pioneering	1960-1975	1975-1990

APPENDIX J

TRAINING RESOURCES AVAILABLE IN THE U.S. AND CANADA

UNIVERSITY OF AKRON
College of Engineering
Akron, OH 44325
(216) 375-7817

Facilities:
HW: Calcomp 30" plotter
Tektronix 4015 interactive graphics terminal

The university is in the process of implementing a comprehensive CAD system. Planned for installations is a Prime 850 Processor with MEDUSA software and 20 to 30 terminals with a plotter, printer, and disc access.

The course work structure for CG and CAD in Mechanical Design are only in the planning stage at present.

UNIVERSITY OF ALABAMA-HUNTSVILLE
Dept. of Industrial and Systems Engineering
Huntsville, Alabama 35899

CAM facilities:
HW: T**3 Robot
Minirobots
Machine tools
Fisher Technic kits

The university is now in the development phase for a CAD lab for Undergraduates.

Courses: The university is developing two courses which will examine advanced manufacturing systems concepts and will include material on robotics, NC, CNC, Computer-Aided Process Planning, etc.

UNIVERSITY OF ALABAMA-UNIVERSITY
Dept. of Engineering Mechanics
University, Alabama 35486
(205) 348-7241

Facilities: The University Seebeck Computer system is a UNIVAC 1100/61 with about 70 interactive terminals, including at least 3 Tektronix storage tube terminals and 2 digital plotters.

The Interactive Computer Graphics Laboratory:

HW: HP-1000A minicomputer system running under the RTE-A.1 real time, multiuser operating system that supports a powerful editor, db management, high level languages, and device independent graphics.
- Tektronix hardcopy device
- Disk storage system
- Ramtek 6210 Color Graphics Terminal
- 4 interactive terminals
- HP-2623 raster scan-serves as the system console
- HP-2671F thermal printer attached to the above.
- TEK 4015 storage tube terminal
- Victor 9000 raster scan microcomputer (stand alone computer or intelligent terminal)
- Ramtek 6210 intelligent terminal
- Large digital plotter
- Printer
- Victor 9000 microcomputer system which is interfaced to the HP-1000A (intelligent CG workstation)
- Apple II microcomputer

SW: FORTRAN 77, and Graphics/1000-II Device Independent Graphics Library.

Courses, Undergraduate: Many courses involve CAD activities, e.g, Dynamic Systems, in which digital simulation is used in parameter selection of dynamic systems. Many other examples of this kind exist.

-Computer Graphics: Basic course at senior/1st year graduate level.
-Artificial Intelligence
-Design of Automated Systems: Intro to robotics and CAM

Courses, Graduate:

-Numerical Modeling of Fluid Systems
-Engineering Optimization

UNIVERSITY OF ALASKA
School of Engineering
Fairbanks, AK 99701

Facilities: In rudimentary stages at the present time.

HW: Honeywell 66 main frame computer with graphics capability

CNC milling machine

Individual departments are attempting to develop their own stand-alone systems built around micro-computers.

UNIVERSITY OF ARKANSAS
Department of Mechanical Engineering & Engineering Science
Fayetteville, AR 72701

Facilities:
HW: 23 Pets microcomputers
25 TI 99/4A microcomputers
10 digitizer boards, light pens, and graphics pkgs.
4 4052 Tektronix terminals
1 4015 Tektronix terminals

Courses:

-Computer-Aided Mechanical Design: Introduction to microcomputers, remote terminal usage, APL, and JCL. Design of mechanical systems by means of procedure-oriented and simulation languages. Applications programs and interactive graphics.

Two other courses are being developed.

BOSTON UNIVERSITY
College of Engineering
110 Cummington street
Boston, Ma 02215

Courses:

-Computer Geometry and Design: A user-oriented project class in the application of computer modeling, CAD, CG, data definition, and animation techniques. Typical projects include: polyhedra and geodesic dome calculation and construction as well as definition and drawing management of a large graphics data base such as a model of the Campus.

-Computer-Aided Design: Use of the computer to facilitate and extend the design process. CG. Production of engineering drawings. Selected problems in geometry, topololy, finite element methods, and pattern recognition. Applications from several engineering disciplines.

-Computer Graphics: Techniques for computing, representing, and displaying 2- and 3-D objects. Topics include: 2- and 3-D transformations, symmetry, data reconstruction, surface modelling, and realistic imaging.

BRADLEY UNIVERSITY
College of Engineering and Technol.
Dept. of Manufacturing
Peoria, IL 61625

Facilities:
HW: University CYBER 171 System (with proposed upgrade to 174 configuration).

SW: TIPS-1, AUTAP, CAPP.

The Manufacturing Dept. proposes to expand its activities and facilities, including the acquisition and implementation of advanced CAD/CAM software, with appropriate facilities for instruction and research in modern design, graphical communications and CAM.

UNIVERSITY OF BRITISH COLUMBIA
2356 Main Mall
Vancouver, B.C., CAN V6T 1W5

Facilities:
HW: Amdahl V8, MTS
Several graphics terminals
Digitizing table

Courses, Undergraduate:

-Introduction to Computer Graphics: Introduction, Input/Ouput Devices for CG, Hardware Architectures of Interactive Graphics Systems, Software Architectures of Graphics Programming Systems, Machine Languages for Graphics Systems, the VGM Subprogram System, Mathematical and Algorithmic Aspects of CG, High-level Graphics Languages.

Courses, Graduate:

-Follow-up Computer Graphics course.

UNIVERSITY OF CALIFORNIA, LOS ANGELES
Graduate Studies Office
School of Engineering & Applied Science
Los Angeles, CA 90024
(213) 825-2212

Facilities: The CAD/CAM Laboratory: Directed by Prof. M. Melkanoff, provides students with the opportunity to learn computer-aided drafting, CAD, and CAM. It is structured around the use of CADAM, available on-line through IBM 2250 and 3250 consoles connected to the University's IBM 3033 central computers, utilized through 12 terminals. Soon, the CAD lab will be expanded with several new 3-D CAD/CAM systems. The university is also planning a new NC laboratory where students will be able to cut parts that they designed using the CAD systems.

Courses, Undergraduate:

-Fundamentals of CAD/CAM : Topics include an intro to CG, components of CAD/CAM systems, computer representations of 2- and 3-D objects, a survey of available systems, and field trips.

-CAD Lab: Teaches the use of the CADAM system to design and draw objects.

Courses, Graduate:

-Advanced Graduate course in CAD will include the use of Finite element Methods for stuctural analysis of CADAM designed parts.

-Advanced course in CAM will include numerical tool control, manufacturing process planning and manufacturing data processing.

Research in CAD/CAM: Includes the design and implementation of CAD/CAM databases; analysis of CAD languages; automation of manufacturing process planning; modeling of rigid solid objects, machines and processes; and applications of CAD/CAM to mechanical parts and VLSI.

UNIVERSITY OF CENTRAL FLORIDA
Dept. of Mechanical Engineering & Aerospace Sciences
Orlando, Florida 32816
(305) 275-2416

Facilities: College of Engineering CAD Laboratory:
HW: 9 Tektronix 4051 Series Graphics microprocessor-based minicomputers

Courses, Undergraduate:

-Computer-Aided Design: Intro to computational methods in mechanical and thermal systems design.

Courses, Graduate:

-Computer-Aided Design: Theory, application and implementation of digital computer oriented algorithms for the synthesis, simulation, analysis, and design of mechanical systems.

CLEMSON UNIVERSITY
Dept. of Mechanical Engineering
Clemson, SC 29631
(8Ø3) 656-347Ø

Facilities:

HW: Tektronix graphics terminals
Hard copy units
Large drum plotter
Large Versatec printer-plotter
3-axis CNC milling machine

2 VAX-11/78Ø systems are currently being installed. They will be primarily devoted to CAD and research activities. One system will have extensive interactive graphics capabilities.

SW: Comprehensive system of utility software.

Courses: Several engineering graphics courses are presently devoted to CG:

-Engineering Design Graphics: Graphical analysis as a means for evaluating a design. Units of study include descriptive and vector geometry, graphical statistics, and CG.

-Computer-Aided Graphics: The use of automated graphic devices and systems for the digitizing, plotting, and display of engineering drawings. Upon completion, the student should be proficient in preparing and storing software such as that used in conjunction with the IBM 37Ø and Calcomp plotter.

-Computer-Aided Design Graphics: Continuation of the above with emphasis on sculptured surfaces. The process involves translation from designer notes, to animated drawing, to testing model, and finally to a 3-D computer display. The student will learn how to apply the theory of CAD graphics to the solution of product design problems.

-Computer-Aided Process Planning-Graphics: Introduces the student to the computer-aided processes used in an A & E office. It is designed to be compatible with current industrial practices, equipment, and procedures to produce construction drawings.

A number of courses are also taught in the College of Engineering that include elements of CAD, and several courses totally devoted to CAD are under development.

Courses, Continuing Education:

-Computer Aided Graphics, 2 day workshop
-Computer Aided Design, 2 days
-Applications for Industrial Process Control, 5 days
-Computer Communication Networks, 2 days

COLORADO STATE UNIVERSITY
College of Engineering
Center for Computer Assisted Engineering
Fort Collins, CO 80523
(303) 491-7708

Facilities:
The Center for Computer Assisted Engineering:
HW: DEC VAX 11/780
VT125 graphics terminals
6 Evans & Sutherland PS-300 Workstations
System has direct access to a CDC 205 Vector computer for number crunching problems.

Courses, Undergraduate:

-CAD/CAM course for juniors: Introduction to 2- and 3-D CAD with use of all equipment in the Center for Computer Assited Engineering. Mechanical Engineering seniors can use NC machines for milling and lathe operations. A robotic welding machine is also on order.

Course, Graduate: Planned for next academic year.

COLUMBIA UNIVERSITY
School of Engineering & Applied Science
New York, NY 10027

This university is currently planning a CG facility and two or three courses. Detailed information will not be available until early 1983.

CORNELL UNIVERSITY
College of Engineering
Campus Road
Ithaca, NY 14853

Facilities: The CAD Instructional Facility:

HW: DEC VAX-11/780 CPU
Distributed Processing system of 3-11/44 peripheral controllers.
6 Evans & Sutherland picture systems
6 Grinnell frame buffers, color raster
6 Tektroniz 4014 storage tubes
Each of the 18 user stations is provided w/ a digitizing tablet and pen, and an alphanumeric editing and command-system terminal.
4 disk drives & tape drive for mass storage
3 printers
Plotter

UNIVERSITY OF DELAWARE
Newark, DE 19711

Facilities: Computer-Aided Engineering Laboratory

HW: DEC VAX-11/780
Printer/Plotter
Evans & Sutherland Multi-Picture System
2 Monochrome picture stations with alphanumeric keyboards, data tablets, control dials, and joysticks.
Hewlett Packard bed plotter
DEC VT-100 alphanumeric terminal
3 Hewlett Packard 2648A graphics terminals
2 Hewlett Packard 2621A alphanumeric terminals
5 Zenith alphanumeric terminals (faculty offices)

SW: VAX/VMS operating system
FORTRAN 77 compiler

Software to be acquired will include packages for: FEA, Vibration analysis, Geometric modeling, Machine element design, Mechanism analysis and design, Design optimization, Simulation of lumped parameter systems, simulation of continuous systems.

DELTA COLLEGE
University Center, MI 48710
(517) 686-9000

Facilities: Delta College has reached a contractual agreement with a local industry to offer CAD to ME and Design Technology students.
HW (off campus): 5 Terminals, McAuto System.

Training: 15 hours of classroom instruction by a faculty member & training at the terminals by an industry engineer. Training is initially concentrated on drafting.

Courses, Undergraduate: One course planned. Advanced courses will be offered in the future in stress analysis.

UNIVERSITY OF DETROIT CAD/CAM CENTER
Mechanical Engr. Dept.
4001 W. McNichols Road
Detroit, MI 48221
(313) 927-1243

Facilities:

HW: Computervision CGOS 200 Graphics Processor
Disc Storage
Magnetic Tape Drive
Calcomp 960 Plotter
2 Raster Display terminals w/hard copy units

SW: Mechanical Design & Drafting; Plant Design & Documentation; Numerical Control; FEM; Group Technology; Process Planning

DUTCHESS COMMUNITY COLLEGE
State University of New York
Pendell Road
Poughkeepsie, NY 12601

The college is planning to integrate CAD/CAM into the Electromechanical Technology curriculum and to arrange some usage of CG terminals through a local industrial facility. The system will be CADAM. Present facility is "meager and somewhat outdated".

UNIVERSITY OF EVANSVILLE
School of Engineering & Applied Science
P.O. Box 329
Evansville, Indiana 47702

Facilities: The university is in the process of installing an engineering-oriented CG system based on a DEC PDP 11 processor and 10 GIGI terminals. Plans call for a later expansion of the system, which will be in conjunction with the University of Missouri-Rolla School of Engineering. (See below).

FLORIDA INSTITUTE OF TECHNOLOGY
Mechanical Engineering Dept.
Melbourne, FL 32901

Facilities: A limited-budget microcomputer-based CAD system:

HW: Commodore 8032 computer w/ MTU graphics board.
3 complete workstations (computer, dual floppy disk drive, tablet, plotter, and printer).
Commodore 2022 printer
X-Y enterprises 80-Z Drum Plotter
Houston Instruments 'HI PAD' digitizer pad

SW: Micro-CAD (written by the faculty)
MTU graphics software (machine language)

It should be noted that the faculty does not claim that a microcomputer-based CAD system can effectively replace the larger mainframe systems in capability of speed, but it is still effective in teaching students the basic principles and techniques involved in the use of larger CAD systems. The high cost ($100 -500K) of available turnkey CAD systems makes it extremely difficult for universities to utilize them in the quantities needed to properly train students in their use. "The basic assumption is that one does not have to own a Cadillac to learn to drive an automobile."

Courses, Undergraduate:

-Computer Aided design: Projects-oriented course in which students are to conceive a design for a realistic object and then complete six projects using CAD to present their design.

-Computer Aided Mechanical Design: Study and development of techniques for application in industrial CAD laboratories, including plotting routines for FEM grids or complex gear shapes, etc., and graphic simulation of dynamic mechanisms including multibar linkages, slider-crank mechanisms, and others. Utility routines to support 2- and 3-D graphic displays.

FOX VALLEY TECHNICAL INSTITUTE
1825 N. Bluemound Drive
P. O. Box 2277

Appleton, WI 54913
(414) 735-5777

Facilities: Institute is in the process of requesting bids for 10 Apple II Microcomputers to be used in the Design/Drafting department.

Courses: Anticipate being able to offer a basic course in March, 1983.

GEORGE WASHINGTON UNIVERSITY
School of Engineering and Applied Science
Washington, D.C. 20052
(202) 676-6158

Facilities: Center for Academic and Administrative Computing
HW: IBM CPU (OS/VSI)
PDP 11 minicomputer for terminal-based text-editing

SW: Full range of compilers and application software packages

Courses, Undergraduate:

-Computer-aided Design
-Application of Computer Graphics in Engineering
-Numerical Methods in Engineering

Courses, Graduate: Master of Science and Professional degrees are offered in Computer-Aided Design. NASA-Langley's Research Center in Hampton, Va., which includes extensive scientific and engineering facilities and equipment is utilized whenever feasible.

-Algorithmic Methods and High-level Languages
-Introduction to Computer Systems
-Computer Programming
-Discrete Sturctures in Computing
-Data Structures
-Interactive Computer Graphics
-Management Information systems and data Base Management
-Computer-Aided Design
-Application of Computer Graphics in Engineering
-Finite Element Methods in Engineering Mechanics
-Advanced Finite Element Methods in Structural Mechanics

UNIVERSITY OF HOUSTON
Houston, TX 77004

Courses, Undergraduate:

-Applications of Mechanical Engineering: Designed to train seniors in the use of analystical, experimental and computational techniques for solving problems. Incorporates 5 weeks of lectures, 8 weeks of project work, and 2 weeks of wrap-up lectures. Subject matter includes: Design environment, Decision analysis, Model relevant to design synthesis, Principles of solution, and Communication.

HOWARD UNIVERSITY
School of Engineering
Washington, D.C. 20059
(202) 636-6565

Facilities: The Computer Learning and Design Center will soon have CAD/CAM capabilities.

Courses: Electives in Computer Science in which CAD/CAM is a major topic are offered in all engineering disciplines.

ILLINOIS CENTRAL COLLEGE
Mechanical & Industrial Technologies Dept.
Community College District No. 514
East Peoria, IL 61635
(309) 694-5011

Facilities: A limited CG facility consisting of:
HW: Tektronix 4014
Small Tektronix Plotter
DEC PDP-11/60 (using Plot 10 Software)

A CAM system consisting of:
HW: Bridgeport CNC milling machine
Numeridex tape preparation equipment.

IOWA STATE UNIVERSITY
College of Engineering
Ames, Iowa 50011

Facilities:
HW: DEC VAX computer
Tektronix 4051 terminals
Graphics retrofitted ADMs
Tektronix 4014
Digitizing tablet
Several 4631 Tektronix plotters
Flat bed plotter

Course, Undergraduate:

-Computer Graphics

Research: Quite a number of MS and PhD candidates throughout the Engineering College are, or will be engaged in preparation of software for use in design.

UNIVERSITY OF IOWA
Iowa City, Iowa 52242

Facilities: Computer-Aided Engineering Instructional Laboratory.

HW:
- Tekronix 4027 color graphics terminal
- 10 HP 2648A B/W graphics terminals
- Tektronix 4012 storage tube terminal
- 8 Alphanumeric terminals
- Printronix P-300 line printer
- HP 7221T 8-color pen
- Advent Projection System
- Radio Shack TRS 80 Model II Microcomputers

HW on order:
- HP 2648A graphics terminal
- HP 2631G graphics printer/plotter
- HP 9111 digitizing tablet

SW: GCS, MOVIE-BYU, FREFORM, IGAP, ICAL, GIFTS, SPAR, SAPIV, NASTRAN
Specialized software programs for use in particular courses.

Courses, Undergraduate:

-Principles of Design I: Introduces optimization techniques to junior-level students. It is heavily CAD oriented.
-Dynamic Analysis of Structures
-Finite Element Techniques I
-Structural Design III
-Computer-Aided Design I
-Kinematics of Mechanisms

Courses, Graduate:

-Applied Optimal Design
-Computational Methods in Dynamics
-Computer-Aided Design II
-Finite Element Techniques II

KANSAS STATE UNIVERSITY
Manhattan, Kansas 66506
(913) 532-5580

The College of Engineering is in the process of evaluating CAD hardware and software for purchase and use. No courses are available at present, but at least one is hoped to be developed in the next year.

LAKESHORE TECHNICAL INSTITUTE
1290 North Avenue
Cleveland, WI 53015

Facilities:
HW: Textronix 4052 Graphics terminal

Courses, Undergraduate:

-Introduction to Computer Graphics: Utilizes the Apple II Computer and graphics tablet along with software that has been developed to simulate the Computervision CAD system.

Courses: Continuing Education:
-Introduction to Computer Graphics

LEHIGH UNIVERSITY
CAD/CAM Program
267 Packard Lab 19
Bethlehem, PA 18015
(215) 861-4114

Facilities:
HW: 3 minicomputers
20 graphics terminals
A variety of peripherals such as printers & plotters.

Coupling CAD and CAM is the objective of the Lehigh educational program. The university uses the equipment in virtually all courses throughout the curricula of the Mechanical and Industrial Engineering departments, thus making the experience available to a broad number of individuals. Although the current program has a decidely undergraduate bias, graduate student research is also encouraged. A growing number of short courses and seminars are also being offered by the faculty to people from industry.

Courses, Undergraduate: The use of the CAD and CAM laboratories is taught throughout undergraduate courses in mechanical drawing, vibrations, strength of materials, manufacturing processes, and others.

-2 CAD/CAM courses for seniors are taught each year.

Courses, Graduate: None at present.

LOUISIANA STATE UNIVERSITY
Mechanical Engineering Dept.
Baton Rouge, Louisiana 70803
(504) 388-5792

Facilities: Computer Graphics Research and Application Laboratory (CGRAL):
Central Laboratory:
HW: DEC, PDP 11/40 Minicomputer
DEC, PDP 11/45 Minicomputer
2 IMLAC PDS4 Refresh Display Minicomputers
CENT. 101A Line Printer
DEC LA 36 Hard Copy Terminal
DEC VT52 CRT Terminal
TEK 4014 (Enhanced graphics) and 4010 Storage Graphics Terminals
TEK 4631 Hard copy unit
TEK 4953 Digitizer
Alphanumeric CRT
Modems
IMSAI 80/15 Microcomputer system

Research Laboratory:
HW: IMSAI 8080 Microporcessor Development system
LEAR SIGLER ADM3 Alphanumeric CRT terminal
Modem
TEKTRONIX 4956 Digitizer
TEK 8002A Microprocessor Development System.

Software Development and Presentations Laboratory:
HW: DEC 11/23 Network Computer
DEC LA38 Console Terminal
3 TEK 4010 Storage graphics Terminals
Modem
2 DEC 11/23 Graphics Systems

A recent NSF grant has provided funds for the inception of an undergraduate CAD laboratory to create an enhanced learning environment for design students. 3 microprocessors and 3 graphics display terminals will serve as the nucleus of this laboratory network.

Courses, Undergraduate: Two courses, one in CG and one in CAD are taught at the senior/beginning graduate student level. Students are exposed to highly interactive computing involving refresh graphics through 2 or 3 programming assignments through the campus computer center and the CGRAL minicomputers.

Courses, Graduate:

-Advanced course in CG explores the more mathematical elements of the area. Complex geometry modeling and the efficent transformation of such data is one focus of study.

-A course in advanced concepts in CAD. The effective use of interactive computing and minimization schemes in solving multiparameter design problems receives much attention in the course.

-A course addresses modern digital and analog instrumentation and computer interfacing.

Research: Original research is conducted at this institution with the central theme being the man-computer interface, based on the goal of making the computer a natural extension of the designer/user's mind. The problems involved span hardware and software considerations, and systems and applications questions. The areas of investigation include:

-Visual man-machine communication
-Audio man-machine communication
-resource networking
-Interactive device design
-Design analysis and synthesis aids

UNIVERSITY OF LOUISVILLE
Speed Scientific School
Louisville, Kentucky 40292

Facilities:
HW: PDP 11/34
10 DEC GIGI graphics terminals
2 Tektronix 4051 interactive graphics systems
2 Tektronix 4006 graphics terminals
2 Tektronix 4631 hardcopy units
Tektronix 4663 flat-bed plotter
Tektronix file manager
DEC MINC systems with hard copy and graphics terminal.

SW: A variety of software packages related to design and analysis of mechanical devices and systems.

Courses:

- Intro. to Computer Graphics
- Finite Elements for Mechanical Design
- Computer Simulation of Dynamic Systems
- Modal Representation of Mechanical Vibrations

UNIVERSITY OF LOWELL
Dept. of Mechanical Engineering
Lowell, MA Ø1854
(617) 453-3797

Facilities: Computer Aided Engineering Center:
HW: Applicon Turnkey CAD/CAM System with a workstation which includes a CRT, keyboard, function menu, tablet, and stylus
HP Structural Dynamic Analyzer
DEC VAX 11/78Ø
2 MINC laboratory data acquisition systems

The university expects to have a new Computervision Designer V turnkey system (includes 3 fully equipped workstations and a Calcomp plotter) on-line within the next year.

Course, Undergraduate:

- Computer Aided Design: Course designed for junior/senior level mechanical engineering students to introduce CAD/CAM technology and present in-depth training in computer-aided drafting.

- Computer Aided Design Lab: Intense hands-on use of university's Computer Aided Engineering Center, with the emphasis on computer aided drafting.

LOYOLA MARYMOUNT UNIVERSITY
College of Science & Engineering
Loyola Boulevard at West 8Øth St.
Los Angeles, CA 9ØØ45
(213) 642-2833

Facilities: The university is in the process of establishing a CG laboratory utilizing Apple II microcomputers.

Courses: No mechanical CAD/CAM training is available at present.

LYCOMING COLLEGE
Williamsport, PA 17701

Facilities:
HW: Houston Insturments DMP-7 Plotter
Apple Graphics tablet
Sanyo color monitor
IDS 560G printer.
PDP 11/70 processor (under RSTS/E with local processing & communications handled by an Apple II Plus with 2 disk drives.

A Computer Graphics Laboratory for use by Faculty and advanced undergraduate students is presently in the planning stages.

MACALESTER COLLEGE
1600 Grand Avenue
Saint Paul, Minn., 55105
(612) 696-6000

The college is planning an undergraduate course in general computer graphics.

UNIVERSITY OF MANITOBA
Faculty of Engineering
Winnipeg, Manitoba, CAN R3T 2N2

Facilities:
HW: 18 Apple II Microcomputers (graphics capability)
3 printers
6 Microcomputers
2 Minicomputers

Courses, Undergraduate:

-Graphics: Approximately 4 weeks of the freshman graphics course is devoted to CG.

MARQUETTE UNIVERSITY
Milwaukee, WI

Facilities: Computer Services Division:

HW: Honeywell/Xerox Sigma 9 (with a full complement of peripherals and software including: standard languages such as APL, PASCAL, FORTRAN, COBOL, BASIC, RPG.; and applications package including MANAGE, TXT, SPSS, IMSL, various graphics routines.

VAX-11/780 (used for time-sharing and program development)

Courses, Undergraduate:

-Computer Graphics: Introduction to CG involving considerable actual CG experience. Topics include: history and motivation for CG; point-plotting and line-drawing techniques; techniques used by commercially available graphics displays; 2- and 3-D graphics; clipping and windowing; graphics I/O devices; considerations in interactive graphics and future trends.

-Topics in Computer Systems Engineering: Topics include: utilization and control of computers which are integrated into systems, design of interfaces, application to digital logic elements; conversion systems; control of processes and/or tools; data acquisition and display. Offered occasionally.

MCNEESE STATE UNIVERSITY
Department of Engineering
Lake Charles, Lousiana, 70609

This University is just getting into CAD, purchasing the following equipment:

HW:
- 4 Color Graphics Terminals
- 2 Interfaces
- 4 Graphics tablets
- 4 Disc/Controllers
- Interactive Digital Plotter
- Video Hard Copy Unit

SW:
- Device drivers
- Character & Symbol Fonts
- Panel Routines
- Smoothing Routines
- 3-D Routines
- Cluster Controller
- Tektronix 4970

MICHIGAN STATE UNIVERSITY
College of Engineering
East Lansing, MI 48824

Facilities: CASE Center for Computer-Aided Design. Established in 1978 for teaching and research in design and manufacuring practice aided by computers and interactive graphical display, the Center provides the following facilities:

HW: PRIME 750 Computer
2 Disk Drives
Tape Drive
4 Modems
5 Zenith Z-19 terminals
13 Tektronix 4006 terminals
Tektronix 4014 and 4027 Color terminal
Advent 110A Projection System
Tektronix 4954 Digitizer
Tektronix 4631 Hard Copy Unit
Printronix Printer
GenRad 2507 Structural Analysis System
Hewlett-Packard 5423A Structural Dynamics Analyzer
Hewlett-Packard 7245A Digital Plotter
PCB Hammer Kit K291A

SW: The International Mathematical subroutine Library and the following programs: MOVIE.BYU (BYU), DRAM (MDI), SUPERTAB (SDRC), MODAL (SDRC), ANSYS (SWANSON), PLOT 10 (TEKTRONIX) IGL (TEKTRONIX), GIFTS (U OF ARIZONA).

Courses, Undergraduate: Two programs available are the CAD/CAM option in Mechanical Engineering and the CAUSE project sponsored by the National Science Foundation. The CAD/CAM option is a set of coordinated technical elective courses which stress the use of modern CAD/CAM software packages in engineering design and manufacturing methods. Some direct programming experience with graphics is included but not emphasized. Courses include:

-Computer-Aided Manufacturing: Numerical control, APT.
-Computer-Aided Design I: Basics of interactive graphics; line fitting and surface development; FEA
-Computer-Aided Design II: Empirical methods for modal analysis.
-Theory of Matrices: Theory and application of matrices.
-Interactive Computer Graphics: Graphics Systems: graphics languages.
-Independent study: Permits the student to use CAD/CAM under faculty supervision in a variety of interest areas.

Courses, Graduate: The graduate program encourages a deeper level of understanding of CAD/CAM methods, including more mathematical sophistication and an enhanced ability to exploit current software in complex applications. In mechanical engineering, the master's program in CAD/CAM is primarily project-oriented and requires a thesis. A research program (M.S. and Ph.D.) is also an option. Because the Center has close ties with an Industrial Advisory Board, much of the research is oriented toward industrial problems. Representatives from industry serve on Ph.D. commitees.

MICHIGAN TECHNOLOGICAL UNIVERSITY
College of Engineering
Houghton, MI 49931
(906) 487-2292, 2005

Facilities: Microcomputer Based Graphics System:

HW:
- Cromemco Z-2D Microcomputer with a micromodem to the UNIVAC 1100/80 main frame computer.
- Cromemco HDD
- Hewlett Packard color plotter
- Houston Instruments HI PAD digitizing tablet
- Cromemco joy-stick
- 2 Cromemco 3102 terminals
- Anadex 9501 Printer w/ graphics
- Slow scan video sampler
- Cromemco SDI color graphics interface with 2 port frame buffers
- Lenco encoder
- Lenco video distribution amplifiers
- Sony video cassette recorder
- Inflight Services Inc. V-Star 4 large screen projector
- Digital graphics Monitor/Receiver
- Barco high resolution color monitor

Graphics Laboratory:

HW:
- IBM 4341 Main Processor and Storage (running CADAM software package) which is interfaced with the university Univac 1100/80 for CAD/CAM
- IBM 3277 w/ graphics attach Tektronix 618 Monitors, hardcopy unit, and digitizer
- 2 IBM Timesharing computers
- 2 IBM 3350 Disks
- 3 Tektronix 4014 terminals
- 2 IBM 3410 Tape Drives
- 11 Versatec 1200 plotters
- 24 Versatec 8224 plotters
- 4 IBM 3251 display workstations
- 3 Adage CS 4250 Display workstations

SW: The university also uses several design and analysis packages from Structural Dynamics Research Corp.

Courses: Mechanical CAD/CAM instruction is available at the undergraduate and graduate levels. The student is exposed to and/or has hands-on experience with CAD/CAM throughout many of the mechanical courses.

Courses, Undergraduate:

-Numerical Control of Manufacturing Processes: Uses CADAM and other Application Software.
-Special Topics in Design-CAD/CAM
-Design Project I, II, III: Uses CADAM

UNIVERSITY OF MICHIGAN-ANN ARBOR
Ann Arbor, MI 48109

The school has been awarded a $3.4 M research contract by the U.S. Air Force for its new Center for Robotics and Integrated Manufacturing. Work conducted under the grant will be basic research, principally in the areas of robotics and information management.

MIDDLE TENNESSEE STATE UNIVERSITY
Dept. of Industrial Studies
Murfreesboro, Tennessee 37132
(615) 898-2776

Facilities:
HW: NC Bridgeport milling machine
2 Olivetti 6060 minicomputers for CAM

The Computer Technology program equipment includes:
HW: Intelligence System minicomputer
Hewlett Packard plotter
Hytachi Digitizer

The university has intentions to develop some capability in the CAD/CAM area.

Courses: No specific CAD/CAM courses (presently in planning). At present the above equipment is merely supplementing normal equipment for classes.

MISSISSIPPI STATE UNIVERSITY
Dept. of Engineering Graphics
P. O. Drawer EG
Mississippi State, Mississippi 39762
(601) 325-3922

Facilities:
HW: Tektronix 4006-1 terminal
Calcomp 1039 drum plotter
Calcomp electrostatic plotter

Courses, Undergraduate:

-Computer Aided Design & Drafting: Uses a FORTRAN-based language (DRAWL, from the Universtiy of Michigan) which does not require previous computing experience. Students are taught to code points in 3-D coordinate space and to develop those coded points into parts and assemblies.

UNIVERSITY OF MISSISSIPPI
School of Engineering
University, Mississippi 38677
(601) 232-7219

Facilities: The university is in the process of acquiring:
HW: Several mini and microcomputers including HP, Tektronix, IBM, etc. Several Smart and Dumb terminals with graphics capabilities
Several plotters

Courses, Undergraduate:

-Some courses are offered such as machine design, automated control, independent design projects, etc. in the area of CAD.

UNIVERSITY OF MISSOURI-ROLLA
School of Engineering
Rolla, Missouri 65401
(314) 341-4151

Facilities:
HW: IBM 4341 host computer
24 Tektronix 4014 terminals with data tablets, hardcopy output
Calcomp pen plotter

University is currently doubling the CG capability.

SW: The university is using a software based on that developed by IPAD.

Courses: 2 courses incorporate CG and 2 courses treat CAD/CAM and robotics. Several other courses utilize interactive computer-aided analysis and design tools as an integral part.

UNIVERSITY OF NEBRASKA-LINCOLN
175 Nebraska Hall
Lincoln, NE 68588
(402) 472-3495

Facilities: Starting with the second semester of the 82/83 year:
HW: DEC VAX 11/780 computer system
24 workstations

Courses: Curricular development in CAD/CAM is still in its infancy. There is presently one three-course sequence that starts with an introduction to CAM, introcution to group technology, and control theory; and a course in automation dealing with the various elements of an automated factory.

UNIVERSITY OF NEW HAMPSHIRE
College of Engineering and Physical Sciences
Durham, New Hampshire 03824
(603) 862-3778

Facilities:
HW: AED 512 Color Graphics Device
Grinell Color Graphics Device
GT 46 Random Scan Refresh Device
Many Retrographics Terminals
Many Teletronix terminals

Courses, Undergraduate: Special topics courses at the advanced undergraduate level in Mechanical Engineering and Computer Science.

NEW MEXICO STATE UNIVERSITY
College of Engineering
Las Cruces, NM 88003

Facilities: Laboratories emphasizing CG and CAD in Mechancial Engineering, Industrial Engineering, Electrical Engineering, and Engineering Technology.

Courses: In the stages, fully operational in about one year.

UNIVERSITY OF NEW ORLEANS
P. O. BOX 1098
New Orleans, LA 70148
(504) 286-7180

Facilities: CAD Lab:

HW:
- Tektronix 4113 Intelligent color terminal
- 4 Tektronix 4052 desk top computers
- 2 Tektronix 4110 storage tube terminals
- Several Heath-Zenith VDT's
- Disk drives, plotters, hard copiers, printers, and a digitizer.
- Supported by the Computer Research Center mainframes: DEC 10 and VAX 11/780.

SW:
- IGL from Tektronix
- PADL (U. of Rochester)
- DINAS (Germanischer Lloyd)
- SHCP (U. S. Navy).

Courses, Undergraduate:

-Computer-Aided Geometric Design: Course covers solid modeling, theory and practice.

Courses, Graduate (being developed):

-Curved Surface Design and Analysis: Will teach methods of designing engineering surfaces such as the shells of ships, aircraft, automobiles, and hydraulic conduits. It will include applications of differential geometry to engineering surfaces.

NORTH DAKOTA STATE SCHOOL OF SCIENCE
Wahpeton, ND 58075
(701) 671-1130

Facilities: The school is acquiring a Tektronix Graphics Computing Systems stand-alone micro-processor, Model 4054A and some peripheral hardware, which will be utilized for computer-aided drafting tasks.

Courses: Classes in CAD will be offerred this Spring, 1983.

UNIVERSITY OF NORTH DAKOTA
Department of Correspondence Study
Box 8277, University Station
Grand Forks, ND 58202

Courses:

-Engineering Grpahics
-Descriptive Geometry

NORTHEASTERN UNIVERSITY
College of Engineering
360 Huntington Avenue
Boston, MA 02115

Facilities:
HW: Computervision Designer V Systems
3 Instaview Workstations including CRT's, tablets & pens, and image control units
Plotter

SW: CADDSIV software package (202A level.

Courses, Undergraduate:

-Computer Aided Design: Course topics include graphics concepts and systems, geometry and vector algebra, CAD applications, CAM and Programming.

Courses, Continuing Education:

-Introduction to CAD/CAM Technology: This course is aimed at engineers and manufacturing managers, designers, drafting supervisors, and others desiring an introduction to emerging CAD/CAM technology. Topics include a survey of available hardware and software for various applications, feasibility determination, system selection, the role of management implementation, and system evaluation. The features of particular turnkey systems are highlighted by guest lecturers. A design session on an actual CAD/CAM system is also scheduled during the course.

-Interactive Computer Graphics: This course addresses the objectives, techniques, and problems of interactive graphics and affords participants an opportunity to acquire a greater appreciation of the options inherent in designing and using graphics systems. Interactive I/O devices, algorithms, data structures, and display devices are considered.

TECHNICAL UNIVERSITY OF NOVA SCOTIA
Dept. of Computer Services
P. O. Box 1000
Halifax, Nova Scotia, Can B3J 2X4

Courses, Undergraduate and Graduate:

-Introduction to Computer Graphics
-CAD/CAM Systems in Engineering Analysis and Design
-Finite Element Method

Services: The University offers to industry the following services:

-Finite element programs
-Computer graphics support
-CAD/CAM system evaluation and selection.
-CAD/CAM Laboratory based on Control Data Corporation's Integrated Computer-Aided Engineering and Manufacture (ICEM) system

OHIO STATE UNIVERSITY
Dept. of Mechanical Engineering
Columbus, OH 43210

Facilities: Advanced Design Methods Laboratory

HW: Fully expanded and optioned DEC PDP 11/60 minicomputer w/ dual RK06 disk drives under the RSX-11M operating system.
Communications line which connects the 11/60 to the University's Amdahl 470/V6 main frame.
Microprocessor controller connected to the 11/60 for data acquisition
DEC LA36 and VT52 terminals
4 Tektronix 4014-1 terminals (enhanced graphics)
3 HP 2648A grpahics terminals
HP 2647A intelligent graphics terminal
Printronix 300 printer/plotters
2 30" X 40" TEK 4954 graphics tablets

SW: The laboratory has an agreement with SDRC to utilize a number of its software products which include: 3-D mode shape animation display & graphics tablet data input routines for FEM, Tektronix TCS, Advanced Graphing II, Graphics Tablet Utilities, IGL programs, and some locally generated programs

Courses, Undergraduate: The main thrust of the teaching program is to provide all mechanical engineering undergraduates with an exposure to interactive CG and FEM techniques primarily at the junior and senior level.

Optional courses which concentrate on computer-based engineering methods form the basis of the CAD technical option program. Some topics of the program include:

-use of micro and minicomputers in conjunction with mainframe computers for solving design and analysis problems
-display technologies
-FEM and beam-type computer modeling programs
-computer-based analytic models
-commercially available software
-real-time computer acquisition of experimental data

Undergraduates taking the CAD technical option will study the following areas in addition to those listed above.

-assembly-level computer programming
-internal hardware workings of graphics systems
-static and dynamic finite-element programming
-computer-aided manufacturing
-computer design optimization and reliability analysis techniques

Courses, Graduate: Graduates taking the special CAD program will be equipped in the following areas in addition to those listed above for undergraduates:

-in depth knowledge of advanced FEM techniques
-experience doing research in a specific CAD area
-practice in using FEM techniques in complex design situations

Research: Deals with long-range problems associated with the CAD/CAM process. Conducted in concert with a sponsoring company or a consortium of industries. Also deals with creating a common resevoir of knowledge about CAD/CAM hardware, software, and resources.

OWENS TECHNICAL COLLEGE
Toledo, OH

This college has spent more than $.5M equipping its new machine shop lab to teach CNC, EDM, and similar advanced machining methods. Owens has another $860K earmarked for equipment to teach CAD/CAM & robotics.

UNIVERSITY OF PENNSYLVANIA
Computer and Information Science
Philadelphia, Pennsylvania 19104
9215) 898-5862

Facilities:

HW: Tektronix 4010 storage tube display
Ramtek GX-100B color raster display
Vector General 3404 high performance interactive vector display

SW: 2- and 3-D drawing packages
Polygon manipulation system
Curved surface design program
Image processing system.

Courses, Graduate:

-Computer Graphics: Basics of CG, including drawing and display hardware, graphics software, graphic data structures and representations, interactive techniques, and algorithms for the display of 2- and 3-D objects. Augmented by substantial programming and user experience with the graphics devices and software. Topics include: Graphics hardware and systems, 2- and 3-D graphic data in various representation systems, graphic transformations, display techniques, graphic standards, visible surface algorithms, shading, color, interactive techniques, graphic languages, animation techniques, and image processing. Case studies, examples, and displays from actual systems are an integral part of the course.

POLYTECHNIC INSTITUTE OF NEW YORK
333 Jay Street
Brooklyn, NY 11201

Facilities:
Computer Center:

HW: IBM 360/365 main frame computer
9 disk drives
4 magnetic tape drives
2 card readers
2 printers

Farmingdale campus facility:

HW: Data 100-Model 74 remote batch terminal connected to the IBM via a high-speed communications line.
Printer and card-reader

Brooklyn campus

HW: DEC PDP 11/70 computer running PWB/UNIX, for time-sharing

Minicomputer laboratory:
HW: Various minicomputers and individual small computers used on specific research and/or laboratory work.

Courses, Undergraduate:

-Computer Methods in Design: Introduction to the computer as a design tool. Discussion of visual displays, drawing and design capability of modern computing systems. Iteration, parametric studies and optimization of mechanical designs. Studies and projects. Efficient numerical computational techniques.

Courses, Graduate:

-Computer Graphics and Image Processing: Problems in CG. Display components and algorithms, data structures, classical graphics, image detection, and processing techniques.

-Interactive Computer Graphics: Analysis and synthesis of graphical information. Discussion of display devices, graphical data structures, graphic languages, transformations. Interactive techniques, characteristics of interactive input devices. Manipulation of 2-D forms. 3-D graphics, hidden lines and surfaces, perspective, shading.

PORTLAND STATE UNIVERSITY
Dept. of Mechanical Engineering
P. O. Box 751
Portland, OR 97207
(503) 229-4290

Facilities:
HW: 2 Tektronix 4051's
1 Tektronix 4052
3 Apple II Computers
Associated printers, hardcopy unit, and DECwriter
Honeywell 66-20 mainframe computer.

Courses, Undergraduate & Graduate:

-Computer-Aided Design: Instructs students to synthesize analytics, computer programming, code development, and use of computer-oriented design tools. The course has two objectives: (1) introduction to the use of modern computers and graphics sytems, and (2) experience with the development, implementation, and application of computer software as a tool in the design process. Course includes intodoctory lectures, graphics lab projects, and term projects in software development.

PURDUE UNIVERSITY
The Computer Integrated Design Manufacturing
and Automation Center
West Lafayette, IN

Facilities: The university has entered a cooperative venture with 5 corporations to create the Computer-Integrated Design, Manufacturing and Automation Center on campus. Joining Purdue are Cincinnati Milacron Inc., Contol Data Corp., Cummins Engine Co. Inc., Ransburg Corp., and TRW Inc.

CADLAB (Computer Aided Design and Graphics Laboratory):

HW:
- CDC Cyber 170-720 computer with 4 disk drives, 2 magnetic tape units, a network processing unit, a line printer, and alphanumeric terminals.
- DEC PDP-11/40 minicomputer
- 2 Imlac programmable refresh display minicomputers
- Megatek 7000 3-D refresh display
- Ramtek 9351 color raster display
- Ramtek 9400 color raster display
- 3 Evans and Sutherland 3-D refresh vector displays
- Versatec 1200A electrostatic printer/plotter
- Tektronix 4014 storage tube terminals
- Calcomp 502 flatbed plotter (microprocessor controlled)
- Microprocessors
- Various digital and analog I/O devices for graphical interaction and data acquisition.

The Robotics And Automation Laboratory: provides for a number of robots and sensors interfaced directly to a dedicated VAX 11/780 computer. The laboratory supports development of robot programming languages, control algorithms, and sensor development.

The manufacturing laboratory consists of several robots, material handling devices and a machining center.

SW: In addition to the standard system software (NOS), many industrial application programs will run on the CYBER system, including:

AD2000 (drafting and NC), UNISTRUC (finite element pre-and post-processor), SYNTHAVISION & ROMULUS (geometric modelers), MOVIE.BYU (color display of 3D data), SAP4 (FEA), TIGS (graphics package), UNIPLOT (graphics package), IMP (integrated mechanisms package)

Courses, Undergraduate and Graduate:

-Interactive Computer Graphics
-several special project courses

Research: The CIDMAC is an organization which was established to conduct an interdisciplinary study of design and manufacturing to significantly increase industrial manufacturing productivity. The goal is to integrate the traditionally disjoint research areas of CAD, CAM, robotics, automation, group technology, and simulation of product processes, and management techniques for production management. It is a cooperative venture organized by the university and industrially and federally sponsored. Research areas of the organization include:

CAD: Integrated CAD/CAM Database Systems; Design, Analysis, and Graphics;
CAM: Manufacturing Processes;
Manufacturing Modeling and Simulation;
Robotics and Automation: Sensor Controlled Robots;
Industrial Robot Design.

UNIVERSITY OF REGINA
Faculty of Engineering
Regina, Canada S4S ØA2
(3Ø6) 584-4Ø43

Facilities: limited facilities
HW: IMLAC PDSID refresh graphics system
CROMEMCO Z26H color refresh graphics system
TEK 4ØØØ Series refresh graphics system

Courses, Undergraduate (1985, tentative):

-Computer Aided Design and Manufacture: computerized design aids, design languages, design verification, simulation and testing, control system fundamentals as applied to NC machining systems. Specification, design, implementation and documentation of a design system.

RENSSELAER POLYTECHNIC INSTITUTE
Interactive Computer Graphics Center

Troy, NY 12181

Facilities: Center for Interactive Computer Graphics
HW: 36 Imlac DYNAGRAPHIC 6220 vector refresh terminals with light pens
2 PRIME 500 computers.
Link to the IBM 3033 central campus computer
Card reader
Line printer
7 alphnumeric terminals
Versatec 1200 A electrostic printer/plotter

Graphics Research Laboratories with ADAGE, DEC, and IDI equipment

SW: DOREDI, SPAR, SAP, IMP, PADL, ORACLS

UNIVERSITY OF ROCHESTER
Dept. of Mechanical engineering
Rochester, NY 14627
(716) 275-4072

Facilities:
HW: 2 VAX 11/780 computers
30 Color graphics terminals
2 B & L Producer CAd workstations

SW: NASTRAN & EASE2 FEM programs
PATRANG FEM modeling program
PADL1 & PADL2 solid modeling program

Courses, Undergraduate and Graduate:

-Mechanical Design
-Finite elements
-Computational Geometry

Courses, Graduate:

-Programmable Machining Systems
-Advanced Geometric Modeling
-CAD of Distributed Parameter Systems
-VLSI systems

RUTGERS STATE UNIVERSITY
College of Engineering
P.O. Box 909
Piscataway, NJ 08854
(201) 932-2214

Facilities:
HW: PRIME 750
IBM 370
VAX 11/780

SW: MEDUSA system for the Prime Computer
General Purpose Graphics software such as CA1-Comp., Tektronix Easygraphing and IGL, and the NCAR package.

Courses: CAD is a normal part of the ME curriculum. CAM instruction is not available.

SOUTH DAKOTA SCHOOL OF MINES AND TECHNOLOGY
Rapid City, South dakota 57701
(605) 394-2256

Facilities: Control Data CD2000 CAD/CAM graphics package.

Courses: Training in the application of CAD is provided through a number of CAD packages available on campus and incorporated throughout the intructional program.

UNIVERSITY OF TENNESSEE
Mechanical & Aerospace Engineering
Knoxville, TN 37996

Facilities: Proposal is pending for 8 microcomputers and associated hardware for CAD applictions.

The college is committed to expansion of programs in CAD/CAM. Presently, students are exposed to the theory of CAD and will be required to develop and document specialized computer codes for the design of mechanical components.

UNIVERSITY OF TULSA
College of Engineering and Physical Science
600 South College Ave.
Tulsa, Oklahoma 74104
(918) 592-6000

Courses, Undergraduate:

-Engineering Computer Graphics: The use of the digital computer (3 Apple II Plus microcomputers, an Apple graphics tablet, and an Epson printer-plotter) for the generation of visual displays. Principles of graphic representation and engineering drawing. applications in automatic graph plotting and creation of 2- and 3-D representations.

UNITED STATES AIR FORCE ACADEMY
Colorado, 80840

Facilities:
HW: VAX 11/780 Minicomputer
11 TERAK color terminals
8 TERAK B & W terminals
2 Summagraphic Digitizers

SW: MOVIE.BYU for 2- and 3-D Pictures
GIFTS 5 for Strucutral Analysis with Graphics
TCORE Graphics Package for incorporation of graphics into other software.

The academy has had very limited CAD/CAM implementation to this point. The Dept. of Engineering Mechanics has used the facilities to help optimize designs accomplished as part of an aircraft structural design course. There are plans for further implementation in the future.

UNITED STATES NAVAL ACADEMY
Aerospace Engineering Department
Annapolis, MD 21402

Facilities: Computer Aided Design/Interactive Graphics (CADIG):
HW: Hard wire lines to the Academy's Honeywell 6060 Timesharing system.
40 Tektronix 4051 graphics systems with communications interface
2 Tektronix 4054 graphics systems with refresh capability
2 Tektronix 4052 graphics systems
20 Tektronix hard copy units
20 Tektronix data tablets
2 Tektronix 4014 graphics terminals
Tektronix 4016 graphics terminal
2 Tektronix digitizers
4 Tektronix 4907 floppy disc units
15 Spintronix terminals
3 Centronix remote printers
Evans & Sutherland Picture System I w/ tablet, function keyboard & alphanumeric keyboard
DEC PDP-11/45 w/ disk drive, dual tape drive, paper tape punch, line printer, magnetic tape drive, communication interfaces
DEC PDP-11/34 w/ cartridge disk unit, 2 floppy disk units, communication interface

Large screen video projection system
Various data acquisition system
Xynetics Model 1200 Flat Bed Plotter
Autonumerics/Bridgeport NC milling machine
Autonumerics/Bridgeport NC lathe
Pratt & Whitney Trimac XV NC Machining Center

SW: All of the programs and software have been written by students, faculty or the CADIG staff of the Engineering & Weapons Divition. In order to support this effort, a device independent graphics system called DIGS has been implemented in both BASIC and FORTRAN. Applications include standard engineering plots, computer aided ship hull design, aircraft stability and control, fluid dynamics, kinematics of mechnisms, wind tunnel testing, flight simulation, etc.

Courses:

-Kinematics of Mechanisms with Computer Graphics: Topics: CG hardware and software, 2-D and 3-D transformations, 2-D curves, loop equations, kinematic motion curves, geometric properties.

-Computer Graphics, Computer Aided Deisgn, Computer Aided Manufacturing: Topics include CG hardware and software technology, 2-D and 3-D transformations, techniques for refresh display, 2-D curves-conics, basic mathematics for circles & lines in NC, NC/APT Programming, 3-D curves, 3-D surfaces.

VANDERBILT UNIVERSITY
Mechanical Engineering & Mat'l science
Nashville, TN 37235
(615) 322-2781

Facilities: Computer Aided Engineering Facility:
HW: DEC PDP 11/34 computer
Disk drive
Magnetic tape unit
5 video terminals
3 DECwriter hard-copy terminals
Tektronix graphics terminal
Tektronix x-y plotter
Additional terminals in the library

The Department also utilizes 2 PDP 11/03 laboratory compters for research and teaching.

SW: A limited software library is presently available. Efforts are under way to increase it.

Courses, Undergraduate and Graduate: None exclusively devoted to CAD or CAM; approach is to integrate CAD/CAM concepts into existing courses such as kinematics, machine design, and graduate courses in design.

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
College of Engineering
Blacksburg, VA 24061

Facilities: The Engineering Design Laboratory
HW: DEC VAX 11/780 w/VAX/VMS operating system, dedicated to student CAD use.
Will eventually include approx. 25 work stations
14 Lear-Siegler terminals with Digital Engineering's Retro-Graphics boards for Tektronix 4010 emulation.
Tektronix 4010, 4112, and 4114 terminals
5 DEC GIGI terminals
DEC DECwriter IV graphic printer
Versatec V-80 printer/plotter

SW: VAX-11 BASIC & FORTRAN, AD2000, SPAR, RIM, ISL, ANSYS, SUPERTAB, SUPERB, IMP, ASCL, MIP, RECSYN, MESS, MOVIE.BYU

Courses, Undergraduate: The Mechanical Engineering Department intends to provide CAD insturction and experience for all ME students in several required courses. Each student will spend approximately 5 hours per week for each course at computer terminals on outside-of-class assignments. The emphasis will be on applying CAD techniques to enhance engineering design, not on computer hardware or the development of software. It is expected that every student graduating from the ME department will have a working knowledge of the following:

-Computer-aided modeling & simulation techniques for the design of dynamic mechnical systems, -Basic data preparation techniques for FEA and the use of such analysis packages, -The use of graphics software and the generation of programs employing graphics for interpreting experimental and analytical data, -The use of computer-aided techniques for design optimization.

Courses, Graduate: University has CAD components in various graduate level courses, and will pursue thesis and dissertation research in CAD or CAD-related areas.

WASHINGTON STATE UNIVERSITY
Dept. of Mechanical Engineering
Pullman, Washington 99164

Facilities:
HW: PRIME 400 Mincomputer
Tektronix terminals
Plotter

SW: Graphics Compatibility System on an Amdahl mainframe computer.

The university has a grant arrangement with the Boeing Company to use their computer system:

SW: Automatic Program Tools (APT) for plotter graphics & NC tape preparation.

Courses, Undergraduate:

-CAD: Introduces the student to the fundamentals of CG, mathematics of CG, and application software related to the CAD area. The software includes CAD mechanical design programs, dynamic simulation programs, finite element computer codes, and special purpose statistical packages.

-CAM: Introduces the student to the control problems relevant to the computerized manufacturing system. It incorporates fundamental control theory, digital infterface considerations, and software requirements for computerized control. (Laboratory work will be included in the future.)

WICHITA STATE UNIVERSITY
College of Engineering
Wichita, KS 67208

Facilities:
HW: IBM mainframe computer
6 Tektroniz terminals

The university is developing a proposal to acquire a full capacity CAD/CAM system with 4 - 8 workstations.

Courses, Undergraduate:

-Engineering graphics: Topics include projective geometry and dimensioning conventions used on engineering drawings.

-Another graphics course covers vector analysis, computer graphics, and design projects. The CG component comprises 1/3 - 2/3 of the course. Presently, the students enter data describing design in card form to the mainframe. They view it on a graphics terminal connected to the mainframe. The students use the terminals interactively to dimension the drawings. Hard copies are also available.

WORCESTER POLYTECHNIC INSTITUTE
Worcester, MA 01609

Facilities:
HW: Several Apple II microcomputer systems
DEC-20
PDP 11/40
Computervision Graphics Design System

Courses, Undergraduate:

-Engineering Design Graphics: Multiview and pctorial graphics techniques, standards for dimensioning, sectioning.
-Engineering Applications of Computer Graphics: application of CG fundamentals. Heavily project oriented. Modern CG systems.
-Introduction to Mini/Microcomputers
-Introduction to Stress Analysis
-Applied Graphical Design: Application of graphics techniques to practical mechanical problems. Introductory CAD applications.
-Descriptive Geometry: Representation and solution of engineering problems by graphical methods.
-Computer Aided Manufacturing: Monitoring, controlling, and optimizing manufacturing processes.
-Computer Methods of Mechanics: The solution of sophisticated mechanics using the digital computer.

APPENDIX K

RELEVANT LITERATURE RESOURCES

BOOKS

1982 Directory of CAD/CAM Systems and Vendors

Directory lists 44 companies selling interactive CAD/CAM systems. Contains over 11,000 items of information about systems and vendors. Useful to prospective users, marketing executives, sales representatives, consultants, product designers and others needing a CAD/CAM reference source. Each vendor listing includes a financial profile, sales figures, market share, a list of key executives and a services profile that details each company's field service, customer support and other resources for end users.

Author: Foundyller, Charles M.
Source: Daratech Assoc.
Cambridge, MA

Turnkey CAD/CAM Computer Graphics: A Survey and Buyer's Guide for Manufacturers

A comprehensive tutorial guide that explains ready-to-use interactive CAD/CAM systems in clear terms. Written specifically for mechnical design and manufacturing users, there are sections on systems and components to explain what they do and how they work, different technologies and approaches used by various vendors, the significance of each feature and its impact on performance. Extensively indexed and organized for easy reference.

Author: Foundyller, Charles M.
Source: Daratech Associates
P.O. Box 410
Cambridge, MA 02238

International Book Standard Number: ISBN 0-938484-00-1

A Survey of Commercial Turnkey CAD/CAM Systems, 2nd Ed.

Sourcebook for information on CAD/CAM turnkey system vendors, their systems' capabilities, the important questions to ask when evaluating alternative systems for particular requirements; software vendors and their systems.

Source: Productivity International, Inc.
P.O. Box 8100
5622 Dyer Street
Dallas, Texas 75205
(213) 739-3506

The Guide for the Evaluation and Implementation of CAD/CAM Systems

An exhaustive guide for an organized, efficient evaluation of CAD/CAM systems and recommendations for implementation.

Author: Chasen, S.H. and Dow, J.W.
Source: CAD/CAM Decisions

The Complete CAD/CAM Anthology

Source book containing 160 pages of articles taken from 50 journals, magazines, and proceedings-plus a definitive graphics glossary.

Editor: Orr, Dr. Joel N.
Source: CAD/CAM Alert
Resevoir Executive Park
824 Bolyston Street
Chestnut Hill, MA 02167
(617) 232-8080

Principles of Interactive Computer Graphics, 2nd Ed., 1979

Author: Newman, W.M. and Sproull, R.F.
Source: McGraw-Hill
New York, NY

ISBN 0-07-046338-7

Interactive Computer Graphics: Data Structures, Algorithms, Languages, 1978

Author: Giloi, W.K.
Source: PrEntice-Hall
Englewood Cliffs, NJ

ISBN 0-13-469189-X

The S. Klein Directory of Computer Graphics Suppliers, Hardware Software Systems and Services, 1982-83 Ed.

Editor: Klein, S.
Source: 27-730 Boston Post Road
Sudbury MA 01776

ARTICLES

For information on CAD data by itself, see a classic set of papers presented in 1976:

-Ciampi, P. L. et al., "Control and Integration of a CAD Data Base", Proc. of the 13th Design Automation Conference, (1976), pp. 285-289.

-Ciampi, P. L. et al., "Concepts in CAD Data Base Structures", Proc. of the 13th Design Automation Conference, (1976), pp. 290-294.

For information on the development of integrated CAD systems and their desired features, as well as their advantages over stand alone programs:

-Biji, A. et al. Integrated CAAD Systems. EdCAAD Studies, Final Report prepared for DOE, March, 1979.

Information on the Hardware, software, and process knowledge and control developments of the inception period of real time computer control of industrial processes:

-Savas, E. S. Computer Control of Industrial Processes. McGraw Hill Book Company 1965.

-Scrimgeour, J. H. C., "Computer Control of Complex Plants", Canadian Chemical Engineering Conference, Sarnia, Oct. 1970.

-Smith, C. L., "Digital Control of Industrial Processes", Computer Surveys, A. C. M. Vol. 2, No. 3. Sept. 1970

Concerning Raster Scan Graphics:

-Newman, W. M., "Raster-Scan Graphics in CAD," CAD Systems, by Allan, J. J., 3rd Ed., (North Holland, 1977), pp. 369-377.

-Newman, W. M. and Sproull, R. F. Principles of Interactive Computer Graphics. (New York:

McGraw-Hill, 2nd Ed., 1979).

Concerning the techniques and details of software design methodologies, including key references:

-Myers, G. J., Software Reliability: Principles and Practicesl (Wiley, 1976).

Concerning geometrical modeling systems for the description of mechanical solids. These systems use a set of primitive elements which can be manipulated in 2- and 3-space to produce relatively complicated assemblies for analyses:

-Braid, I. C. A New Shape Design System. CAD Group Document No. 89, Computer Laboratory, Cambridge University, 1976.

-Braid, I. C. Designing with Volumes. Ph.D. Thesis, Cambridge Univ., England, 1974.

-Voelcker, H. B. et al., An Introduction to PADL, Publication TM-22 Production Automation Project. University of Rochester, 1973.

-Voelcker, H. et al, "The PADL-1.0/2 System for Defining and Dsiplaying Solid Objects," Proc. of SIGGRAPH '78, Aug. 1978, ACM.

-Baer, A., Eastman, C., and Henrion, M., "A Survey of Geometric Modelling," Institute of Physical Planning Report No. 66, Carnegie-Mellon Univ., Pittsburg, 1978.

-Braid, I.C. "New Directions in Geometric Modeling," Proc. of the Workshop of Geometric Modeling, CAM-I Inc., Arlington, Texas, 1978.

Concerning the representation of curves and surfaces for the description of solids; methods of approximation and interpolation:

-Coons, S.A., "Surface for Computer Aided Design of Spaces, Forms, MAC-TR-41, Project MAC, MIT (1967).

-Bezier, P., Numerical Control--Mathematics and Applications. (London: J. Wiley, 1972).

-Barnhill, R. E. and Riesenfeld, R. F. Computer-Aided Geometric Design. (New York: Academic Press, 1974).

BIOGRAPHICAL SKETCH OF THE AUTHOR

Julliette M. Carignan was born in 1958 in Lowell, Massachusettes, and attended Lowell High School, graduating with honors in 1975. She was later certified in Plastics Technology by the Lexington Minuteman Regional Technical School. She received her Bachelor of Science Degree, cum laude, from The University of Lowell in 1980, with a double major in Biological Science and Art. While studying for her Master of Science degree in Plastics Engineering, also at the University of Lowell, she was employed as a Composites Development Engineer by the Army Materials and Mechanics Research Center in Watertown, Massachusetts.

In May 1982, she received a Student Paper Award from the Society of Plastics Engineers (SPE) for her publication: "CAD: Introduction to an Exciting Tool for the Plastics Designer", which she delivered in San Francisco at the 40th Annual Technical Conference of the SPE.

She is embarking on a career in industrial project engineering with Parker Brothers in Beverly, Massachusetts. She anticipates using her plastics, art and design skills in the toy company's product development department, where she will be continuing her study of, and training in Computer Aided Design Systems as design tools.

She is a member of the University of Lowell's Student Chapters of the Society of Plastics Engineers, the Society of Women Engineers, and the American Society of Mechanical Engineers.