Computer-aided Drawing and Design

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Preface

This book is intended for engineers, computer scientists, managers and all those concerned with computer graphics, computer-aided design and computer-aided manufacture. While it is primarily intended for students, lecturers and teachers, it will also appeal to those practising in industry. Its emphasis on applications will make it easier for those not currently concerned with computers to understand the basic concepts of computer-aided graphics and design.

In a previous text (*Engineering Drawing and Computer Graphics*), two of the authors introduced the basic principles of engineering drawing and showed how these were related to the fundamentals of computer graphics. In this new text, the authors attempt to give a basic understanding of the principles of computer graphics and to show how these affect the process of engineering drawing. This text therefore assumes that the reader already has a basic knowledge of engineering drawing, and aims to help develop that understanding through the medium of computer graphics and by the use of a number of computer graphics exercises. The text starts by giving an overview of the basics of hardware and software for CAD and then shows how these principles are applied, in practice, in the use of a number of graphics packages of different levels of complexity. The use of a graphical database and the implications for computer-aided design and manufacture are also discussed.

This book is unique in its applications approach to computer graphics. It gives sufficient detail to explain the fundamentals of the computer graphics hardware and software, without adopting the usual computer specialist approach that can confuse a newcomer to this area. The book assumes no prior computing knowledge. It concentrates on the wider aspects of the applications of computer graphics. The text will be ideal for those who have bought, or are about to buy, a CAD package and want to know what underlies the 'button pressing' activities that are given in most instruction manuals of packages. Similarly, those who are now familiar with the basic concepts of engineering drawing can supplement their knowledge by undertaking exercises in computer graphics whilst learning about CAD principles. Those managers and industrialists who wish to gain a quick overview in a jargon-free, readily understandable way, will find this an ideal text. It is not our intention that this text will give sufficient detailed knowledge about any single package to make a user's manual redundant. Rather it will supplement such manuals by explaining the generic principles underlying many of the procedures and which are common to a number of different systems.

The sequence of the book starts with an overview of CAD/CAM and its benefits. There is then a discussion of the various forms of hardware and software, underlying the majority of CAD systems. The graphics process and how a computer draws lines on the display screen are then considered.

Next the methods of generating features in two dimensions are reviewed, e.g. how to draw a line, square or circle, and leading on to the construction of simple block types of objects. The use of 2-D packages for industry are then considered, together with their advantages and disadvantages. Examples are then given of the use and capabilities of a number of packages, ranging from the simple to the more complex PC-based systems. The use of simpler 3-D modelling packages, as typified by AutoCAD (Release II), are then discussed. After looking at the extension of such systems to 2½-D objects, such as are found in simple milling and turning, the full range of 3-D modelling is considered. The various methods of generating the full solid geometry are reviewed.

Finally, a number of examples are given of the benefits to be expected from integrating the whole range of CAD and CAM processes into a total CAE system. Examples are also given of the various analysis and manufacturing processes which benefit from the use of a 3-D computer database. The problems and benefits of introducing CAD into an industrial company are also discussed. Exercises are provided throughout the text which will be of benefit to both teachers and students.

We believe that this text will fulfill an important role since it bridges the gap between texts of a theoretical computer science nature and those which are user manuals for a single CAD package. The applications orientation should be useful to a wide range of engineers and managers in giving them an understanding of the generic principles of computer-aided drawing, graphics and design.

Contents

Introduction

1

1.1 THE ENGINEER AND COMPUTER-AIDED ENGINEERING

An engineer can be defined as a person who is concerned with the many processes leading to the production of artefacts which will aid mankind. These processes include a span of activities which start with the inception of the idea, pass through the design and manufacture phases and finish with the safe scrapping of the product.

Traditionally, the engineering drawing has played a crucial role in these processes, because its graphical form is ideal for quickly conveying complex ideas in an unambiguous manner. It is used by a variety of specialist engineers, for example the designer who, as he sketches and draws, carries on a conversation with himself and others to refine his design ideas step by step. The analyst and the researcher define from drawings the precise geometry of parts for mathematical analysis. Managers in industry discuss aspects such as length of manufacturing times, costs of manufacturing parts, material requirements and other such details with the aid of sets of engineering drawings. The draughtsman will use a range of drawings to ensure that parts are correct in shape and form, have the correct dimensions and tolerances and will assemble together properly into a working device. Engineering drawings, therefore, provide an essential means of communication between a wide variety of types of engineer.

In order to communicate as much information as possible in a concise form, a system of drawing views known as **orthographic projection** has been developed. Orthographic projections show single views of faces alongside other views seen from directions which are at right angles to each other. The views of individual component parts can be drawn and fully dimensioned to specify their precise geometry, size, shape and form. However, it is necessary for those using orthographic projection to build up in their minds a three-dimensional visualization of the parts shown in the various views of the drawing. They have to interrelate the separate two-dimensional views. The ability to read and understand engineering drawings remains an essential part of any engineer's skills.

More recently, however, all the processes leading to the production of an artefact have been aided by the use of the computer, but most notably computer-aided manufacture (CAM) and computer-aided design (CAD). Both CAD and CAM depend upon an accurate definition of the geometry of the product within the computer database. This is achieved by a range of computer graphics activities, but depends mostly upon a good three-dimensional modelling system and upon a good computer-aided draughting system. In computer graphics it is now relatively easy to generate a number of pictorial views of a part seen from a variety of directions. These show more than one face in a single view and quickly give a better overall impression of the three-dimensional nature of a part. Such pictorial views are generated from the data in the computer that holds all the geometry of the part being displayed. As the use of computer becomes more widespread, it is likely that the use of pictorial views will eventually result in orthographic projection (and hence the traditional engineering drawing) diminishing in importance.

The last decade has seen an explosion in the use of CAD, CAM and computer-aided draughting. The reduction in hardware and software costs, together with their ever increasing sophistication, has resulted in facilities which are now used by the average engineer which a decade ago were available to only a few specialist CAD companies. The engineer today has available at his desk as much computing power and capability as the specialist CAD software house of the late 1970s. It is for this reason that it is important for every student or professional engineer, no matter which branch of the discipline that is being followed, to become thoroughy familiar with the basic principles and the capabilities of CAD, computer-aided drawing and computer graphics. The whole range of computer graphics activity in engineering is dealt with in this text, gradually building towards utilizing computer-aided drawings and three-dimensional models to integrate together all the design, analysis, manufacture and management processes into a single computer-aided engineering (CAE) system. As will be seen from later chapters, it is from this integration of the range of engineering activities that the maximum benefit can be obtained.

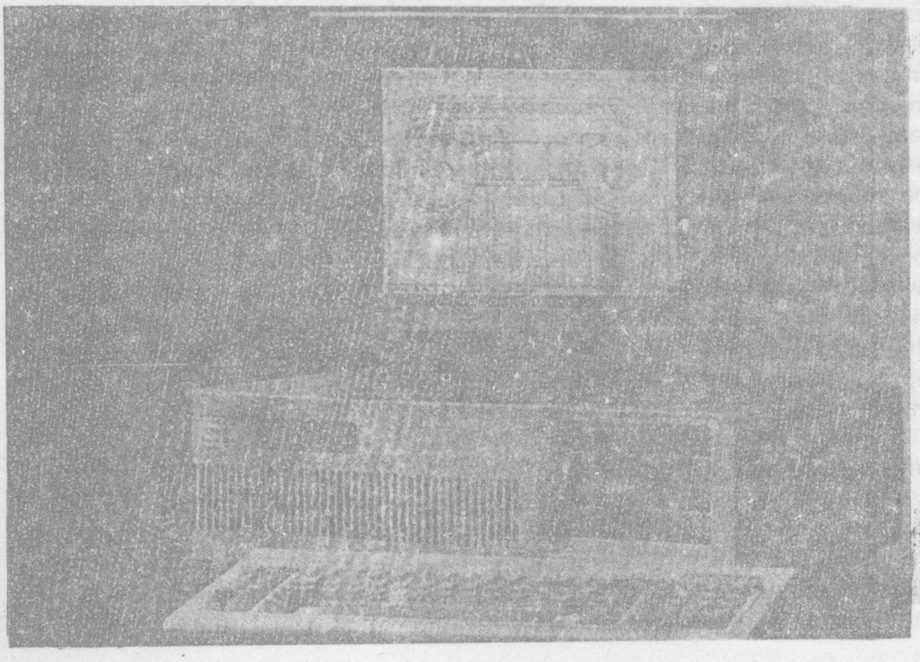
1.2 THE ROLE OF COMPUTER-AIDED DESIGN AND ITS IMPLICATIONS FOR ENGINEERING DESIGN

Engineering design is a decision-making process which requires a wide range of knowledge and expertise. Early design activities, in which all calculations were performed manually, required that the models being analysed were greatly simplified in order that the mathematics involved was sufficiently simple to allow standard techniques of analysis to be applied. However, the simplifications were often so extreme that the resulting mathematical model bore little relationship to the reality. With the tremendous processing power of computers as an aid to the design process, the models can now be much more complex. In fact some analytical techniques, such as finite element analysis, can only be effectively carried out by using a computer. Thus, until recently, it has been the calculation power of the computer which has had the most impact on the process of engineering analysis and design. The introduction of the low-cost microcomputer, available on the desk of the majority of engineers, has meant that the computer is available for a number of calculations requiring relatively small programs with simple graphics output, e.g. graphs and diagrams to represent shear force and bending moments. The storage of data and standard codes of practice on a computer disk, together with purpose-written programs, can give the engineer the guidance and step-by-step advice at his computer terminal that was previously only obtainable from specialist consultants.

Until quite recently, graphical computing aids for the engineer were restricted to graphs and 2-D draughting systems. The 2-D draughting systems were comparatively simple and contained no intrinsic knowledge of the geometry of the part to be drawn. An example of the output from a popular system of this type, which is often used in education, is shown in Fig. 1.1. Many of the cheaper microcomputer-based systems contain only 2-D draughting systems with this level of complexity. These systems display the views of an object on a graphics screen in just the same way as an engineering drawing on paper. However, because all points and lines are held in computer memory, changes to the drawing can easily be carried out without having to re-enter all the data by hand. Only those lines which are to be modified need be re-entered and all the rest can then be automatically regenerated on the screen. However, individual views are drawn using the lines on the screen, but there is no facility for representing the three-dimensional (3-D) nature of the part. It was therefore necessary for the designer to be able to specify, for example, hidden features by showing them by hidden detail lines or by showing cross-hatching lines for sectioned planes.

The advent of a type of 3-D computer graphics, known as 2½-D has improved this situation. The dramatic reduction in the computer graphics hardware costs has also helped. A 2½-D system is one which is used only for shapes where a

Fig. 1.1 *AutoSKETCH: a typical PC-based 2-D draughting system.*



2-D profile is translated linearly by a small distance to make a 3-D object of constant depth. Alternatively a 2-D profile of an object can be rotated through 360° to make a roughly cylindrical type of 2½-D component. These shapes are of particular value because they are of a type often used in engineering and are relatively easy to produce on a simple numerically controlled lathe or milling machine. The programs can now be provided on relatively small and cheap microcomputers and graphical displays. The use of 2½-D facilities in 2-D draughting has meant that many design offices have been able to show savings of a factor of three or four on productivity.

The process of modelling, in a computer, a complex engineering component in three dimensions is difficult. It requires both sophisticated computer programs and special computer hardware for the graphical display systems. The topic of **solid modelling** is one in which a full 3-D representation of the product can be constructed. This is an area that has only recently been developed on a large scale, partly because the previously high cost of computer hardware has recently come down to more acceptable levels, and partly because of advances in computer programs which have produced many new techniques. It is this area of computer graphics that has the greatest potential for changing the way that products are designed. The ability to produce a full solid model, or an outline of an object as a **wire frame**, means that the full 3-D geometry of a part is available as a database. This data-based geometry is then available, not only to produce 2-D drawings of an assembly and its constituent parts, but is also available for transmission to other computer programs for design, analysis and manufacture. This central nature of the geometric database, together with the manner in which it integrates with a range of design and manufacture activities, is shown in Fig. 1.2. This figure shows that it is the graphics display screen which now readily enables the geometry of the part to be specified. The 3-D geometry can then be used in design and analysis, for example to pass to a finite element pre-processor which breaks down the geometry into a mesh which can then be analysed by a further program. The other major area where the geometric database is used, is in manufacture and management activities. Not only is the information of value for the automatic generation of numerical control machine tool motions, for example so that a computer numerically controlled lathe can produce turned objects, but also for such activities as scheduling the motions of robots and automated guided vehicles. The total computer information is also available for management activities in planning production and maintenance, in costing, sales and marketing. Although any single one of these activities may only have a marginal cost advantage taken on its own, by bringing them all together, the whole process becomes very cost effective. The result is that the engineer is relieved of many routine tasks and can use his time more creatively.

The availability of specially written programs means that a small business can have access to information, expertise and guidance which was previously available only to larger corporations. This process is likely to change the skills required of the engineer. The knowledge of a large number of detailed standards and procedures will no longer be necessary as they can be accessed directly from a computer. The emphasis on analytical ability is also likely to decrease for the generalist engineer, who will rely more on the standard analytical tools available

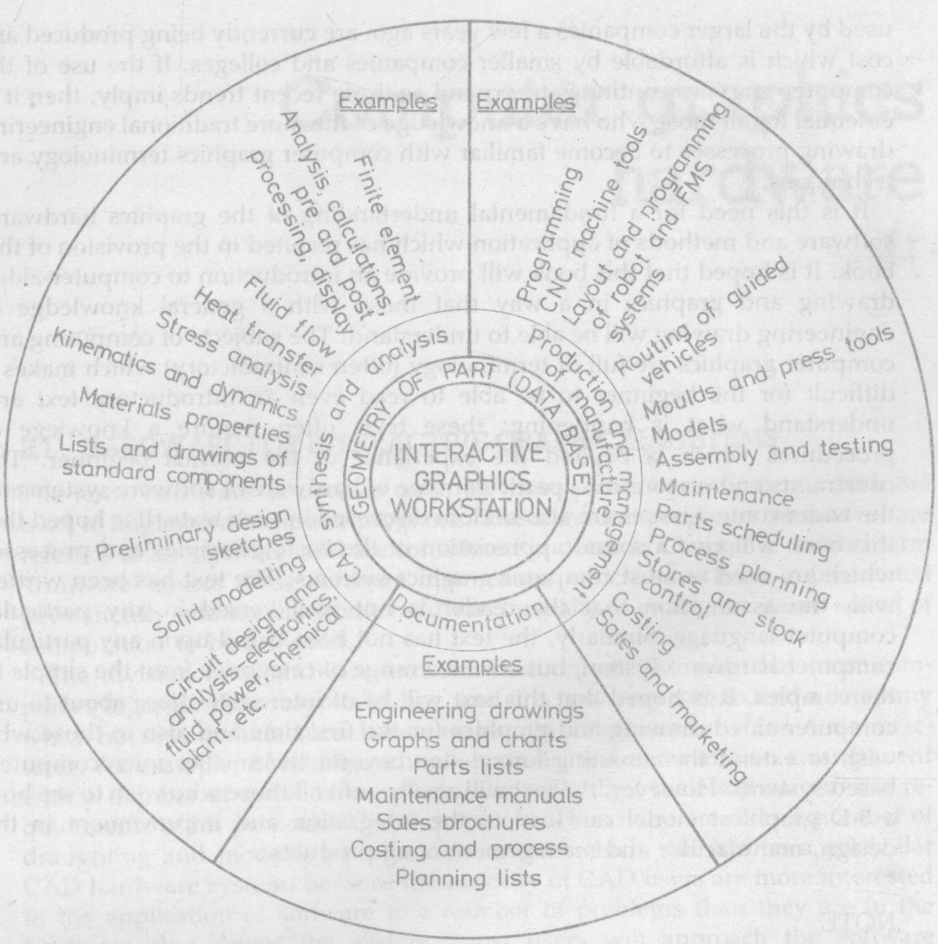


Fig. 1.2 The central role of computer graphics in CAD/CAM.

on the computer. For a small number of mathematicians and researchers, who will be responsible for developing or updating computer programs, the mathematical process will remain important. For the average engineer, however, the main activity is likely to become one of using the computer as a synthesis tool to enhance creativity. This reliance on the use of standard computer programs implies that their integrity must be fully verified and that the limitations of their application are well documented and understood. Until the time when totally integrated sophisticated computer graphics systems are in widespread use, it is generally thought necessary for every engineer to understand at least the basic analytical principles of a range of engineering subjects and to be able to understand the type of thinking and processes that underlie existing computer programs.

The recent trends in computer graphics have shown that there is a greater availability of larger systems with more memory and faster operation at very competitive prices. Thus, computer-aided design systems similar to those being used by the larger companies a few years ago, are currently being produced at a cost which is affordable by smaller companies and colleges. If the use of the computer graphics continues to expand as these recent trends imply, then it is essential for all those who have a knowledge of the more traditional engineering drawing processes to become familiar with computer graphics terminology and techniques.

It is this need for a fundamental undertanding of the graphics hardware, software and methods of application which has resulted in the provision of this book. It is hoped that this book will provide an introduction to computer-aided drawing and graphics in a way that those with a general knowledge of engineering drawing will be able to understand. The subjects of computing and computer graphics are full of terminology (often contradictory) which makes it difficult for the beginner to be able to read even an introductory text and understand what is happening; these texts often require a knowlege of procedures which is beyond the experience of the normal beginner. The constraints and reasons for a particular type of hardware or software system and the wider context issues are also seldom discussed in such texts. It is hoped that this book will give a sound appreciation of the basic principles and processes which are used in most computer graphics systems. The text has been written with the assumption that the reader is not well versed in any particular computer language. Similarly, the text has not been based upon any particular computer hardware system, but covers a range of categories from the simple to the complex. It is hoped that this text will be of interest to those about to use computer-aided drawing and graphics for the first time and also to those who wish to extend their existing knowledge beyond the smaller microcomputer-based systems. However, the text will also benefit all those who wish to see how a 3-D graphical model can lead to the integration and improvement in the design, manufacture and management of all products.

NOTE

We have already seen that computer graphics is at the heart of computer-aided design (CAD) and of computer-aided manufacture (CAM). There is much confusion about the use of the term CAD because for many years computer graphics systems were purely concerned with draughting and so the term CAD has mistakenly been used in some texts to mean computer-aided draughting. In this text, CAD is taken to refer to the application of computers in the whole design process.

Computer graphics hardware

2

2.1 HARDWARE FOR INTERACTIVE GRAPHICAL SYSTEMS

The term 'hardware' is used to cover all those pieces of equipment which are used to implement computer programs. The computer programs themselves are referred to as 'software' and are considered in detail in Chapter 3. A third term 'firmware' covers those software instructions which have been implemented permanently into the electronic hardware, usually to enable increased speed of computation to be achieved.

The division into hardware and software reflects the way that most companies organize their responsibilities, and it is now very rare to find a company which not only manufactures hardware but also originates software. A manufacturer, for example, of intelligent work stations, will enter into an arrangement with a number of software suppliers who will adapt their software to the requirements of his particular CAD equipment. Thus there are often a number of draughting and modelling programs available which will run on a particular CAD hardware system. Because the majority of CAD users are more interested in the application of software to a number of problems than they are in the hardware that drives the system, most users will approach the software company initially. The software company will then recommend a particular hardware system and generally take responsibility for seeing that the hardware and software will operate well together and perform to the customer's requirements.

Hardware includes the computer with its memory and central processing unit (CPU), the means of storing programs on disk or magnetic tape, the display screens, various devices for inputting instructions to the computer, e.g. keyboards, digitizers and tablets, and the output devices which can give 'hard copy', e.g. printers and plotters. We will look at each device in turn before considering how these elements are brought together to form a typical CAD system.

2.2 THE COMPUTER

The term 'computer' is often liberally used with reference to all the hardware components of a CAD system. Here, we use the term computer to refer to the processor which controls the operation of the CAD system. In this sense, the computer is only one part of the system. Depending upon the complexity of the system, the computer required to operate a comprehensive range of CAD applications software may vary from a small personal computer with a memory size of 640 Kb, to an intelligent work station with up to 10 Mb memory, or to a larger machine with up to 30 Mb of memory. In all cases the computer processor operates in a similar way.

It is not necessary completely to understand how a computer functions to operate a CAD system, but a basic knowledge of the fundamentals of how a computer works is essential for selecting hardware and software for your system, and to ensure the equipment and programs are used to best effect. The computer itself is often the most 'remote' component of the CAD system, inasmuch as the operations it carries out are 'invisible' to the user. Every computer has an **operating system** to control the flow of information between the computer processor and the various peripheral devices to which it is connected, i.e. keyboards, display screens, printers, plotters and other computers. The operating system provides the user with a command language to control these devices and to manage the storage of information on the system. Applications software allow specific tasks such as draughting, modelling, analysis, simulation or machine tool control to be carried out. Without either an operating system or applications software, which are considered further in Chapter 3, the computer is of little practical value to the operator.

Although computer technology has developed rapidly over recent years, the fundamental principles of operation of the processor itself, which were defined by John Von Neumann in the 1940s, have not changed. The sequential operation of the central processing unit, whereby instructions are processed in series, is the basis of the microprocessor used in most CAD computers. While **reduced instruction set computing** (RISC) technology currently gives a higher performance, by making more effective use of the processor, it is **parallel processing**, whereby a number of instructions are carried out simultaneously by the same processor, that will significantly improve the performance of future computers in CAD systems. This will be especially true in applications where interactive computer graphics play a major role. Although these processors have recently attained commercial maturity, they are not readily available for use in all current CAD systems, but the larger processing power per unit cost of these devices will surely secure their place in future CAD technology.

2.2.1 CENTRAL PROCESSING UNIT

The central processing unit (CPU) is the key element of the computer; it is the microprocessor at the heart of all modern computers. The central processing unit regulates the action of the computer, controlling the input, storage, manipulation and output of all information and data. The information received from input devices or retrieved from secondary storage media is temporarily held in the computer's memory; this is know as **main memory** or **internal memory**. The **arithmetic logic unit** (ALU) of the CPU performs four tasks: addition, subtraction, comparison and data transfer between itself and the main memory.

Instructions, numbers and characters are stored in memory and manipulated