ELEMENTS OF COMPUTER-AIDED DESIGN AND MANUFACTURING

CAD/CAM

Y. C. PAO

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The University of Nebraska, Lincoln

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PREFACE

The original manuscript of this book was prepared for a pilot course "Introduction to Computer-Aided Design (CAD)" offered during the spring semester of the 1982–83 academic year at the University of Nebraska. It was a part of a coordinated effort by the College of Engineering and Technology at the University of Nebraska—Lincoln to bring computer-aided design and manufacturing technology into the college curriculum.

The acquisition of two Tektronix 4054 computer graphics systems makes possible the development of the computer programs, displays, and hardcopies presented in this text. The first 4054 system was acquired in March 1982 by a $22,000 grant from the Fred J. Kelly, II Fund of the University of Nebraska Foundation. It was the result of a teaching and research proposal that I submitted as principal investigator and assisted by Professors R. T. DeLorm, L. Kersten, C. W. Martin, R. N. McDougal, and G. M. Smith. The second 4054 system was later acquired by a fund from the College of Engineering and Technology, the University of Nebraska—Lincoln. I am grateful for all of this support.

Many of the BASIC programs presented herein are the translated versions of FORTRAN programs reported in works that I had previously published. The following graduate assistants and friends have contributed to the preparation of these programs: L. C. Chang, T. A. Huang, W. T. Kao, C. M. Lin, M. N. Maheshwari, G. K. Nagendra, J. Nikkola, K. A. Peterson, R. M. Sedlacek, D. S. S. Shy, A. J. Wang, J. D. Wilson, and S. J. Zitek. Some of them were or are supported by the General Motors CAD/CAM fellowship program. I would like to acknowledge them and the General Motors Corporation for their contributions to this text.

Leon Hill of the Boeing Company, Dr. Han-Chung Wang of the IBM Thomas J. Watson Research Center, and Erik L. Ritman, M.D., Ph.D., of the Mayo Clinic read the manuscript thoroughly and made numerous constructive suggestions for the improvement of this book. I am indeed indebted to these long-time friends for their invaluable contributions.

I would like to thank Professors Donald R. Riley, Gary L. Kinzel and Lawrence L. Durocher of the University of Minnesota, the Ohio State University, and the University of Bridgeport, respectively, and Dr. Kenneth W. Neves of Boeing Computer Services Company for their helpful comments while reviewing the manuscript. These reviewers have provided many constructive suggestions for changes,

particularly the addition of the APPLE, IBM, and TRS-80 BASIC versions of some of the developed BASIC programs to facilitate the readers who may not have a high-resolution Tektronix 4054 system but possesses one of the popular microcomputers. Appendix D has therefore been included to partially fulfill such a need and to present some applications of the PLOT-10 software. Many thanks go to Professor David W. Brooks of the Chemistry Department and Professor George R. Schade of the Mechanical Engineering Department, both at the University of Nebraska-Lincoln, for allowing me and my assistants to use their IBM Personal and APPLE microcomputers.

Mrs. Louise Simmons has typed many of the author's publications. Again, a great portion of this text is the result of her expert skill. The pleasure of working with the editorial staff should also be mentioned. They are dedicated, conscientiously hard-working, and most cooperative. It is indeed a happy and rewarding experience. I thank them wholeheartedly, and particularly to Bill Stenquist, Susan Winick, Elyse Rieder, and Cindy Stein. Last, but not least, my wife Rosaline Shao-Ann's patience and understanding during the preparation of this text should be especially mentioned and acknowledged.

Y. C. Pao

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CONTENTS

PART ONE

INTERACTIVE COMPUTER GRAPHICS AND SIMPLE EXAMPLES OF CAD

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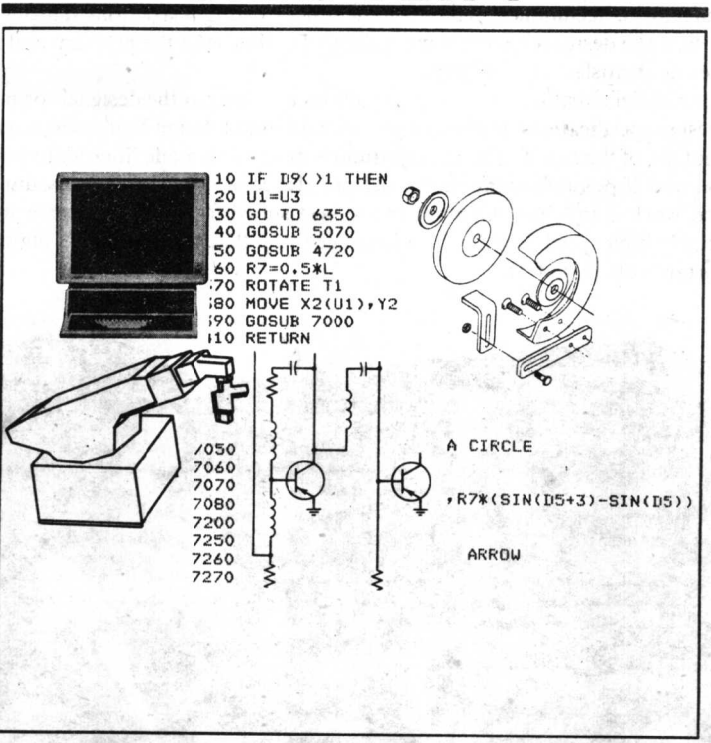
CHAPTER 1



INTRODUCTION

1.1 COMPUTER-AIDED DESIGN AND COMPUTER-AIDED MANUFACTURING (CAD/CAM)

Design and manufacturing of marketable products are the principal concern of the engineering profession. Designers apply imagination and creativity and usually go through the process of making sketches, drawing flowcharts and block diagrams, building test models, and conducting experimental tests. They have to work within cost limitations, select from a finite number of available materials and manufacturing techniques, and overcome other existing restrictions. Through **trial** processes, the designer becomes increasingly familiar with the problem and finally arrives at a satisfactory solution.

In practical situations, various possibilities are open to the designer for meeting the design **specifications**. It often begins with an initial design that meets a number, but not all, of the specifications. **Adjustments** need to be made in order to improve, refine, and if possible **optimize** the design. Hence, a considerable amount of repeated work is involved. Computers are best suited for doing repetitive work at extremely high speed. It is in the adjustment step that the computers play a very important role (Fig. 1-1).

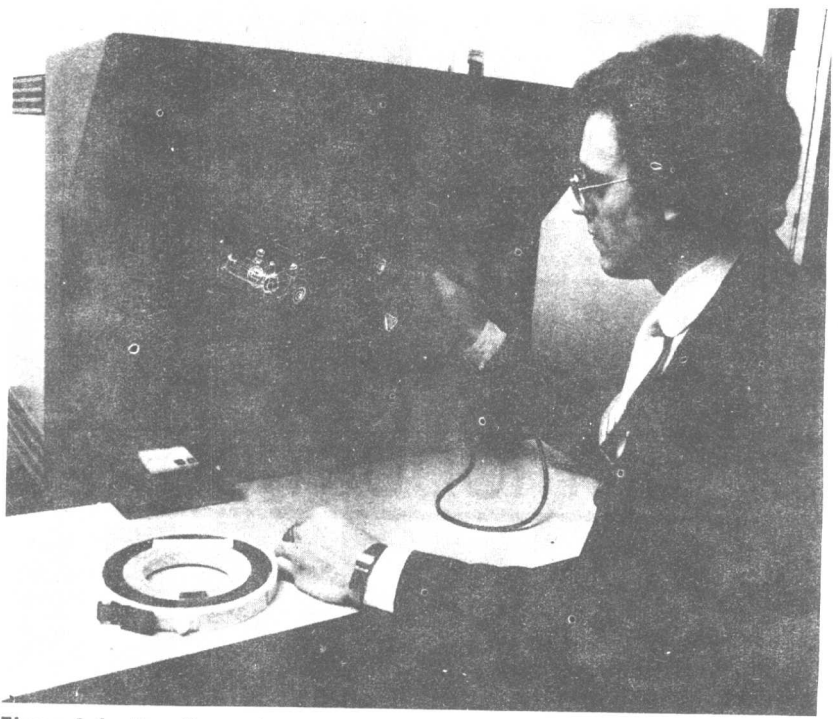


Figure 1-1 Use of interactive graphics device for altering the design of a certain part of a passenger car. (Courtesy of Ford Motor Company.)

TABLE 1-1
Application of CAD/CAM in Industry

Application	No. of Representatives Using the Application[a]
Computer-Aided Design	
1. Designing of machine and structural elements and circuit boards	21
2. Problem solving	17
3. Interactive graphics design	14
Computer-Aided Drafting	
4. Editing and alteration of existing drawings	14
5. Automated drafting	25
Computer-Aided Manufacturing	
6. Scheduling inventory, control processes, personnel records, etc.	20
7. Numerically controlled machines	19
8. Materials handling and monitoring	8
9. Interactive parts nesting	4
10. Nondestructive and other testing	3

Source: Adapted from "Some Common Characteristics in Industrial Applications of CAD/CAM," *Engineering Design Graphics Journal*, American Society of Engineering Education, Fall 1981. Courtesy of Professor R. N. McDougal.

[a] See Table 1-3.

When a design that satisfies all specifications has been chosen, manufacturing of the design may also proceed with the aid of computers. Minicomputers may be used to numerically control the motions of the machine tools. Many other aspects of the manufacturing processes may also be controlled in real time by use of computers.

Hatvany et al.[1] performed a survey of the applications of computer-aided design in 1977. More recently, Professor R. N. McDougal has published the results of a survey of industrial application in the United States of computer-aided design and computer-aided manufacturing, abbreviated hereon as CAD and CAM, respectively. Tables 1-1, 1-2, and 1-3 are presented to show the variety of applications and industries involved in CAD, CADR, and CAM where CADR is commonly used as an abbreviation for computer-aided drafting. According to the November 1981 issue of the *Engineering Times* published by the National Society of Professional Engineers, "the worldwide market for computer-aided design and manufacturing (CAD/CAM) will reach more than $5.8 billion in 1986, up from $900 million in 1980."

In a recent article[2] by S. H. Chasen, the activities of the CAD/CAM field are

[1] T. Hatvany, W. M. Newman, and M. A. Sabin, "World Survey of Computer-Aided Design," *Computer-Aided Design*, Vol. 9, No. 2, 1977.

[2] S. H. Chasen, "Guidelines for Acquiring CAD/CAM Information," *Computers in Mechanical Engineering*, Vol. 1, No. 1, August 1982, pp. 37–42.

TABLE 1-2
Industrial Computer-Aided Applications

Application	No. of Representatives Using the Applications[a]
Computer-Aided Drafting	
1. Automated drafting	39
2. Editing and alteration of existing drawings	25
Computer-Aided Design	14
1. Designing of machine and structural elements and circuit boards	21
2. Problem solving	17
3. Interative graphics design	14
Computer-Aided Manufacturing	
1. Scheduling, inventory, control processes, personnel, records, etc.	20
2. Numerically controlled machines	19
3. Materials handling and monitoring	8
4. Interactive parts nesting	4
5. Nondestructive and other testing procedures	3

Source: Adapted from "Some Common Characteristics in Industrial Applications of CAD/CAM," *Engineering Design Graphics Journal*, American Society of Engineering Education, Fall 1981. Courtesy of Professor R. N. McDougal.
[a] See Table 1-3.

explored in five major categories The author provides information on (1) publication media, (2) educational services, (3) users, (4) vendors, and (5) consultants. As he asserted that the field is changing at such a rapid rate, the article could not possibly be exhaustive. It did provide good sound advice for potential users of CAD/CAM in acquiring essential knowledge of the field and in selecting the available hardware and software in the market.

1.2 ENGINEERING DRAFTING AND COMPUTER PLOTTING

Designers begin their trial designs by making sketches on paper. As the design gradually develops into final form, carefully scaled drawings are then needed for checking whether or not the sizes of the parts involved will fit properly. Especially for manufacturing, more detailed descriptions of every part will have to be drawn. **Engineering drafting** is a required course in almost all engineering curricula, in which the basic techniques and rules are learned regarding scales, dimensioning, lettering, and drawing orthographic and auxiliary views of the designed objects.

Descriptive geometry plays an essential role in engineering drafting, as it determines the geometric information connected with **three-dimensional designs**. For the reason that all drawings are two-dimensional, projections of three-dimensional objects have to be taken. Equations must be derived for calculation of the angles

TABLE 1-3
Industrial Representatives Using CAD/CAM

Industrial Representative	Use of CAD/CAM[a]
Allis Chalmers	2,4,5,6,7,9
American Plywood Assn.	1,2,6,8
AMOCO (Std. Oil Co. of Ind.)	3,5,6,7
ARMCO Building Systems	1,5,7
Bechtel Power Corp. (Enq. Div.)	2,5
Bell Laboratories	1,5
Black & Veatch	1,3,5,6
Brunswick Co. (Defence Div.)	7
Burlington Northern	1,5
City of Los Angeles (County Engineer)	1,2
Colt Industries (Fairbanks Morse Pump Div.)	1,2,7
Deere & Co. (Manufacturing Eng. Div.)	2,3,4,6,7,8,9,10
Firestone Tire & Rubber Co.	5,6,7
Fisher Controls Co.	1,2,6,7
Ford Tractor Div.	1,2,3,4,5,6
General Dynamics (Electric Boat Div.)	2,3,4,7,9,10
General Motors Corp.	1,2,3,4,5,6,7,8,9,10
General Portland Inc.	6
International Paper Co.	6,7,8
Johns-Manville Sales Corp.	4,5,6
Martin Marietta Aerospace	1,3,4,5,6,7,8
McDonnell Douglas (Aircraft Co.)	3,5,7
McDonnell Douglas (Astronautics Co.)	1,3,4,5,7
Monsanto Co. (Eng. Dept.)	1,5
Phillips Petroleum Co. (Corporate Eng. Div.)	2,3,4,5
Proctor & Gamble	2,3,4,5,6,7
Republic Steel	1,5,7
Sandia Laboratories	1,2,3,4,6,7
Texaco (Computer Services Dept.)	1,3,4,5
The Schemmer Assoc. Inc. (Architectural Dept.)	1,5,6
Trane Co.	1,2,4,5,7,9
Union Oil Co. of California	2,5,6,8
Union Pacific R.R. Co.	5,6,8
United Technologies Research Center	1,6
Valmont Ind. Inc.	2,3
Western Electric	1,2,4,5,6,8
Westinghouse Elec. Corp. (R & D Center)	1,5,7

Source: Adapted from "Some Common Characteristics in Industrial Applications of CAD/CAM," *Engineering Design Graphics Journal*, American Society of Engineering Education, Fall 1981. Courtesy of Professor R. N. McDougal. [a]Refer to Table 1-1 for explanation of application of CAD/CAM

between lines, between a line and a plane, between planes, between a plane and a surface, and for the calculation of the areas, lengths, and other dimensions.

Computers can help engineering drafting in various ways (Fig. 1-2). For its speed and precision, a computer can easily take over the task of freehand lettering

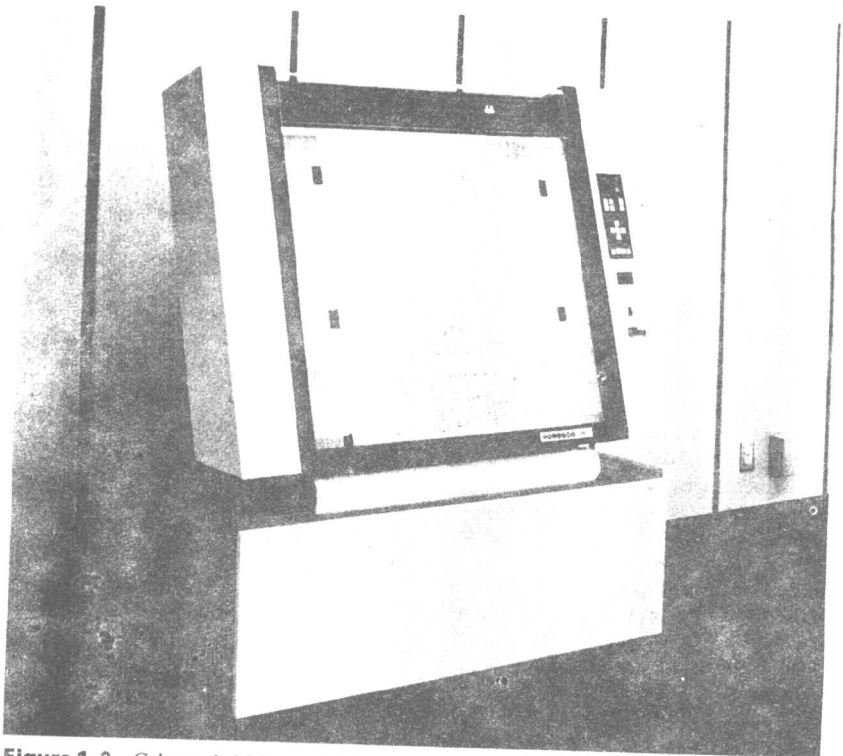


Figure 1-2 Calcomp's high-speed 960 plotter. (Courtesy of California Computer Products, Inc.)

of alphabetic and numeric characters. And if a standard part is often used in designs, the layout of that part may as well be routinely plotted by a computer.

Computer plotting, automated drafting, computer-aided drafting, computer graphics, and many other terms all have been used interchangeably. In a follow-up survey by Professor R. N. McDougal, various applications of computer-aided drafting in education (Table 1-4) and in industry (Table 1-5) have been tallied. As the field is expanding at an extremely rapid pace, it should not be a surprising revelation that in a later publication the lists will have increased to tenfold or even 100-fold.

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