An Introduction to CAD Using CADKET®

Hugh F. keedy

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Hugh F. Keedy
Vanderbilt University

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Note: All exercises in this book can be completed using CADKEY Version 1.4E or a higher level version. Some features described in the text are available on higher level versions (2.1 or 3.0) only, but they are clearly marked as not being part of Version 1.4E. The advanced features included are for those who have access to a version above 1.4. Many of the final results of the advanced features can be accomplished by the features of the 1.4E version, but not as quickly and conveniently, and sometimes only with some degree of ingenuity.

Preface

Material for this book of CADKEY principles and related exercises was developed in the School of Engineering at Vanderbilt University for two one-semester-hour freshman engineering courses in computer graphics. It was distributed in handout form when the courses were first offered in the fall semester of 1985. Based upon class testing both at Vanderbilt and other engineering schools for over two years, this edition incorporates revisions made to strengthen the content, organization, and pedagogic value of the original material.

Two types of users are assumed for this book, students in a classroom setting and individuals who wish to learn CADKEY on a self-study basis. The multiple options offered for each exercise make the text usable, without duplication of assignments, for two or more semesters of classroom use. Individual users as well as students in a class should experience a good learning curve that progresses smoothly and quickly from simple 2-D constructions to exploded and assembly views in full 3-D.

Scope of the Material

The information about CADKEY principles and related exercises are designed to help users learn and apply those principles effectively as an engineering tool. Students will learn CAD skills they can use throughout their school work. After graduation, they can apply the concepts to any CAD system they might encounter on the job. Those who use the book for individual study of CADKEY will be guided into true three-dimensional CAD through exercises that are outlined step-by-step.

The first of the two major parts of the book is devoted to fundamentals of CAD and CADKEY. This part begins with a brief overview of CAD in engineering, followed by a detailed description of the CADKEY screen display and menu structure, as well as CADKEY features that users need as general background.

The second part of the book contains 12 exercises, along with information about other CADKEY features needed to complete the exercises. The exercises cover the major topics found in most introductory drafting courses. If desired by an instructor, special topics such as fasteners and tolerencing can be added as supplementary material. Exercises use only the English system of measurement, but changing to the metric system requires only a few keystrokes.

Exercises and associated information assume the user has access to a digitizing tablet or mouse to control movement of the cursor on the screen. Those who do not have one of these must use the arrow keys on the keypad area of the keyboard to move the cursor. Instructions are given in the text for using arrow keys rather than a mouse or tablet.

Users need to understand the pedagogic rationale under which steps were developed to guide the learner through the exercises. Information given in Part I and on pages following most exercises give keystroke sequences that will produce a specific feature, such as moving selected entities about on the screen or adding a note to the screen display. The list of suggested steps to complete any exercise assumes that users know how to produce the features mentioned; if not, they should review the keystrokes needed before proceeding. Users should develop the habit of watching the Prompt line for instructions and following them. The objective, therefore, is to start the user in the proper direction and then depend on the Prompt line for guidance.

Finally, emphasis in this book is on the creation of an accurate 3-D database and a hard copy representation of it. It is considered beyond the objective of the book to include methods of transferring the database to numerical control machinery, analytic software, or other uses of the database. Such transfers are possible through CADL, a type file not available on the 1.4E version, or by transformation to the international graphics exchange standard format known as IGES.

Some Notes About Course Administration

Material specific to course administration, hardware and software facilities being used, and additional or detailed information about drafting principles is not included in the text, since each user's situation is different. For classroom use, additional or in depth notes on CADKEY operation and information that is school or course specific can be distributed as a handout.

As indicated before, the book contains 12 exercises along with sufficient information to complete them. This material, if supplemented by personal instruction during lab periods, has been found to be adequate for two semester-hours of work by Vanderbilt students. We have also found that peer instruction, which is encouraged by assigning two students to each computer during class periods, produces a healthy atmosphere and fosters learning in unexpected ways.

We use the first six exercises as a one semester-hour freshman course that meets five hours per week for five weeks. The remaining six exercises form a second one semester-hour course that follows immediately after the first one, and also meets five hours per week for five weeks. All engineering students at Vanderbilt are required to take this first course; the second course is a departmental option. Experience with the assignments indicates that the workload and pace are reasonable, although more intense for the second course than the first.

Each exercise has a stated objective; any figure compatible with the assignment and its objective will work well. At least two alternate figures are supplied for most exercises. For repeated offerings of a course, use the alternate figures that appear for early offerings and in subsequent offerings supply another figure that is compatible with the description and steps of the exercise.

An hour of lecture time, on average, should be ample to discuss each exercise, although this will vary with the exercise. If drafting principles are being presented along with the CADKEY principles, about half of that time will be needed to discuss each. We do not use an accompanying drafting text, but do show some films on drafting techniques from time to time.

A projector that projects the screen display of the instructor's computer is an invaluable teaching aid. Details of CADKEY features, geometric constructions, and demonstration of the steps suggested for an exercise are much more quickly and accurately presented than is possible using a blackboard or overhead.

Students should develop the habit of using the windowing feature of CADKEY to enlarge suspect areas of a drawing—which you soon come to recognize in a classroom situation—so that they can obtain the precision that they should have. Nearly every exercise contains subtle points in the use of the software that students are likely to overlook or forget. Failure to understand the more subtle points often causes students to produce figures that are not precise, although the figure might appear to be correct on a hard copy.

We require that each exercise be submitted in two forms: a hard copy (from a printer or plotter), and as pattern and part files on a floppy disk. While some grading can be done from the hard copy, files loaded to the computer are invaluable in checking for precision that is not visible on hard copies. Be sure that files are named uniformly within a class; grading becomes chaotic if they are not.

I wish to express my gratitude to all the people who have contributed to the development of this book. Thanks of a special nature go to Peter Smith of CADKEY who urged me to develop the original set of handouts into a preliminary edition of this book, and to those users of that edition who provided further encouragement. Thanks also are extended to W. George Devens, Virginia Polytechnic Institute and State University; William C. Cooley, George Mason University; Dryver R. Huston, University of Vermont; and James A. Harback, U.S. Merchant Marine Academy, whose reviews of that edition provided valuable constructive criticism for this edition. Special appreciation is extended to Sharon Hardy for her capable and diligent work on the figures for the text. And, finally and foremost, I wish to thank my wife, Marge, for her understanding and patient support during this project.

All feedback about the book's features, good and bad, will be valued and given careful consideration in the preparation of future editions.

Hugh F. Keedy

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Part I

Fundamentals of CAD and CADKEY

1 The Role of CAD and the Database in Engineering

1.1 Introduction

Before launching into the details of the CADKEY software, let us look at how it fits into Computer Aided Design (CAD) and the engineering work world. CADKEY, first introduced in early 1985, was the first true three-dimensional (3-D) software CAD package for use on a microcomputer or personal computer (PC). Several upgraded versions have been released since, with Version 3.0 being the latest industrial level package available. Meanwhile, many microcomputer labs using the educational version 1.4E, which is supplied without cost under a grant program of CADKEY, have been developed in colleges, universities, and technical schools across the United States.

Few people today are surprised to hear someone say that the computer has caused major changes, both in what can be accomplished and how. Those who investigate soon realize how deep and sweeping the effects of computers have been in the design and manufacturing process. Major changes have certainly been evident in the entire range of process steps, from conceptualization to delivery to the customer.

1.2 A Brief History of CAD

The advent of the computer caused major changes in industry. The first real progress in the use of computers in the manufacturing process came in the late 1950s with the introduction of numerical controlled (NC), and later computer numerical controlled (CNC), machine tools. Data supplied to the machines, on tape, controlled the motions of the tools that produced the parts of an assembly. There was no direct link to the designer other than drawings and tables of values.

An important change came with the introduction of CAD in the early 1960s. CAD allowed the designer to interact graphically with the computer. Designs could be modified or added to with relative ease, with the result that alternative solutions could be investigated quickly. Previously, with drawings on paper, a designer was limited, by time and money, in the number of alternatives or modifications that could be investigated.

Early CAD software was strictly two-dimensional, which was and still is sufficient for some applications but very inadequate for many others. The need for three-dimensional databases, large memory, and speed in the auto and aircraft industries led to development of 3-D software packages that required a mainframe computer. As these design packages came into use, it became more evident that the database created by the designer is central to the design and its implementation.

Until the early 1980s little real progress was made in merging the crucial database into other aspects of the industrial operation. Missing was an efficient method of transferring data quickly to the wide variety of software packages used by the manufacturing, materials handling, management, and evaluation systems comprising a production operation. Although the problem is far from solved, a big step toward data transfer was taken by the introduction in 1981 of the International Graphics Exchange Specification (IGES) system. Any software package compatible with IGES can receive from or send data to any other package that is also IGES compatible.

Advances in microcomputer technology provided the next major step in CAD progress. The amount of memory required and the speed needed by CAD systems were only available on mainframes when CAD first came into use. However, memory capacity and speed of the PC increased rapidly, and the early 1980s saw the introduction of 2-D CAD software that could be run on PCs then available, especially if the system included a hard disk and a math coprocessor to augment memory and speed. The first PC software with a true 3-D database was introduced in early 1985 by CADKEY. Declining costs of PCs and increasing sophistication of CAD software have generated a trend toward more CAD work being done on stand alone or networked PCs. As an impetus to this trend, numerous third-party software packages have been marketed to do analysis work that abets interactive CAD design.

A number of acronyms have become associated with the role of the computer in the manufacturing process. These include CAD (Computer Aided Drafting, or Computer Aided Design), CADD (Computer Aided Drafting and Design), CAM (Computer Aided Manufacturing), CAD/CAM (Computer Aided Design and Manufacturing), CAE (Computer Aided Engineering), CIM (Computer Integrated Manufacturing), and FMS (Flexible Manufacturing System). Without being more specific about distinctions between the areas represented by these acronyms, suffice it to say here that the computer is central to each. But, most importantly, it is the computer that provides the vital link between design and production—the database that is generated and stored electronically.

1.3 The Database as the Central Product of CAD

To see the importance of having available a 3-D database, remember that we live in a three-dimensional world and that the products we design and produce are all three dimensional. True, the third dimension in numerous cases is constant or not important (in circuit design for example), in which case a two-dimensional analysis and a 2-D CAD software package will suffice.

To further see the effects of CAD software on the design and manufacturing process, first picture an engineering office before the advent of the computer. In order to solve a problem or create a new product, an engineer conceptualized three-dimensional objects as a solution. Properties of these three-dimensional objects were routinely communicated to others by preparing two-dimensional drawings on paper using standard drafting procedures. These drawings, the central product of the design process, were sent to the shop where a machinist or production engineer used them to fabricate the object. Inspection was also related to the drawing.

Contrast yesteryear's process with a typical modern design process. A designer begins by interactively creating a database, using 3-D CAD software, to record the features of an object electronically as well as graphically on the screen. A hard copy of the graphics can be produced if visual communication is desired.

The diagram on page 6 depicts the database and its role in a typical industrial setting. The completed database is transferred to a central data system where it is simultaneously accessible to other phases of the company operation. From there, it might be transferred to a software package that provides an engineering analysis of properties of the object and possibly modifies the database to meet engineering criteria. The modified database, when approved, can be transferred to other software that will develop NC programming and tool design for the manufacture of the object. Still other software might use the database in process planning and quality control planning. The same database might also be used for such management functions as purchasing, cost accounting, and production planning and control. In the production plant, the same database might be used in manufacturing and testing of individual parts as well as robotic control of the assembly process, testing, and packaging of the final product.

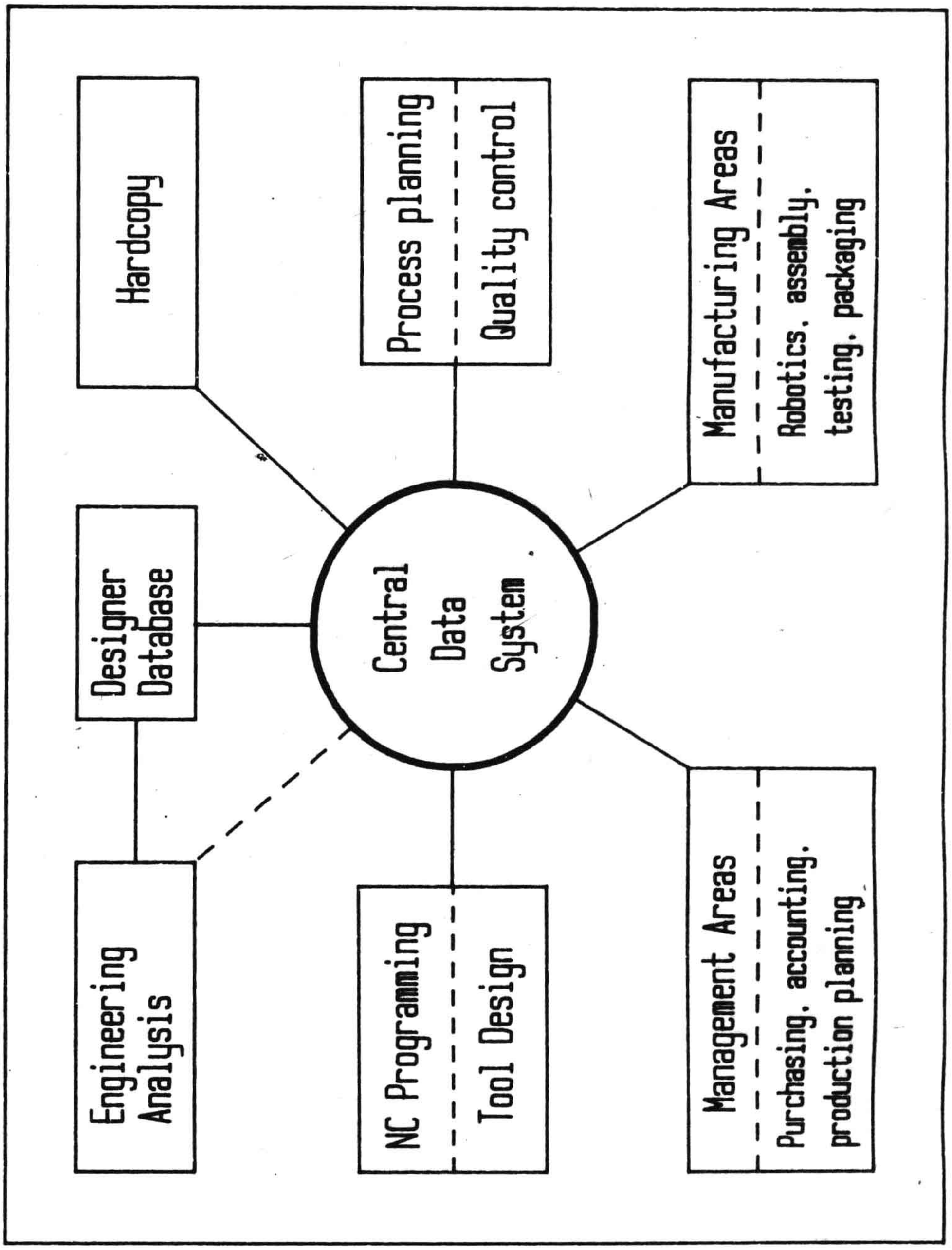
So, with the advent of CAD, ideas and data formerly represented by lines and numbers on paper are now being represented by numbers in the memory of the computer and lines on the computer screen. The database is being recognized as that which describes the object completely and uniquely, and which can be used without change in all phases of production, inspection, and management. The primary constraint is that the database must be compatible with all software of the overall operation for maximum efficiency. Thus, the CAD database has replaced the drawing as the central feature of many industrial settings.

Although the concept described above is a goal, progress has been slow in many cases. Problems with compatibility of software and obsolescence of existing machinery have impeded full integration of the database into the overall production process. However, the concept, which is known as the Flexible Manufacturing System (FMS), is receiving wide acceptance and application in industries whose products range from appliances to automobiles to locomotives.

1.4 Types of CAD

Many CAD software packages are available. Some work only on mainframes; some are for PCs. In general, those for mainframes are more sophisticated and can handle larger and more complex designs. Two major classification systems are common when discussing CAD; namely, the dimensionality of the package and the manner of representing the object.

Dimensionality: CAD software is at least 2-D, in which two coordinates (usually x and y) are sufficient to record data in the database. Software packages that produce screen images appearing to have three dimensions but do not store three coordinates for all pertinent points are known as $2\frac{1}{2}$-D packages. While able to produce drawings depicting 3-D objects, the database is not three dimensional and not useful in many production settings. A true 3-D software package produces a database in which each point is located by its x, y, and z


Central Data System
Hardcopy
Designer Database
Engineering Analysis
Process planning
Quality control
NC Programming
Tool Design
Manufacturing Areas
Robotics, assembly, testing, packaging
Management Areas
Purchasing, accounting, production planning

coordinates. In this case, although the database is truly three-dimensional, the screen representation and hard copy are actually two-dimensional—as they are for any CAD package.

Representation: Objects in CAD may be represented in three basic ways. Wireframe representation is the most simple, and the one used by most PC based CAD software and some of the mainframe software. In the wireframe representation, the database contains information about all corners of the object and the edges that connect those points. Although very simple and useful, a wireframe database may have serious shortcomings. A wireframe database might be ambiguous. That is, it could represent more than one object since surfaces are not defined, only corners and edges. Also, a valid wireframe database might not represent any real object, again a weakness related to the lack of surface identifications.

Surface modeling is the second method of representing an object. In it, not only are the corners and edges of the object defined in the database, but the surfaces as well. This method requires more memory and is only now beginning to appear in software that can run on a PC.

Solid modeling, the third method, may be generated in two different ways. In one, Constructive Solid Geometry (CSG), a solid is constructed by Boolean combinations of two or more of a set of solid "primitives." The primitives (cylinders, boxes, cones, etc.) are combined by unions, intersections, or differences to form the desired object. In the second representation, boundary representation (B–rep), the object is formed in a manner very similar to the surface modeling described above. The difference is that, once the surfaces are defined, the program recognizes volumes as well.

Solid modeling is by far the most complete representation of an object, but demands placed upon memory and computer speed are so great that only recently have PC based software packages begun to appear. As the capacity and speed of PCs increases, the likelihood of solid modeling on the PC also increases.

1.5 Where We Are Now

In view of the above discussion, where are we now and where might we expect CAD to go? CAD has demonstrated at least four advantages over manual drafting methods. First, in the production of drawings, the ability to use libraries of standard objects (drawn once and repeatedly recalled) has reduced time requirements drastically, as have the automatic dimensioning and hatching features of CAD software. Second, many geometric constructions are easier using CAD, so revisions and modification time are reduced significantly. Third, the ability to easily produce any isometric view of an object is also valuable; in fact, isometric views and perspectives may well replace orthogonal representations to a large extent in coming years. And finally, the precision that can be attained in the computer generated database cannot be matched by previous drafting methods.

Solid modeling, the CAD method of the future, is the focus of efforts by many software developers. Advances in the capabilities of PCs will make solid modeling on them practical in the near future. With solid modeling will come better visualization through removal of hidden surfaces, representation of surface textures, and shading of surfaces to correspond to given light sources. Solid modeling will also allow more detailed engineering analyses to be made with related software.

In production, the FMS concept is being applied more widely, with the database as a central feature. When fully developed, such a system will allow a product to be designed, manufactured, inspected, packaged, and shipped without a single drawing ever having been made!

1.6 Choosing a PC System for CADKEY

This section concludes with a description of a typical PC system used with CADKEY software. Those who are thinking about purchasing a PC for CADKEY might use this description as a guideline for selecting a system.

Minimum requirements for a PC system to run CADKEY vary with the version of the software being used. While an 8088-compatible computer is currently adequate for all current versions, many prospective buyers are considering as a minimum an 80286-compatible computer, of which there are now many. A few others are considering the higher level 80386-compatible systems that are currently state-of-the-art.

Regardless of the level of processor central to the computer, a PC system to run the Version 3.0 (latest current release) of CADKEY should include the following features as a minimum. A system with these features should also be sufficient to run upgraded versions of CADKEY that are likely to be released in the near future.

- At least 640K on-board RAM memory;
- An EGA graphics card (which will work with either a color or monochrome monitor and provide good screen resolution);
- At least one floppy disk drive (either 5 1/2″ or 3 1/4″);
- A hard disk with a capacity of at least 20M (30M or more might be useful);
- A math coprocessor for added speed;
- An available clock speed of 8 MHz or more.

Choice of a color or monochrome monitor is a personal preference, and the number of serial and parallel ports needed will be a function of the amount of peripheral equipment desired. A complete PC system will include a printer and/or plotter for a hard copy output. Input can be accomplished through a number of devices, with the mouse and digitizing pad being the most common input devices, other than the keyboard.

2 Getting CADKEY Started

General Information About Floppy Disks

Users of this book will need to create files for storing information. If you are in a class that requires floppy disks to be submitted with exercise files on them you will need at least two floppy disks. Be sure that disks are of the proper type for the system you are using, both in size (5.25" or 3.5") and the format of the disk (single density, double density, high density, etc.). All disks must be formatted for the system before they are usable. See the operating manual for your computer system for instructions on proper formatting procedures.

Floppy disks need to be treated with care. Although they are relatively rugged and dependable, they can easily be mistreated to the point where files are lost or the entire disk made useless. Be very careful to never touch exposed parts of the disk itself, never place disks near magnetic fields (such as on your digitizer), and not bend the disk in any way.

If you are using a system that others will also be using, save all your work on floppy disks, even if only temporarily. Do not depend on a hard disk for saving anything past the time you are currently using the computer.

A good habit to develop is that of saving your work periodically as you create it. This ensures that if there is a power failure, or the system crashes, or something equally disastrous happens, you will lose only the amount of work done since you last saved. This policy is usually adopted readily by those who have lost an hour or more of construction because they did not save their work when their system crashed.

The system you work on will have a hardware configuration (computer, monitor, graphics boards, printer, plotter, digitizer, etc.). That configuration must be compatible with CADKEY and must be made known to CADKEY through what is known as the configuration program supplied by CADKEY. The assumption here is that your system has already been configured properly. If not, consult the CADKEY manual for details on configuration.

1. Turn the system on and access DOS (Disk Operating System).
2. Load the CADKEY software as follows (here, it is assumed that the CADKEY program is on a hard disk):