Seventh edition

Fundamentals of engineering drawing

for design product development, and numerical control

Warren J. Luzadder, p.e.

Fundamentals
of
engineering drawing

Preface

In addition to meeting present-day course requirements, a worthwhile text should anticipate trends and include new material that may profitably be presented to students over the several years that must pass before another edition can be justified. Anticipating trends is sometimes difficult, but the author has made an attempt to do so by expanding and up-dating computer graphics and by giving the measurement values for most of the illustrations and problems in millimeters, centimeters, kilometers, kilograms, and so forth. When our largest corporations, such as General Motors, Ford, IBM, TRW, McDonnell Douglas, Honeywell, Rockwell International, John Deere and Company, and International Harvester are all converting to metric, it is time for authors and educators to turn to the SI metric system (Système International d'Unités). The conversion period may be a long one, covering a decade or more. During this time, we could have widely different rates of progress in industry, with some companies, such as John Deere and Company and International Harvester, changing over quickly and totally to metric (as they have already done), while other companies remain in limbo for several years, depending upon a dual-dimensioning system to meet their needs. The long period of time that will be needed for the American National Standards Institute (ANSI) to change the many standards will act as a brake to slow down the rapidity of our movement toward a totally metric U.S. However, with the change to metric now well under way, a total changeover seems to be inevitable. At the time that this preface is being written, a special committee set up by ANSI to study and produce an Optimum Metric Fastener System has released OMFS Recommendations 2, 3, 4, and 6, which relate to metric screw threads. Hopefully, this will lead to a new and complete standard for ANSI–OMFS Metric Screw Threads sometime in the near future. The completion of this task and the release of a new standard for threads, however, will still leave much to be done before new sets of standards for fasteners can be made available to users. The instructor using this text is advised to point out to the students that many of those companies that claim to have gone totally metric still specify threads, fasteners, and standard parts using the inch system of the existing standards. In addition, their drawings include an inch conversion chart for the use of suppliers who are not equipped to handle metric dimensions. Metric equivalents, conversion multipliers, and tables for metric drills and metric threads have been added to the Appendix.

It has been reported that ANSI committee Y14.5 is at work on a revision of the standard to incorporate metric dimensioning. If so, it is possible for this revision to be approved and published as early as 1978. In the revision of this text, the author has been guided largely by the metric design and drafting standards furnished by General Motors, John Deere and Company, and International Harvester. International Harvester furnished an almost complete standard, while GM furnished material needed for metric screw threads and surface quality. The thoughtfulness and kindness of the several administrators and standards engineers is deeply appreciated.

This text has not been made totally metric because ANSI standards were not available to make this possible. Also, since the English inch, foot, mile, acre, pound, and so forth will be with us for many years to come, it was thought to be wise to retain some drawings that show dimensions in inches and to prepare some of the illustrations showing how dimensions are to be given using both systems. In general, this was done in the chapter covering dimensioning. Elsewhere, illustrations and problems show all metric or they have been dual-dimensioned. Where problems show inch measurements, the instructor may either require the part to be dimensioned in inches or he may ask the students to use millimeters. If a conversion to metric is made by the students, they will acquire a better understanding of the metric system. The author has had the good fortune to have been forced to face the metric system in 1960 with a Spanish translation of an earlier edition.

For convenience this text has been arranged in seven main parts: Part I, Basic Graphical Techniques; Part II, Spatial Graphics: Shape Description and Spatial Relationships; Part III, Design; Part IV, Graphics for Design and Communication; Part V, The Computer; Part VI, Graphic Methods for Engineering Communication, Design, and Computation; and Part VII, Design and Communication Drawing in Specialized Fields.

Part I covers the use of instruments, lettering, and engineering geometry. Part II provides essential information on basic graphics, spatial geometry, and pictorial representation. Part III presents the procedures of the design process and endeavors to show the interrelationship between design and manual drafting that includes both sketching and instrumental drawing. This chapter is new for this edition. Part IV presents information needed to prepare engineering drawings. The chapters in this part are: Chapter 13, Size Description: Dimensions and Specifications; Chapter 14, Threads and Standard Machine Elements; Chapter 15, Shop Processes, Shop Terms, and Tool Drawings; and Chapter 16, Production Drawings: Preparation and Duplication. Part V (Chapters 17 and 18) covers the field of computer-aided design, automated drafting, and numerically controlled machine tools. At all institutions, particularly where computer-aided design systems are available, Chapter 17 should be assigned for reading and discussion. In addition, since practical knowledge of these systems can only be gained by either working experience or by on-the-scene observations, instructors of graphics and design should schedule plotter time and CRT (cathode-ray tube) console time for demonstrations. If this is not possible, several excellent motion pictures are available (see the Bibliography) that may be shown in lieu of actual demonstrations.

Part VI presents the graphic methods commonly employed for communication, design, and computation. Finally, Part VII provides the information needed to prepare drawings in specialized fields so that problems may be assigned to broaden overall knowledge of the field of graphics, particularly in an area of individual and class interest.

To bring this text abreast of new technological developments, a number of leading industrial organizations have generously assisted the author by supplying appropriate illustrations that were needed in developing specific subjects. Every commercial illustration supplied by American industry has been identified using a courtesy line. The author deeply appreciates the kindness and generosity of these many companies and the busy people in their employment who found the time to select these drawings and photographs that appear in almost every chapter.

The author is grateful to Professors K. E. Botkin, R. L. Airgood, R. P. Thompson, and other members of the graphics staff at Purdue University for their many valuable suggestions in regard to the content and organization of this seventh edition.

Special appreciation must be expressed for the contributions of Professors W. L. Baldwin, R. H. Hammond, Byard Houck, and J. F. Zimmerly of the Ford Motor Company. Professor Baldwin of Purdue University developed the material on linkages. Professors Hammond and Houck contributed new material to the chapter on computer-aided design. Professor Houck is an authority on the TRIDM program that has been prepared at North Carolina State University at Raleigh, since he played a large role in its development. Mr. Zimmerly supplied the author with new information and material in the area of computer graphics that has been included in Chapter 17. Not to be forgotten is the

fact that there are many persons, some known and others unknown, who have made valuable contributions to this classroom text. The author's indebtedness to these persons is hereby reaffirmed.

Last, I would like to acknowledge two gentlemen for their outstanding work on this text. The first, Mark A. Binn, senior book designer, did an excellent job on the cover and interior designs. The second, Ken Wisman, production editor, did superb work handling all aspects of production. My sincere thanks to both.

W. J. L.
Purdue University

Contents

26

Appendix

1 Introduction

1.1

Brief History of Drawing. For upward of twenty thousand years, a drawing has been the principal means for the portrayal of ideas through the use of lines. Its beginnings, however, are still further back in time, for our early ancestors undoubtedly explained their ideas by marking in the dust on the floors of their caves. It is deeply rooted in our instincts and, in a sense it is our one universal language even today, when some of our drawings are prepared by computers and plotters (Fig. 17.17). The earliest records of man are graphic, depicting people, deer, buffalo, and other animals of the time on the rock walls of caves. These drawings were to satisfy an elemental need for expression, long before the development of writing. However, drawing gradually freed itself from this early usage when writing was developed and it then came to be used primarily by artists and engineering designers as a means of setting forth ideas for the construction of finished works such as pyramids, war chariots, buildings, and simple mechanisms useful to man. Most of the very early drawings that still exist were made on parchment, which was very durable. Later, during the twelfth century, paper was developed in Europe and came into general use for drawings.

Only a few of the earliest drawings for fortresses, buildings, and simple mechanisms are in existence today. Those that have come down to us have been largely pictorial in nature, and they exist as carvings and paintings on walls of structures or have been woven into tapestry. One of the earliest representations shows the use

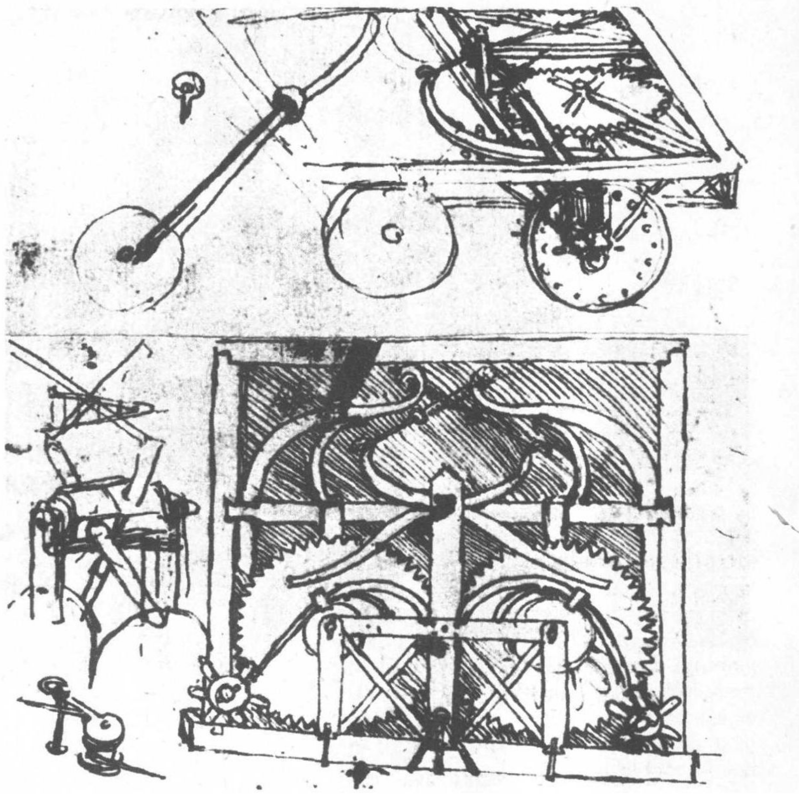

Fig. 1.1 Idea sketch prepared by Leonardo da Vinci (1452–1519). The da Vinci "automobile" was to have been powered by two giant springs and steered by the tiller, at the left in the picture, attached to the small wheel. (*From Collection of Fine Arts Department, International Business Machines Corporation*)

of the wheel about 3200 B.C. in Mesopotamia. The drawing presents a wheelbarrow-like structure being used by a man to transport his wife or child. The pictorial is primitive without any depth of perspective. Also, a ground-plan type of drawing for a fortress exists on a tablet prepared about 4000 B.C.

At the beginning of the Christian era, Roman architects had become skillful in preparing drawings of buildings that were to be constructed. They used straightedges and compasses to lay out the elevation and plan views and were able to prepare well-executed perspectives. However, the theory of projection of views upon imaginary planes of projection was not developed as a means of representation until sometime during the Renaissance period. Even though it is probable that Leonardo da Vinci was aware of the theory of multiview drawing (Fig. 1.5), his training as an artist prevailed and he recorded his ideas and designs for war machines and mechanical constructions by preparing perspective sketches and drawings such as the one shown in Fig. 1.1. No multiview drawings prepared by da Vinci have been found. He knew the value of a pictorial drawing, and it is interesting to note that even in this day of space travel, we prepare pictorial drawings to supplement our other design drawings (see the pictorial drawing of Skylab in Fig. 1.2).

1.2 Interrelationship of Engineering Graphics (Drawing) and Design.

Since design graphics and design are interrelated in the total design process, those persons preparing the design layouts, the detailers, and the production engineer who has been assigned to the project must work closely at times with the project group leader as a part of the total design team. In general, all persons assigned to a project, both designers and those who support the design effort at any stage, should have full

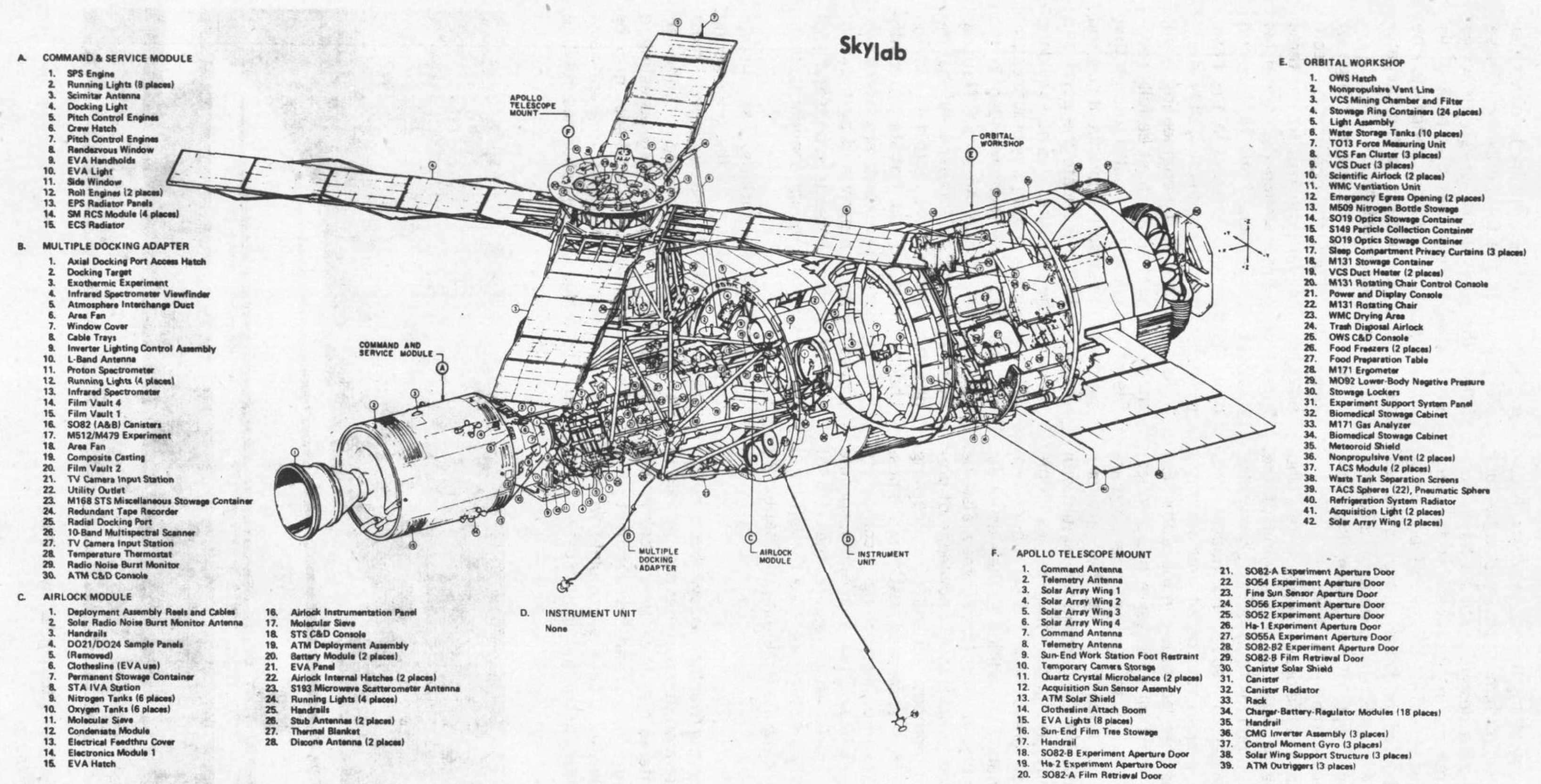

Fig. 1.2 Skylab—manned orbital scientific space station. The Skylab was designed to expand our knowledge of manned earth-orbital operations and to accomplish carefully selected scientific, technological, and medical investigations. (*Courtesy National Aeronautics and Space Administration*)

knowledge of engineering graphics. A design engineer himself, if he is to be successful as a designer, should have thorough training in this area. At the very least, he should be capable of preparing well-executed freehand design sketches and have a working knowledge of all of the forms of graphical expression that have been presented in this text.

Persons in the design support area, who may be expected to solve some of the design problems that arise graphically, prepare design layouts and models, and, finally, prepare the detail and assembly drawings needed for use in the production shops, must all have some basic education in the classroom and then acquire added experience where they are employed in order to become acquainted with company standards and practices. Some of these present-day "design-room professionals," in addition to their usual assignments, as mentioned, may also be expected to have some knowledge of production methods, particularly concerning numerically controlled (NC) machines, and have an understanding of computers (Chapters 17 and 18). In addition, specific design tasks may require the use of digitizers and plotters. (See the left-hand page facing the beginning of Chapter 2.)

1.3

Engineering Graphics Today. Even though the attention of a designer may be said to be centered mainly on the problems that arise in design and development (Fig. 1.3), he must have a complete working knowledge of communication drawing, for it is often his responsibility to direct the preparation of the final drawings. These follow the preliminary design drawings and instructive sketches that he and his aids have prepared in accordance with the basic principles underlying the preparation of working drawings.

For a full and complete exchange of ideas with others, the engineering technologist must be proficient in the three means of communication that are at his disposal: (1) English, both written and oral; (2) symbols, as used in the basic sciences; and (3) engineering drawing.

As a member of the engineering team, the design draftsman must be fully capable of preparing the final drawings that will convey the information about size and shape needed to fabricate the parts and assemble the structure. This must be done in accordance with company practices and with the practices recommended in the publications of the American National Standards Institute. It is expected that the design draftsman keep up to date with the changes in standards that are constantly being made by standards engineers employed by his company and by the committees working under the sponsorship of the American National Standards Institute.

Engineering technicians, assigned to production areas or to the engineering department to aid the engineers, must have considerable knowledge of engineering drawing. Those closely assisting a design engineer or technologist may be called on to solve problems graphically, and to make working sketches relating

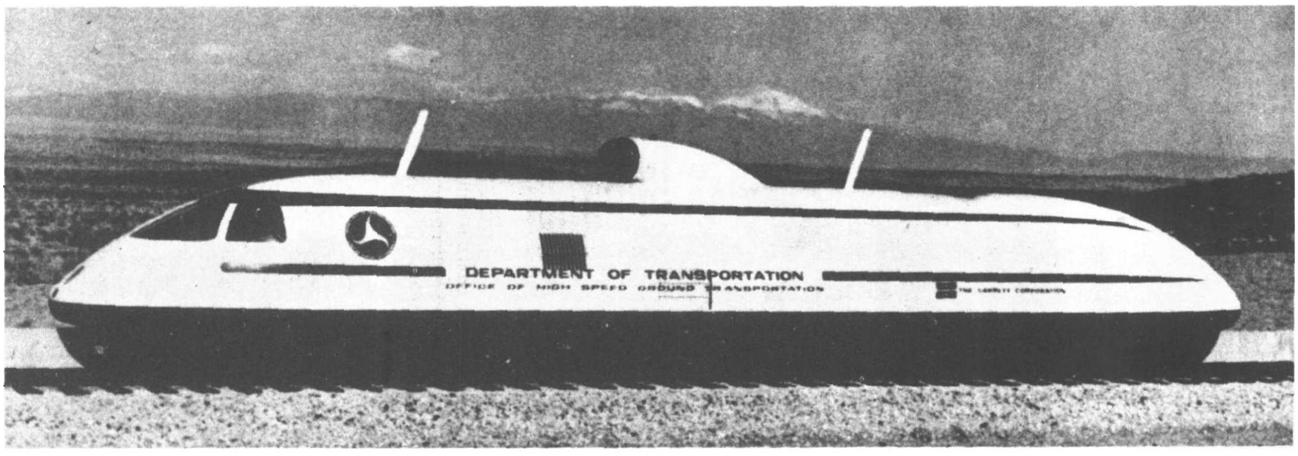

Fig. 1.3 Linear induction motor test vehicle on a run at DOT's testing facility at Pueblo, Colorado. *(Courtesy U.S. Department of Transportation)*

to mechanisms, electrical circuits, and structural systems.

1.4

Organization of the Text. The purpose of this text is to present the grammar and composition of drawing so that those students in engineering colleges and technical institutes who conscientiously study the basic principles will eventually be able to prepare satisfactory industrial drawings and, after some practical experience, be capable of directing the work of others. To facilitate study, the subject matter has been separated into its various component parts: engineering geometry, multiview drawing, dimensioning, pictorial drawing, sketching, design, and so forth. Later chapters discuss the preparation of working drawings, both detail and assembly, computer-aided design, the preparation of topographic drawings, and the construction of charts and graphs. The major portion of the material presented leads up to the preparation of machine drawings, which the prospective members of some of the other branches of engineering technology think is not of interest to them. Since the methods used in the preparation of machine drawings, however, are the same methods used in the preparation of drawings in other fields, a thorough understanding of machine drawing assures a good foundation for later study in some specialized field, such as structural drawing. For those interested in specific types of drawing, some material has been presented with the assumption that the student already possesses a working knowledge of projection and dimensioning.

Proficiency in applying the principles of orthographic projection leads to easy graphical methods of solving space problems such as the determination of the clearance distance between a wheel and a fender or the true angle between a turbine blade route and the engine axis (Chapter 9).

1.5

Graphics and the Computer. The graphic language has become a means for an intimate and continuous conversational style of interchange between man and computer in the process of creative design. At present, computer systems have been developed that are in daily use and that interact with a human partner using the designer's own graphic language (Fig. 1.4). In bringing the computational power of the digital computer to bear on graphical design, special image processing systems have been built that allow the computer to both read and generate drawings. Chapter 17 covers computer graphics in considerable detail.

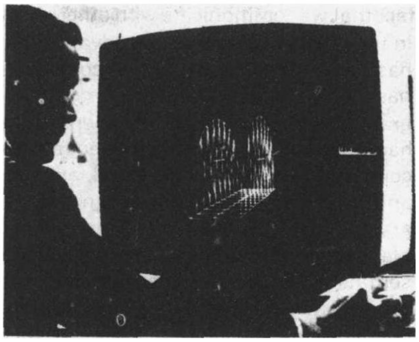

Fig. 1.4 An engineer working at a graphics display unit to find solutions to problems that have arisen in the design. With the electronic "light pen" the designer can revise the image and change the parameters. An engineer may work with diagrams, drawings, or printed letters and numbers directly on the face of the tube. This direct man–computer interaction leads to quick answers and permits concepts to be easily evaluated and then accepted or rejected. *(Courtesy International Business Machine Corporation)*

1.6

The Present and the Future. This is a period of revolutionary change in the field of communication technology. At the present time, we are integrating new methods with the stylized methods of the past, using each method where it would seem to be best suited for the production of technical communications. We will continue to draw graphical representations manually and print out dimensions, notes, lists of materials, and so forth for the foreseeable future. However, plotters used on-line with computers or off-line directed by tapes will continue to gain wider utilization. Plotters are used in particular by aircraft and aerospace companies that produce products having complex contours. They are used also to a limited extent for the preparation of ordinary drawings of machine parts, for printed circuitry, for structural steel drawings, for highway route plans, and for determining the tool paths of milling (NC) machine tapes (Chapters 17 and 18).

Since nothing has happened to alter the

fact that we communicate with others best in the graphic language, one advance that has come about in the use of computers has been the development of computer graphics—that is, the development of the hardware and the software that enable the computer to accept, understand, analyze, and produce engineering design data in graphic form. Persons who are responsible for the preparation of technical representations must become familiar with programming and with the use of both the computer and the plotter. These are their newest design and drafting tools. Although plotters are somewhat sophisticated as well as expensive, they save the designer and draftsman hours of tedious manual labor.

No new developments appear on the immediate horizon that will relieve the designer of the task of thinking out his design or the draftsman of the responsibility of applying the knowledge of his trade. Furthermore, recent technological breakthroughs have served to extend, rather than supplant, the direct application of the principles of engineering drawing by designers and draftsmen. The technical field needs the graphic language in all of its many forms.

As technology advances to meet the rising expectations of people all around the world, more and more drawings and other forms of graphical representation will be required. Most of these, as might be expected, will continue to be prepared manually.

Automation has already entered the field of communication technology and therefore must be accepted by those persons now in the field and by those about to enter. The only question that either a student or a technically trained man now at work can ask himself is whether or not he can adjust to new knowledge, new methods, and different requirements during his career.

1.7

Role of the Computer and Plotter in the Drawing Room. Although words alone may not relieve entirely a person's concern about the continued importance of drafting, an understanding of the true role of the computer and plotter in the design room will answer some, if not all, of the questions that may arise in one's mind. Those who have been employed, where computers have taken over a number of graphic functions, welcome their use because they have learned that computers can accomplish those repetitive tasks, such as wire routing, schematics, and repetitious mechanical drafting, that can be very boring and time consuming to the draftsman. This leaves a large number of drawings in the field of mechanical design still to be done by draftsmen and detailers at the drawing board (see the page facing Chapter 2). In this category are drawings of piece parts that must be prepared manually. In the aircraft industry, where computers, digitizers, and plotters are readily available, manually prepared drawings now constitute at least 50% of the total drawing output. Each of these drawings done on the board is so unique and different as to require human intelligence for its preparation, together with in-depth knowledge of graphics and shop practices. It should also be noted that the design layout, which defines the function and shape of these parts being drawn, was of necessity prepared manually in the preliminary design stage of the design project. Design layouts will continue to be drawn manually until the time comes when we are willing to forgo the idea of producing better products and commit ourselves to the continual production of products and systems already designed. Knowing the restlessness and competitive nature of humankind, this author predicts that this day is far in the future.

It should be noted, however, that at this point in time there are a few types of mechanical drawings that can be prepared other than manually through the use of a digitizer or a cathode ray tube coupled to a design-assist system (Chapter 17), the output in this case being a magnetic tape for a numerically controlled machine (Chapter 18).

Those who may be interested in learning more about the role of the computer in design should read Chapters 17 and 18. These two chapters present detailed information on computer-aided design and numerically controlled machine tools. In reading these chapters, one should come to the conclusion that there is a need to know graphics and that the computer will never make the teaching of graphics obsolete at any level of our educational system.

1.8

Major U.S. Corporations Go Metric. Although the metric system was legally approved for the United States by an Act of Congress more than 100 years ago (1866), it has not been widely used up to the present