A. S. LEVENS

GRAPHICS

WITH AN INTRODUCTION TO CONCEPTUAL DESIGN

A. S. Levens, Professor of Mechanical Engineering
University of California, Berkeley, California

GRAPHICS

WITH AN INTRODUCTION TO CONCEPTUAL DESIGN

John Wiley & Sons, Inc., New York • London

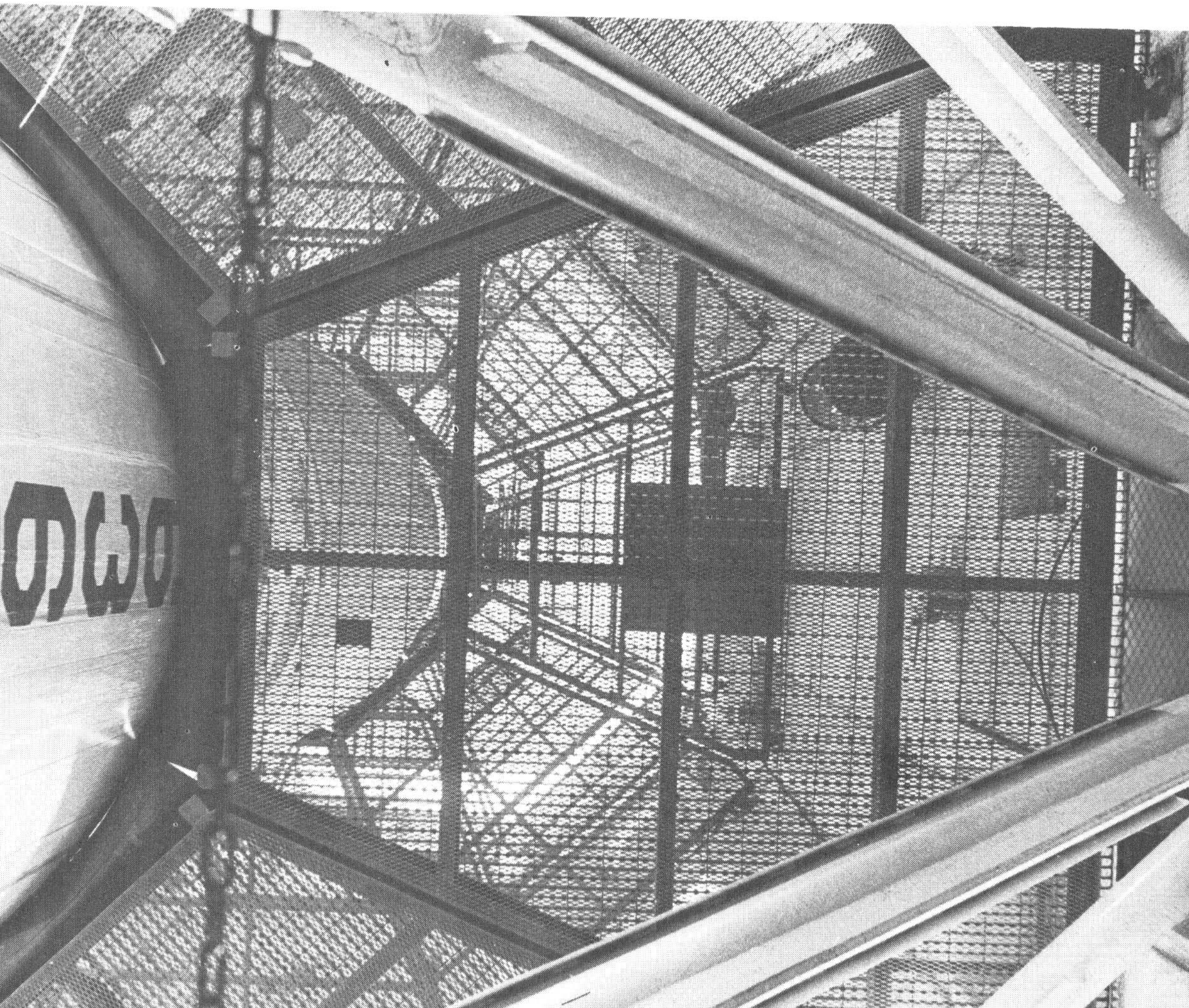
Library of Congress Catalog Card Number: 62–15183

Printed in the United States of America

SECOND PRINTING, MAY, 1963

GRAPHICS

WITH AN INTRODUCTION TO CONCEPTUAL DESIGN



Preface

The well-qualified engineer must be proficient in mathematics, graphics, physics, chemistry, and the engineering sciences. In addition, he should have a good background in the humanities and social sciences.

In developing solutions to real engineering problems, the creative art of conceiving a physical means of achieving an objective is the first and most important step. Analysis of the possible solutions is the second step. Stated simply, synthesis in conception precedes the analysis required to refine the conception.

Graphics plays a most important role in the conceptual design phase; and in many cases it is also most effective in the analysis stage. Of course, the study of analytical courses is very necessary because it is difficult without analysis to predict performance of a conceptual design while it is still on paper.

The technological demands of our scientific era have brought about much closer working relations between engineers and scientists. For effective communication both must be proficient, not only in mathematics, physics, and chemistry, but also in engineering graphics; and certainly in a common form of oral and written expression.

Engineering education must contribute, significantly, to the development of young, well-qualified persons who can and will face new and challenging engineering situations with imagination and confidence.

With respect to graphics and its important role in engineering, it is essential to provide programs of study that are pertinent to the students' preparation for the engineering profession. Certainly, development of facility in freehand sketching —both pictorial and orthographic—is most important for both engineering and science students in order to provide an effective *graphic extension of the mind.*

Engineering as a profession is concerned primarily with design. In fact, the core of engineering is design which, in the broadest sense, includes circuits, machines, structures, processes, and combinations of these components into systems and plants. The professional engineer must be capable of predicting the performance and cost of the components, systems, and plants to meet specified requirements. We must not overlook the fact that the theoretical scientist is primarily concerned with the discovery of new knowledge and the development of new scientific principles, whereas the engineer is concerned with the implementation of these principles. The professional engineer deals with the applications of science, tempered by judgment based on experience, to the solution of real engineering problems.

Designing is a conceptual process which is done largely in the mind, and the making of sketches is a recording process, a reliable memory system, which the engineer uses for self-communication to help him "think-through" the various aspects of his project. Graphics is an integral part of the conceptual phase because, more often than not, the making of a simple sketch to express a design conception does of itself suggest further ideas of a conceptual nature. Engineers who have developed their ability to visualize geometrical and physical configurations and to "think graphically" have a decided advantage in creating a physical means of achieving an objective.

The student who undertakes preparation for the exciting and stimulating profession of engineering must have adequate education in graphics. This means not only facility in freehand sketching, but also thorough knowledge of (*a*) the fundamental principles of orthogonal projection and experience in the application of those principles to the solution of space problems that arise in both engineering and science; (*b*) knowledge and use of graphical solutions and methods of computation; and (*c*) the development of capability to cope with the "many-solutions" type of problems that are so characteristic of engineering.

The principal objective of this book is to provide for the student a modern treatment of graphics and an introduction to conceptual design that will help him become "graphically literate," so that with confidence he can employ graphics—a powerful mode of expression—to the synthesis, analysis, and solution of problems that arise in the fields of design, development, and research.

It is presumed that the student has already developed a reasonable degree of proficiency in manual dexterity with respect to lettering, use of drawing instruments, geometric constructions, etc., in high school or, if feasible, in noncredit prerequisite work in a college. The material in Appendix A of this text, and the problems in the appendix of the workbook, number one, provide ample subject matter for this purpose.

Part 1, Fundamental Principles and Applications of Orthogonal Projection, *lays stress on principles. Rote learning is discouraged. Thorough grasp* of the few fundamental principles will greatly enhance the students' ability to "think through" and solve various space problems that arise in both engineering and science. The student is encouraged to use freehand sketches in planning the arrangement of views that may be necessary for the solutions and in recording his thought process in evolving the solutions. *Emphasis is on thinking, not on draftsmanship.* Interesting examples of the application of the fundamental principles of orthogonal projection to problems that have arisen in the field of research are included.

The diligent student will be able to apply the principles to the solution of many problems that "appear" to be different, but are *basically* the same.

The treatment of vector quantities and vector diagrams with applications to three-dimensional force systems affords the student another opportunity to apply the fundamental principles of orthogonal projection to the solution of concurrent, non-coplanar force problems.

Chapter 11, the final chapter of Part 1, is intended to strengthen the students' ability in analysis. It is suggested that reference to this chapter be made whenever appropriate.

Part 2, Graphical Solutions and Computations, includes the graphical presentation of data; graphical mathematics—arithmetic, algebra, calculus; empirical equations (forms most frequently encountered in engineering); functional scales; and an introduction to nomography. The student will find this part most interesting and stimulating. His understanding of integration and differentiation will be enhanced by his experience with the material on graphical calculus. The student will realize that many problems cannot be conveniently expressed in the symbolic language of mathematics and that a graphical (which is also mathematical in the broad sense) method may be better suited to the solution of the problem.

At the time when the material on graphical, numerical, and grapho-numerical methods of integration and differentiation is presented, it has been found appropriate to *introduce computer solutions.* A number of examples are included to demonstrate the employment of graphical methods in the solution of problems that have arisen in research projects at the University of California at Berkeley.

The material on nomography is an adequate introduction to this most useful and fascinating field. The student will discover that nomograms play an important role in the repeated solution of formulas and also in analyzing the relations among three or more variables for which an explicit or an implicit relation exists. (In very recent years a nomographic method has been developed to test the validity of a family of experimental data curves.*)

Part 3, Introduction to Conceptual Design, affords the student an opportunity "to be on his own." His background in graphics—based on the material in the first two parts—coupled with his course work in mathematics, chemistry, physics, and perhaps some actual job experience will have a direct bearing on his progress in dealing with *projects that have many solutions.* The experience in facing up to such problems will enable the student to approach, with greater confidence, real engineering situations that will confront him later. *We cannot start too early to give the student the experience of confronting and solving, reasonably well, the "open-ended" type of problem. The freshman year is not too soon!* It is recognized that the student's background is quite limited at this stage of his career, and because of this the proposed problems are relatively simple and limited in scope. *Nevertheless, in principle* they are of the same character as some of the most advanced problems in engineering practice. The student will find his experience in conceptual design stimulating, challenging, and rewarding. A good spirit of competition is generated among the students—especially with regard to who has the "best" design.

The chapters on pictorial drawing, sections and conventional practices, fasteners, dimensions and specifications, dimensioning for precision and reliability, constitute additional background material for the chapter on conceptual design. Where the student has had good experience in the above areas, more time can be devoted to conceptual design.

An appreciation of some of the problems that confront the engineer is the matter of "dimensioning for precision and reliability." It is strongly recommended that some time be devoted to this chapter so that students will understand the importance of this subject, especially today in connection with the design of various space vehicles.

As the student progresses in his engineering education and enters upon the study of mechanics, strength of materials, design (in the broad sense), and research, he should continue to employ, whenever appropriate, graphical methods to solve problems that arise in these areas.

* In the author's 2nd edition of *Nomography,* John Wiley and Sons.

Graphics, with an introduction to conceptual design, as presented in this text, reflects our continual effort to develop a meaningful and worthwhile treatment which, we believe, is consistent with the needs of a scientific era. The experience with our students continues to be most gratifying. *Students are stimulated to learn and to apply fundamental principles; to "think-through" a problem, rather than depend upon rote learning;* to learn and use graphical methods of computation; and to appreciate, through their own experience with conceptual design, that the qualified engineer must have the necessary education and experience to cope with real engineering situations that arise, and will continue to arise, in an ever-growing, dynamic technological era.

I deeply appreciate the cooperation received from the following organizations and editors of several journals and periodicals, in permitting the use of certain photographs, charts, and drawings: Aerojet-General Corp., American Standards Association, The Bendix Corporation, The Boeing Co., Columbia-Geneva Steel Division of the U. S. Steel Corp., *Chemical Engineering,* Continental Can Co., Inc., Convair Division of General Dynamics Corp., Firestone Tire and Rubber Co. of California, Food Machinery and Chemical Corp., General Motors Corp., Hiller Helicopter Corp., *Industrial Fasteners Institute,* International Business Machines Corp., Leeds and Northrup Co., Librascope, Inc., Lockheed Aircraft Corp., *Machine Design, Materials in Design Engineering, Military Systems Design,* North American Aviation, Inc., *Product Engineering,* San Francisco Naval Shipyard, Society for Automotive Engineers, Toby Enterprises Corp., San Francisco, Calif., U. S. Electrical Motors, Inc., Varian Associates, and Westinghouse Electric Corp.

My thanks to Messrs A. E. Edstrom and J. F. Schon of the City College of San Francisco—the former for many valuable suggestions, and the latter for his assistance in procuring excellent practical examples for the material on dimensioning for precision and reliability; and for a critical review of the presentation. I am also appreciative of the efforts made by Professor R. W. Reynolds, California State Polytechnic College at San Luis Obispo, California, for his assistance in developing some problem material.

I am grateful to my colleagues at the University of California: Professor H. D. Eberhart, for the use of materials from the Prosthetic Devices Research Project; Professors L. J. Black, J. E. Dorn, F. E. Hauser, R. R. Hultgren, and H. W. Iversen, for experimental data used in connection with several illustrated examples in the chapters on empirical equations and graphical calculus; and to Mr. Paul Urtiew, graduate student, for the photograph and the delineation of the system used in connection with the research project on gas dynamics, shown as an example in the chapter on graphical calculus.

And to my wife, Ethel, whose patience and understanding made possible an environment which was conducive to productive writing, my ever-lasting and heartfelt appreciation.

A. S. LEVENS

Berkeley, California
April, 1962

Contents

Part 1

Fundamental Principles and Applications of Orthogonal Projection

1 Introduction

Engineering education must contribute to the development of men who can face new and difficult engineering situations with *imagination* and confidence. Meeting such situations invariably involves both professional and social responsibilities.

Throughout the history of the development of engineering education, we have witnessed significant changes in engineering curricula—changes that have been necessary in order to keep pace with the rapid growth in technology. The ever-increasing importance of research, development, and design has brought about the need for more "science-oriented" curricula in engineering. Greater emphasis is placed on mathematics, physics, chemistry, and the engineering sciences and less on the "art of engineering." There is little doubt that the demand for *highly qualified* engineers and scientists is still increasing.

The theoretical scientist is primarily concerned with new knowledge. When a new principle of physics is developed, that is science; but when the new principle is used in designing and launching a space vehicle, for example, that is engineering. The engineer is primarily concerned with the implementation of the new discoveries of the scientist. The design of a vehicle (or, for that matter, other useful products) requires of the engineer effective knowledge of the mathematical and physical sciences, and of engineering graphics; professional engineering experience which reflects good judgment in determining need, feasibility, economy, and reliability of a proposed project; and proficiency in the use of the English language in both its oral and written forms.

In the preliminary stages of a project many ideas are presented orally or in written form, with accompanying "idea sketches," layouts, and often models, to enable those in responsible charge to carefully study and analyze problems of feasibility, design, costs, etc. In many situations it is necessary to solve a number of technical problems that may involve research, development, and design. In these areas considerable use is made of mathematics, graphics, physics, and chemistry.

For many decades engineering graphics has been associated, almost entirely, with representation—detailed drawings of components of a mechanism or structure, assemblies of components, product design, and production illustration. Prior to World War II much of this type of work was performed by graduates of engineering schools. Since then, and particularly in recent years, such work is carried on by technicians who are supervised by graduate engineers.

As a student who undertakes the study of engineering with the hope of becoming a competent professional engineer, you must have adequate education in the field of engineering graphics. This means thorough knowledge of the fundamental principles of orthogonal projection and experience in the application of these principles to the solution of three-dimensional problems that arise in the various fields of engineering and science; *proficiency in freehand sketching*—a powerful tool for expressing ideas, for planning solutions, for recording analyses (the "thinking-through process") of space problems; and an understanding and use of graphical mathematics, including empirical equations, functional scales, graphical calculus and elements of nomography.

There are numerous problems in engineering that are best solved graphically. Graphical solutions, in many cases, are much quicker, more vivid, more practical, and less likely to incur accidental errors than solutions obtained algebraically. In some cases a mathematical solution may not be possible. For example, a large and well-known aircraft company was faced with the problem of designing and fabricating a very large acoustic sound generator. Mathematicians had declared the project impossible because the parameters were partially undefinable and a suitable series of equations could not be derived to provide design criteria with sufficient accuracy to satisfy the needs of the design engineers. However, the decision to proceed with the successful design and development was based on a graphical analysis of the various problems involved in the design.

In many situations, technical problems are concerned with length, time, temperature, pressure, etc., quantities that can be measured only approximately. The reading of a thermometer, for example, can be only as accurate as, among other things, the graduated scale (graphical) and the visual acuity of the observer. This is also true of lengths, whose measurement again depends on a graphical scale; or of pressure, whose measurements depend on a gage mechanism and a scale for reading numbers; or, of voltages, currents, and many other quantities which are measured by devices that indicate values on a scale that is read by an individual. The *data are graphical* in nature. Certainly a graphical solution of a problem that inherently is based on graphical data can be arrived at by graphical methods with sufficient accuracy. The fact that we use numbers, obtained by reading various scales, in a mathematical solution of the problem does not, by any stretch of the imagination, make such a solution more accurate than a graphical one.

We know that thorough training in mathematics is essential to sound engineering and scientific activity. It is, however, important that, as a student, you do not get a *warped* view, so that your training will lead to *the intelligent use of several methods* and, it is hoped, to the *development of good judgment* in the choice of methods. In many cases a combination of algebraic, graphic, numerical, and mechanical methods is best suited to the solution of technical problems.

In this treatment of graphics in engineering and science, Part 1 lays stress on the *fundamental principles* of orthogonal projection and the application of these principles to the solution of a variety of problems that arise in technology. Every effort is made to strengthen your ability to visualize and to analyze (the "thinking-through process") space problems, and then to record the solutions graphically. Many opportunities are given you to develop your *creative thinking* and "imagineering."

Included in Part 1 are problems dealing with the determination of true lengths of members (rods, pipes, cables, etc.); the determination of clearances, as in the case of a bomb-release cable and an aileron-control cable, or, for that matter, in any case where specified clearances must be maintained between wires, pipes, or structural members; distance problems—(*a*) from point to line, (*b*) from point to plane, (*c*) between parallel planes, etc.; angle problems—(*a*) between lines, (*b*) between planes, (*c*) between line and plane; intersections, developments; vectors, and *graphic statics*, the treatment of which should enable the student to use the fundamental principles effectively in analyzing force problems and in solving such problems graphically. The first portion of graphic statics is concerned with two-dimensional systems, whereas the second portion deals with the determination of forces in three-dimensional frames. These problems afford the student an excellent opportunity to make use of the fundamental principles. Throughout Part 1—Fundamental Principles and Applications of Orthogonal Projection—the emphasis is on principles, analysis, and synthesis. Interesting examples of problems in the areas of design and research are demonstrated throughout Part 1. The development of power to analyze a space problem and then to solve it by employing the fundamental principles is an essential goal in educating the student to become self-reliant.

Reasonable proficiency in the use of drawing instruments is desirable, but *greater emphasis should be placed upon the development and use of good freehand techniques. The ability to make good freehand sketches is an invaluable asset.* Engineers and scientists should be able to use the techniques of freehand sketching effectively in presenting ideas to their co-workers. Engineers can save much time, and thereby do a more economical job, by preparing good freehand sketches *for use by the draftsman* in making finished working drawings. While still an engineering or science student you should develop facility in making good freehand pictorials and orthographic drawings. You should take advantage of every opportunity—not only in graphics courses—to gain experience in technical sketching.

Practice in making freehand sketches should become a hobby. The full realization of the importance of developing skill in *"talking with a pencil"* will become increasingly evident after you have graduated from college and have entered upon the practice of engineering. You need not be an artist or have special talents to produce good freehand sketches. The essential requirement is to draw a reasonably straight line between two points. Of course, some training and practice are necessary. The skill required is, surprisingly, no greater than any student needs for good legible writing. Good habits of accuracy, neatness, etc., are just as essential to freehand work as they are to the preparation of drawings with the use of instruments.

Part 2—Graphical Solutions and Computations—is primarily concerned with graphical analysis and graphic methods of computation. Included are chapters on Graphical Mathematics; Functional Scales; Nomography; Empirical Equations; and Graphical Calculus. You will greatly enhance your ability through the power of graphical methods that give meaning to algebraic-type problems. You will be able to use graphical methods to solve rate, displacement, velocity, and acceleration problems. In addition, you will have an opportunity to learn the theory and design of functional scales—their importance and use in connection with the representation and interpretation of experimental data. Again, in the design and construction of both Cartesian charts and alignment charts (nomography) further use of functional scales will be made.

Moreover, as a student you will soon realize the importance of nomography in dealing with the graphical representation of equations that require repeated solutions; and in analyzing the relationships among the several variables of a given mathematical expression. It will become apparent that the elementary phases of nomography can be grasped quite readily; that the basic theory is not beyond your understanding. The applications of nomography cut across many fields—engineering, physics, chemistry, psychology, biology, statistics, medicine, business administration, production, research etc.

The chapter on graphical calculus sets forth, in a simple manner, the meaning of integration and differentiation. Many examples—problems dealing with displacement, velocity, acceleration, areas, volumes, etc.—are included to provide interest for the student and to demonstrate the power of graphical calculus, as well as its usefulness. In short, past experience has shown that many students have been stimulated by all the material presented in Part 2, becoming eager to learn and to demonstrate their interest by their accomplishments.

Part 3—Introduction to Design—deals with *conceptual design, the creative art of conceiving a physical means of achieving an objective. This is the first and most crucial step in an engineering project.* The chapters on pictorial drawing, sections and conventional practice, fasteners, dimensions and specifications, and dimensioning for precision and reliability constitute additional background material for the important final chapter—Conceptual Design—Developing Creativity. The material of Parts 1 and 2 will be used in connection with Part 3. Projects provide for experience in synthesis—the opportunity to tie together fundamental principles, analysis, graphic methods of computation, and some introductory experience in engineering.

It should be quite clear that the material presented in this book is a *very significant part of the education of engineers and scientists—not* for the *training* of draftsmen.

It is my strong conviction that effective education in graphics must include the material presented in these three parts. Students so educated in graphics will have a fuller appreciation of the power of graphics and will be better able to integrate graphics with mathematics, physics, chemistry, mechanics, strength of materials, and engineering design. To increase your competence in graphics, take advantage of every opportunity given you to apply what you learn now to course work in the upper division (junior and senior years of college) and at the graduate level to course work and research. Sound education in graphics for engineers and scientists who can best meet the challenges of our accelerated growth in both engineering and science is of the utmost importance.

The engineers and scientists who will have had this education in graphics will greatly enhance their effectiveness by the use of their "graphical thinking" capacity in analyzing technological problems.