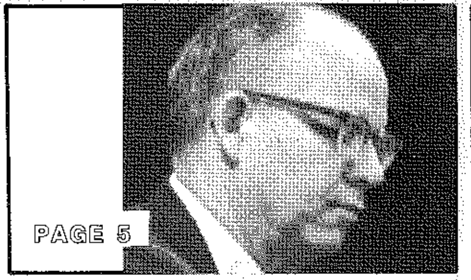

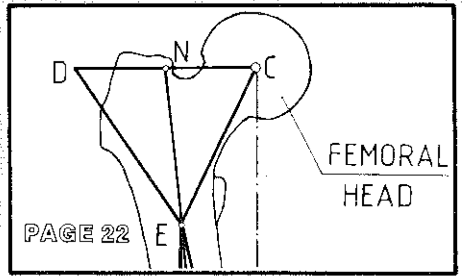

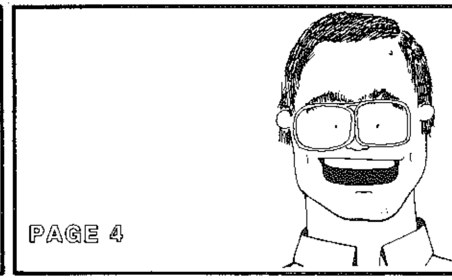

ENGINEERING DESIGN GRAPHICS JOURNAL

AUTUMN 1982 VOLUME 46 NUMBER 3

ENGINEERING DESIGN GRAPHICS DIVISION

ENGINEERING DESIGN GRAPHICS JOURNAL is published - one volume per year, three numbers per volume, in Winter, Spring, and Fall - by the Engineering Design Graphics Division of the American Society for Engineering Education, for teachers and industrial practitioners of Engineering Graphics, Computer Graphics, and Design Graphics, and Creative Design.

The views and opinions expressed by the individual authors do not necessarily reflect the editorial policy of the ENGINEERING DESIGN GRAPHICS JOURNAL or of the Engineering Design Graphics Division of the ASEE. The editors make a reasonable effort to verify the technical content of the material published; however, final responsibility for opinions and technical accuracy rests entirely upon the author.

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ENGINEERING DESIGN GRAPHICS JOURNAL OBJECTIVES:

The objectives of the JOURNAL are:

1. To publish articles of interest to teachers and practitioners of Engineering Grpahics, Computer Graphics and subjects allied to fundamentals of engineering.
2. To stimulate the preparation of articles and papers on topics of interest to its membership.
3. To encourage teachers of Graphics to innovate on, experiment with, and test appropriate techniques and topics to further improve quality of and modernize instruction and courses.
4. To encourage research, development, and refinement of theory and applications of engineering graphics for understanding and practices.

DEADLINES FOR AUTHORS AND ADVERTISERS

The following deadlines for the submission of articles, announcements, or advertising for the three issues of the JOURNAL are:

Fall	September 15
Winter	December 1
Spring	February 15

STYLE GUIDE FOR JOURNAL AUTHORS

The Editor welcomes articles submitted for publication in the JOURNAL. The following is an author sytle guide for the benefit of anyone wishing to contribute material to the ENGINEERING DESIGN GRAPHICS JOURNAL. In order to save time, expedite the mechanics of publication, and avoid confusion, please adhere to these guidelines.

1. All copy is to be typed, doublespaced, on one side only, on white paper, using a black ribbon.
2. All pages of the manuscript are to be consecutively numbered.
3. Two copies of each manuscript are required.
4. Refer to all graphs, diagrams, photographs, or illustrations in your text as Figure 1, Figure 2, etc. Be sure to identify all material accordingly, either on the front or back of each. Illustrations cannot be redrawn; they are reproduced directly from submitted material and will be reduced to fit the columnar page. Accordingly, be sure all lines are sharply drawn, all notations are legible, reproduction black is used throughout, and that everything is clean and unfolded. Do not submit illustrations larger than 198 x 280 mm. If necessary, make 198 x 280 mm or smaller photocopies for submission.
5. Submit a recent photograph (head to chest) showing your natural pose. Make sure your name and address is on the reverse side. Photographs, along with other submitted material cannot be returned, unless postage is prepaid.
6. Please make all changes in your manuscript prior to submitting it. Check carefully spelling, structure, and clarify to avoid ambiguity and maximize continuity of thought. Proofreading will be done by the editorial staff. Galley proofs cannot be submitted to authors for review.
7. Enclose all material unfolded in a large size envelope. Use heavy cardboard to prevent bending.
8. All articles shall be written using Metric-SI units. Common measurements are permissible only at the discretion of the editorial staff.
9. Send all material, in one mailing to: Jon M. Duff, Editor Engineering Graphics Department The Ohio State University 2070 Neil Avenue Columbus, OH 43210

REVIEW OF ARTICLES

All articles submitted will be reviewed by several authorities in the field associated with the content of each paper before acceptance. Current newsworthy items will not be reviewed in this manner, but will be accepted at the discretion of the editors.

CALENDAR

EDGD MIDYEAR CONFERENCES

1982 - California Polytechnic University
Pomona, CA

ASEE ANNUAL CONFERENCES

1983 - Rochester Institute of Technology
Rochester, New York

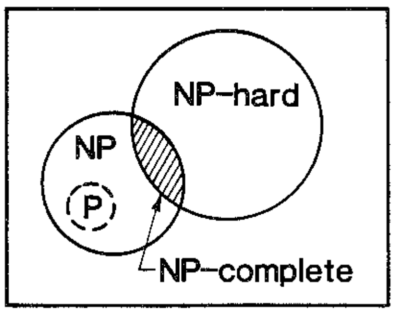
AMERICAN SOCIETY FOR ENGINEERING EDUCATION

ENGINEERING DESIGN GRAPHICS JOURNAL

AUTUMN 1982 VOLUME 46 NUMBER 3

DEPARTMENTS

FEATURES



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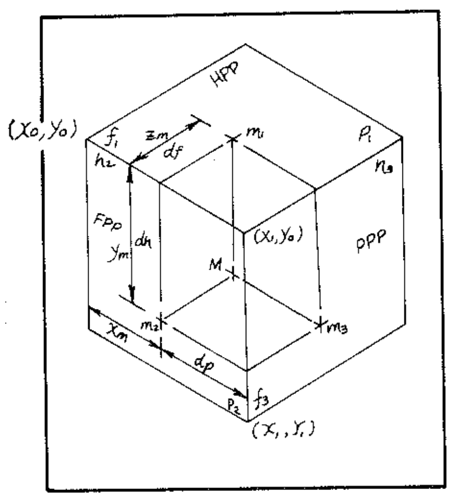

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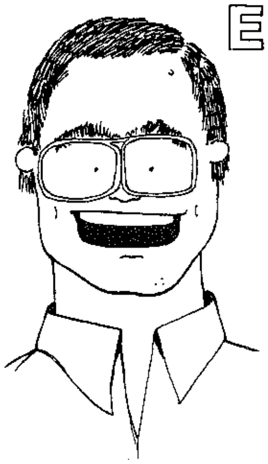
EDITOR'S PAGE



This is my first opportunity as editor to bring you an issue of The Journal and share with you some of my thoughts on our profession and the expanding body of knowledge we call graphics.

The Journal represents, I believe, the most important activity of our division. Rich in heritage and tradition, it has been a welcome friend to many a division member. It has been and will continue to be a forum for conventional and unconventional theory and practice. It gives programs the opportunity to distribute their experiences world-wide. Teachers have the chance to talk about methods, researchers enjoy a vehicle to share findings, and we all have the knowledge that we are in this thing together, and for common goals and purposes.

For many of us, graphics is the most important force in our lives. It's what we do as a livelihood, what we teach as a profession, and what we relax with as an avocation. It separates each of us from the "flat landers" and is both a blessing and a burden.

All of you in your diversity make up the rich fabric of contemporary graphics, and it is to you that these next issues are directed.

equipment, like flesh, is corporal and after it is gone what remains is the stuff that sticks together all of what we do

This first issue combines some really interesting pieces on theoretical geometry, computer graphics, applied graphical solutions, ethics, teaching, and news. It's the kind of issue each of you should find of interest, and represents well the diversity of our enterprise. It is international in scope and interdisciplinary in approach. To maintain this, I encourage all readers of The Journal to submit material for publication. With your contribution it will be possible to bring you the diversity of teaching, research, and practice in graphics.

It will be easy to find sufficient material in computer graphics to fill each issue, but of course that would fill no purpose for there are many fine publications devoted to this area. We would be the first to agree, here at Ohio State, that computers are going to play an increasingly important role in engineering and technology education in general, and by extension the teaching of design and graphics courses in these majors.

But make no mistake, our business is the teaching of graphics, the development of one of the tool skills every engineer and technologist must have. But remember: there was graphics before the quill pen, before the ruling pen, before the technical pen, and before the light pen, as there will be after. Computers are only the most recent development in a continuum of technology to produce, store, and transmit graphics imagery and supporting data. The only questions are when will the next development occur, and what will it be.

We have always been long on equipment talk and short on concept talk – never has this been more evident than with computer graphics equipment. But equipment is corporal, like flesh it is gone and what remains is the stuff that sticks all of what we do together. It is this stuff I invite you to explore in the upcoming issues of The Journal.

The Division of Engineering Design Graphics
American Society for Engineering Education

has bestowed upon

James Hubert Earle

its highest honor

THE DISTINGUISHED SERVICE AWARD

for his dedicated service to the Division and to engineering education, for his devotion to his students and colleagues, and as an expression of the admiration and respect of his professional peers.

James H. Earle, Head of the Engineering Design Graphics Department at Texas A&M University, and Professor in that department, has an outstanding record of professional service and achievement.

He graduated with a bachelor's degree in architecture at Texas A&M University in 1955, and served in the United States Air Force until 1957. During those years he spent his free time as a designer and illustrator, and extended his cartooning skills. Upon his discharge from the Air Force, he continued his education, obtaining a master's degree in 1962, and doctorate in education in 1964. During that period he served as an instructor, Assistant Professor, and Associate Professor in the Engineering Design Graphics Department at Texas A&M. He became Professor and Head of the department in 1969, and has remained in that position until the present.

Jim is a proficient author and illustrator. His cartoon character, "Slouch", which appears in the University's newspaper, The Battalion, has kept the students and faculty at "Aggieland" laughing for the past twenty-five years over events and conditions on their campus. He is recognized as an authority on graphics, publishing, and teaching methods. His many textbooks and teacher's guides on graphics and descriptive geometry are used in schools throughout the North American continent.

MID-YEAR MEETING

AUTUMN 1982

PROGRAM
EDGD-ASEE MID-YEAR MEETING
January 4-7, 1983
KELLOGG WEST CENTER FOR CONTINUING EDUCATION

TUESDAY, JANUARY 4

1:00 PM	Lodging Check-In and Registration
6:30 PM	Executive Committee Dinner and Meeting Faculty Center

WEDNESDAY, JANUARY 5 — AUDITORIUM

8:15 AM - 9:00 AM	Registration: Lobby
9:00 AM - 9:15 AM	Introduction, Program Chairman Robert Ritter Loyola Marymount University Moderator: Morning Sessions Warren White Centenary College
9:15 AM - 10:15 AM	Richard Latimer California State University; Sacramento, CA The Implementation of CAD/CAM into the Mechanical Engineering Technology Program.
10:15 AM - 10:45 AM	Coffee/Coke Break
10:45 AM - 11:30 AM	Ronald E. Barr The University of Texas at Austin Interactive Procedures for Geometric Data Entry and Modeling on a Small Educational CAD System.
12 Noon - 1:30 PM	Business Luncheon Moderator: Afternoon Sessions Jon M. Duff The Ohio State University
1:30 PM - 2:30 PM	Robert L. Norton Worcester Polytechnic Institute Computer Aided Design of Robotics Position Programming.
2:30 PM - 3:15 PM	L. V. Brillhart Triton College Computer Graphics: Comprehensive Utilization
3:15 PM - 3:30 PM	Coffee/Coke Break
3:30 PM - 4:30 PM	Randy Anderson Northrop Corporation Computer Graphics at Northrop Corporation
7:00 PM - 10:00 PM	EXHIBIT LOUNGE Demonstrations by selected manufacturing representatives of interactive computer graphics equipment.

THURSDAY, JANUARY 6 — Tour — Northrop Corporation Aircraft Division

9:00 AM	Bus leaves for Northrop
10:00 AM - 12 Noon	Avionics and Flight Simulation
12 Noon - 1:00 PM	Lunch — Northrop to Host
1:00 PM - 3:00 PM	Manufacturing and Computer Graphics
3:00 PM	Bus returns to Pomona
6:30 PM	DINING ROOM: CONFERENCE CENTER Social Hour and Banquet

FRIDAY, JANUARY 7 — AUDITORIUM

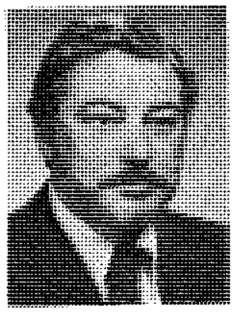
Moderator Warren J. Luzadder

8:15 AM - 9:00 AM	Roland Jenison Iowa State University The First Step Toward CAD.
9:00 AM - 9:45 AM	Frank Croft Speed Scientific School, University of Louisville Verification of Mold Cavities by Computer Graphics Techniques.
9:45 AM - 10:00 AM	Coffee/Coke Break
10:00 AM - 10:45 AM	Peter Miller Purdue University Developing Computer Graphics Expertise— The Purdue Experience
10:45 AM - 11:30 AM	Robert S. Lang Northeastern University 3-D Computer Graphics. It's as Easy as ABC.

Edward D. Galbraith
Industrial & Manufacturing Engineering
California State Polytechnic University
3801 West Temple Avenue
Pomona, California 91768
For additional information call Ed at (714) 598-4365

DIVISION NEWS

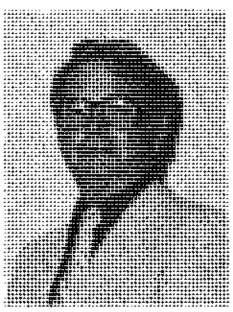
for vice chairman



Garland K. Hilliard
- Coordinator of Graphic Communications, North Carolina State University
- Past Editor of EDGJ
- Past Circulation Manager of EDGJ
- Co-author of several graphics workbooks and papers on self-paced instruction

Roland D. Jenison
- Associate Professor of Freshman Engineering, Iowa State University
- Program Director EDGD
- Co-author of freshman engineering textbooks
- Active in applying computer graphics to engineering instruction

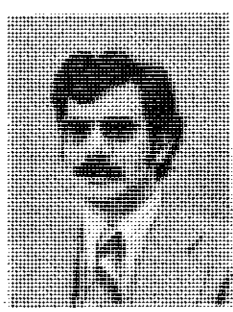
for director of laision



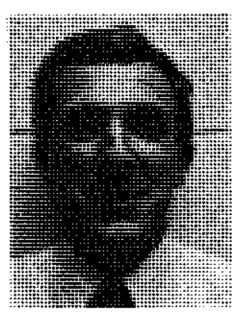
Robert N. McDougal
- Associate Professor of Engineering Mechanics, University of Nebraska/Lincoln
- Active in ASEE computer graphics committee, ASTM, and Nebraska NSPE

Merwin L. Weed
- Associate Professor of Engineering, Pennsylvania State University
- Director of Liaison EDGD
- Chairman MET program
- Received Jefferson Award

for director of programs

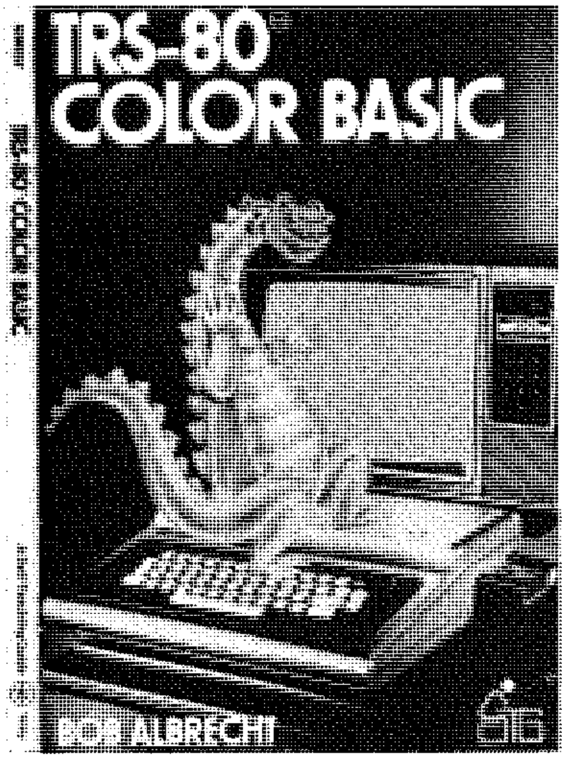


Ronald E. Barr
- Assistant Professor of Mechanical Engineering, University of Texas/Austin
- Co-author of several graphics texts and workbooks
- Program Chairman 1982 EDGD program at A&M
- Member ASEE, IEEE, Sigma X, NCGA



John B. Crittenden
- Assistant Professor Engineering Fundamentals, Virginia Polytechnic Institute
- Program Chairman EDGD MidYear 1982
- Member ASEE, AIAA, Virginia Academy of Science

IN REVIEW



Bob Albrecht. TRS-80 Color Basic: A Self-Teaching Guide. John Wiley and Sons, Inc.

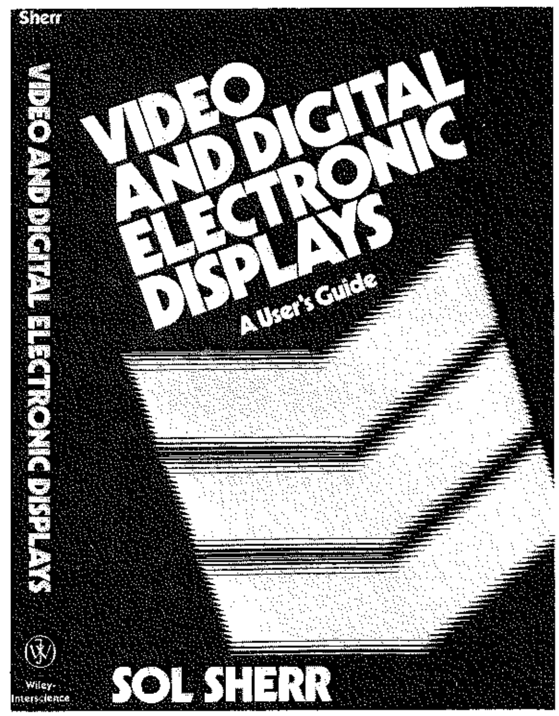
The intent of this puny text is to complement Radio Shack's instructional material for the minimum configuration of the TRS-80 Color computer. It is written for the person who may have just taken a new color computer right out of the box. The format for the first 11 of 12 chapters is a programmed learning approach where "frames" either ask the reader to do something on their computer or respond with an answer to a question. Each chapter has beginning-of-chapter objectives and an end-of-chapter self test. The pace is measured. A high school level reader should have little difficulty comprehending the material.

The book can roughly be divided into four sections. The first part (Chapters 1-5) introduces concepts both the machine and in particular the BASIC programming language. The second rough division (Chapters 6-8) represent the fundamentals of making sounds and displaying text and pixel graphics on the screen. The TRS-80 Color computer has 512 "print positions". Each contains four "set" positions or pixels making the graphics resolution of the screen 64 x 32 pixels. Programming graphics can be a little awkward, but the book does a fine job of explaining how this can be done.

The third component of the book (Chpaters 9-11) is concerned with the intermediate programming concepts of branching logic, string functions, subscripted variables, and arrays. The exercises are fund and will provide good experiences to the reader who types in the short programs and runs them.

The last chapter is not in the programmed learning style. Some advanced programming concepts are introduced. What makes this a fine section of the text are the programming problems and challenges that are posed to the learner/reader. At least one workable solution to each problem is given. This book is a good guide to the TRS-80 Color computer written in a very readable manner.

Reviewed by: William J. Kolomyjec
Assistant Professor
Department of Engineering Graphics
The Ohio State University



Sol Sherr. Video and Digital Electronic Displays John Wiley and Sons, Inc.

This book is intended to give a very thorough explanation of the principles by which most of the computer graphics display devices operate. You can even discover how the liquid crystal display (LCD) on your digital watch operates.

The book is well-written and fairly easy to read. There is only one requirement for reading this book with understanding - you must have some acquaintance with electronics in general. As an example, unless one understands what a beam of electrons is and the fact that the electrons hitting a phosphor cause it to glow, you will have trouble reading the book.

Highly recommended for all who want a good understanding of electronic display devices with the proviso that some electronics knowledge is helpful.

Reviewed by: Richard Hang
Professor
Department of Engineering Graphics
Department of Computer and Information Science
The Ohio State University

Ethics in Engineering Design

Gerard Voland
Northeastern University
Boston, Massachusetts 02115

A brief review of the history of ethics as a topic of professional concern in engineering, particular case studies, the development of codes of conduct, and the role of professional societies in the enforcement of such codes will lead us to specific suggestions for teaching ethics in engineering.

INTRODUCTION

Leonardo da Vinci, in his autobiographical notes, revealed that he had chosen to not disclose his design of a submarine for fear that it would be used to drill holes in enemy vessels (Paschkis, 1975).

Engineers are often confronted by ethical conflicts; for example, to whom does the engineer owe his primary loyalty - his family and himself, his colleagues, his employer, his clients, or society in general?

Ethical choices in engineering design include

1. One's choice of an employer - is work involving energy or weaponry acceptable to the engineer?

2. The employer's general philosophy toward planned obsolescence, the inclusion of safety precautions in designs, environmental concerns (pollution, the depletion of natural resources, etc.), professional regard for the customer (in such areas of concern as easy assembly and repair of the product and minimum maintenance), and other design considerations.

(Brown, 1981)

The engineering student should be exposed to such potential ethical conflicts and choices during his education and professional training if he is to

1. recognize the complexities and difficulties associated with engineerig decisions and

2. act responsibly as a professional - and ethical - engineer.

Table 1 presents several definitions of ethics in engineering which have been suggested in the literature. The engineering educator can certainly inform his pupils of "professional ethics" if such ethics simply consist of the standards of conduct or codes of ethics which have been developed by various professional engineering groups.

He can also teach situational ethics in which particular case studies are analyzed and compared; such analyses would include "technical ethics" (design considerations) and "engineering ethics" as defined in Table 1.

Definitions

ETHICS................"A system of moral principles; the rules of conduct recognized in respect to a particular class of human actions or a particular group or culture; the branch of philosophy dealing with values relating to human conduct..." (Urdang, 1968)

TECHNICAL ETHICS......"A comprehensive and continuing critical evaluation of the societal implications and consequences of an engineering design, and the making of proper choices accordingly." (Brown, 1981)

PROFESSIONAL ETHICS.."Standards of conduct unique to a particular profession and those who practice it." (Huber, 1978)

ENGINEERING ETHICS...(1) "The study of moral issues arising in engineering practice." (Martin, 1981) (2) "Service of the public interest with integrity and honor." (Wisely, 1977)

TABLE 1

HISTORICAL REVIEW

The first general conference (Benjamin, 1975) on engineering ethics, at which several professional societies were represented (including

accreditation of engineering schools could include the requirement of course offerings in professional responsibility and ethics

the American Institute of Chemical Engineers; the American Chemical Society; the American Institute of Mining, Metallurgical and Petroleum Engineers; Institute of Electrical and Electronics Engineers; and the National Society of Professional Engineers), was held in 1975, the proceedings of which have been published by the American Society of Civil Engineers (ASCE) (1975). The issue of ethical conduct in the engineering profession, however, had been considered by numerous groups for many years prior to this conference; Wisely (1977) has provided the following summary:

1893 and 1902 — Proposals of ethical standards in ASCE rejected.
June, 1907 ----- Code of ethics drafted in the American Institute of Electrical Engineers (AIEE) but not adopted.

February, 1910 – Institution of Civil Engineers (ICE) in Great Britain adopts first engineering standards of professional conduct.
May, 1911 ——— The American Institute of Consulting Engineers (AICE) adopts first American code of ethics, based upon ICE standards.
March, 1912 —— AIEE adopts Code of Principles of Professional Conduct.
December, 1912 – The American Institute of Chemical Engineers (AIChE) adopts code of ethics.
June, 1914 ——— The American Society of Mechanical Engineers (ASME) adopts code based upon the AIEE "Principles".
September, 1914 ASCE adopts code comprising parts of the AICE code of ethics.
April, 1920 ——— ASME leads in formation of Joint Committee on Code of Ethics; 1922 draft Code of Ethics for Engineers fails to receive general acceptance.
May, 1923 ——— The American Association of Engineers (AAE) adopts Principles of Professional Conduct intended for all engineers; acceptance is limited.
January, 1941 — The Engineers Council for Professional Development (ECPD) undertakes development of ethical standards for all engineering.
1943 to 1950 —— ECPD Canons of Ethics for Engineers in process of acceptance by ECPD societies.
June, 1952 ——— The National Society of Professional Engineers (NSPE) adopts 15 Rules of Ethical Conduct to supplement ECPD "Canons"; both are replaced in 1957 by the enactment of NSPE Rules of Professional Conduct.
1957 ——————— ASCE and the American Institute of Architects (AIA) jointly produce Interprofessional Principles of Practice for Architects and Engineers.
1963 ——————— ECPD enacts major revision to its Canons of Ethics.
1974 ——————— ECPD approves new Code of Ethics of Engineers, replacing the former Canons of Ethics.
1974 ——————— The Institute of Electrical and Electronics Engineers (IEEE) enacts a new code independent of the ECPD model.
1974 ——————— The American Consulting Engineers Council (ACEC) adopts a new Code of Ethics following ECPD fundamental Canons and guidelines.
1976 ——————— ASCE adopts modification of ECPD code to replace its traditional Code of Ethics.

In order to place this time sequence in perspective, we note that the medical profession's historical consideration of ethics is as follows (Wisely, 1977):

5th Century B.C.–A brief set of ethical principles, the Oath of Hippocrates, is conceived; no penalties or sanctions are imposed.
1803 ——————— The British physician Thomas Percival publishes his "Code of Medical Ethics".
1847 ——————— The American Medical Association (AMA), during its first meeting, adopted a set of Principles of Ethics based upon the Percival code.

(AMA Judicial Council interprets and may impose sanctions; the prime responsibility for disciplinary action rests with the local and state medical societies.)

The legal profession also predates engineering in its discussions and formulation of a code of conduct (Wisely, 1977).

1854 ——————— A series of lectures given by Judge George Sharswood is published under the title "Professional Ethics".
1887 ——————— The Alabama Bar Association adopts a code of ethics based upon the Sharswood lectures.
1908 ——————— The American Bar Association (ABA) adopts ethical standards based upon the Alabama code.
1970 ——————— The ABA Code of Professional Responsibility is introduced.

(The ABA Committee on Ethics and Professional Responsibility interprest questions relating to the code; disciplinary actions are held by the state bar associations.)

In both medicine and law, the existence of a single major professional society simplified the development and the enforcement of ethical standards (unlike the engineering profession, in which more than 150 national organizations existed) (Wisely, 1977).

The generation of such codes of conduct (and the associated licensing procedures) simply reflect the need for every profession to enjoy the public's trust (Rawlins, 1977).

Today, there is increased interest and activity among engineers with respect to codes of conduct and ethical behavior (Brown, 1981) – perhaps as a result of some well-publicized cases involving ethical questions in engineering practice. We review two of these cases in the next section.

CASE STUDIES

CASE STUDY 1: BART (Anderson, 1975)

In 1972, the San Francisco Bay Area Rapid Transit (BART) District introduced the nation's first completely automated transit system.

In March of that year, three BART engineers were dismissed after advising three levels of supervision that there were serious problems in the system. (The press had obtained information about the engineers' concerns from Members of BART's Board of Directors; the dismissals were apparently the result of the adverse publicity.)

The Diablo chapter of the National Society of Professional Engineers (NSPE), together with members of the California Society of Professional Engineers (CSPE), investigated the engineers' allegations and dismissals. Other professional engineers involved in the BART system confirmed the technical problems of the system. A report was submitted by the CSPE Transportation Safety Committee to a California state senator in June, 1972, in order to promote a legislative investigation. (One concern mentioned in the report was that "...a train approaching a station received a false acceleration command. The train traveled through the station at 80 mph". The report asked "does the possibility of train derailment exist at the station terminals? Is the track runout length sufficient?")

In November, 1972, a legislative report was released which substantiated a majority of the concerns identified by the CSPE committee.

However, in October, a crystal oscillator in the automatic train operating (ATO) subsystem had transmitted an incorrect speed command (Friedlander, 1975); a train failed to stop at the last station on the line, left the track, and crashed into a commuter parking lot!

An interesting feature of this case is the reaction of a group within NSPE known as the Professional Engineers in Private Practice (PEPP) to the activities of the CSPE Diablo chapter. The PEPP group was concerned that the CSPE Diablo group's actions could have a negative impact upon the consulting engineering profession. In addition, the CSPE Golden Gate chapter moved (unsuccessfully) to censure the Diablo chapter. And the efforts of the Diablo chapter to obtain support for the three dismissed engineers from CSPE and NSPE were ultimately unsuccessful.

CASE STUDY 2: B.F. Goodrich Company

In 1966, the B.F. Goodrich Company (BFG) aircraft wheel and brake plant in Troy, Ohio, successfully bid to supply wheels and brakes for the A7D light attack aircraft being built by the Ling-Temco-Vought Company (LTV) of Dallas, Texas, for the United States Air Force. BFG had not made a successful bid on an LTV proposal for ten years as a result of a BFG landing gear assembly (built for LTV) failure. BFG was jubilant that the 1966 contract had been awarded to them - and would not accept failure, regardless of the cost.

BFG's proposal was for a lightweight (105 pounds) four-rotor brake. During laboratory tests it became apparent that the brake was a failure - temperatures were too high, resulting in rapid lining failure and disintegration. The brake's designer claimed that the lining material was at fault rather than his design; however, a five-rotor brake had proven successful. Various lining mixes were tested; all were failure.

Meanwhile, LTV was informed that the brake was successful and flight tests could begin in June, 1968. A fabricated test log was submitted to substantiate these claims.

Formal Qualification tests were conducted. Military specifications required that a brake be submitted to a 50-simulated-landings test without mechanical reworking or modifications; in defiance of this requirement, the test brake was often dismantled and machined. Fans were used to reduce heating. Fourteen qualification attempts were conducted; none was successful.

After the thirteenth attempt, the testing laboratory was notified that the brake would qualify on the next attempt.

A false qualification report was issued.

Flight tests were conducted and then cancelled when difficulties developed (e.g., brakes welding together - forcing the aircraft to skid to a stop).

The Federal Bureau of Investigation became involved. BFG eventually acknowledged that the four-rotor design was a failure.

Finally, the Department of Defense issued substantial changes in inspection and reporting procedures.

THE ROLE OF PROFESSIONAL SOCIETIES

The above cases suggest that professional societies should provide active leadership in cases of unethical conduct, the enforcement of professional codes, and licensing practices.

In both the legal and medical professions, there exist professional societal reviews, standing committees for the interpretation and monitoring of ethical behavior and procedures for dealing with code violations (Wisely, 1977). As of 1975, the Engineers Council for Professional Development (ECPD) had no enforcement authority over the individual engineer (Rawling, 1975); enforcement powers remained with the individual societies and, in particular, with the state registration boards.

In the BART case, the professional society's local chapter attempted to take action only to be frustrated at the state and national levels.

It has been suggested that professional engineering societies can encourage ethical behavior in the following ways:

by recognizing and solving, through a set of general guidelines, the conflicting demands placed upon the engineer (Discussion of..., 1975)

by supporting "whistle-blowers", particularly through helping them obtain professional employment (the American Chemical Society has a legal-aid loan program for such individuals) (Discussion of..., 1975)

by filing Amicus Curiae (friend of the court) briefs in legal cases (Discussion of..., 1975)

by publishing results and case histories (Discussion of..., 1975) (Smith, 1977a)

by providing grievance procedures or investigative commissions (Discussion of..., 1975) the format could be similar to that used by the American Association of University Professors in which a complaint is filed, a fact-finding committee is appointed, an attempt at mediation is made, and, if no solution is achieved, the party determined to be at faulty is "censored" by the group (Paschkis, 1975) by requiring that engineering schools offer instruction in the duties and responsibilities of the professional engineer, as is required of law schools by the American Bar Association (Smith, 1977a)

by involving student chapters in these university educational efforts (Lee, 1975).

SURVEY INDICATIONS

Surveys have been conducted which indicate a need for the inclusion of ethics discussions in engineering curricula.

Twenty-nine undergraduate members of an ASCE student chapter at the University of Maryland, together with 162 engineering professionals attending ASCE meetings in Wisconsin and Illinois, were asked (Brannon, 1976) to respond to the eight situational questions given in Table 2. These questions ask for decisions involving

CASE 1: George Ord, a city employee, is the resident engineer for a large sewer contract. With extensive field engineering experience, George is able to suggest techniques and procedures that save both time and money, although the work is done strictly according to the plans and specs. At Christmas time, George receives a case of good Scotch from the contractor with his greeting card attached. May George Accept it? Yes________ No________

CASE 2: As plant engineer for Lotsa Chrome, Inc., Jim Smith knows that the manufacturing process results in periodic discharges of cadmium and chrome in Deadfish Creek in concentrations which may cause serious long-term health effects for downstream water users. Because Lotsa Chrome, Inc., is marginally profitable, management has made a policy to close the plant when and if waste water controls are required. When questioned by the Department of Natural Resources (DNR), Jim's boss understates the levels of cadmium and chrome. Must Jim provide DNR the correct information? Yes________ No________

CASE 3: Paul Rown is project engineer for the state on a seven-mile urban freeway project under contract with Smooth Paving owned by Bill O'Say. Bill tells Paul he's ordering snow tires for the company's cars and he can get a set for Paul at fleet wholesale prices. Paul agrees and pays on delivery. Did Paul breach the ASCE Code of Ethics? Yes________ No________

Case 4: City Engineer Paul Hopeful is convicted of filing a fraudulent Federal Income Tax Return. Is there a Code of Ethics violation? Yes________ No________

Case 5: Vincent Laton, an experienced professional, is appointed chief execntive officer a large metro water and sewer agency. The governing board is made up of nine elected persons. Vendors, suppliers, contractors, and even concultants have formed the habit of giving lavish Christmas gifts to the agency personnel. The practice has progressed to the point where names of people who are to receive gifts are provided these firms in mid-November. May Vincent let the practice continue? Yes________ No________

Case 6: Jack Jones is chief engineer for excellent Company, a manufacturer of recreation vehicles. Jack, who is very photogenic, is asked to appear in TV ads endorsing the company's snowmobiles. The ASCE Code of Ethics provides that a member shall not endorse products of processes in commercial advertisements. Is there an ethical distinction since Jack is responsible for the snowmobile's engineering quality? Yes________ No________

Case 7: Tom Wellborn is retained by the Town of Easy Acres to design a swimming pool. Steve Petite, a salesman for Clear Water, Inc., provides Tom a layout for the circulation and filtration equipment which includes equipment produced by Clear Water, Inc. Tom reproduces the layout on his plans. Is this practice acceptable? Yes________ No________

Case 8: Doug, Tom and Bill graduated form State U in 1940 and were fraternity brothers and close friends. Doug and Tom eventually became partners in a consulting frim while Bill, who was class president, continued a political career and is now governor. Doug and Tom personally contributed $500 and $2000 respectively, to Bill's 1973 campaign. During 1974, their firm received three design contracts from state agencies involving $750,000 in fees over a two-year period. These facts were recently 'exposed' by the press. Jas the Code of Ethics been violated? Yes________ No________

TABLE 2

- the acceptance of gratuities
- loyalty to one's employer
- political contributions and influence
- commercial product endorsements

the engineer-client relationship

Table 3 presents the results of this survey.

A statistical comparison of the results by McCuen (1977) indicated that there were significant differences for several of the questions between the students' responses and those of the professionals; Table 4 presents McCuen's findings.

During the Fall, 1981, term at Northeastern University, I informally surveyed my freshmen engineering design graphics (B.S.) students by using the ASCE survey questions. The results are presented in Table 5. (We did not discuss or review any professional code of ethics before they responded to these questions; as a result, the responses to questions 3, 4, and 8 - in which reference is made to a specific code (ASCE) - may be unreliable.) The student responses surprised me in their variations from the results obtained in the earlier surveys. I will refrain from making any further comment, other than to suggest that these results suggest (once again) a need to include professional ethics as a topic in engineering design courses.

These results suggest that experience influences one's standards of ethical behavior. Indeed, these results indicate that an educational effort involving both students and professional engineers might have a beneficial effect upon members of both groups; the professionals could provide real-worlf industrial concerns and factors, whereas the students could provide the idealism (some would perhaps say naivete) of youth. Certainly all participants would gain from such an interaction.

Another survey of interest was conducted by Chemical Engineering magazine 20, 21, in which a hypothetical situation was described:

> In the search for a new catalyst, Jay's group has narrowed the possibilities to A and B. Data, possibly erroneous, indicate B is the proper choice. However, Jay, his boss, and his entire group believe that A is better. Jay is directed by his boss to write a report favoring catalyst A using falsified data. What would you do in Jay's situation?

The possible responses and the percentage of results were as follows:

(1) "Refuse to write the report, because to do so would be unethical" 41.5%

(2) "Write the report as directed, but refuse to have your name on it as the author" 11.7%

(3) "Write the report, but also write a memo to the boss stating that what is being done is unethical - to cover you in case you are found out" 8.5%

(4) "Go over your boss's head and report that you have been asked to falsify records" 7.1%

(5) "Other" 24%

The variety of responses to this hypothetical situation seems to suggest that discussion of ethical choices involving data falsification and data validity, employee-employer relationships, etc. are needed among engineering professionals.

Finally, surveys were conducted in 1969 and 1976 at the University of Wisconsin (Smith, 1976) to determine student expectations of course sessions on engineering ethics. The student responses were grouped as follows:

	% Responses 1969	% Responses 1976
1. Specific Prohibitions, i.e., students expected to learn the "rules" of ethical conduct.	48	36
2. General notions of professional conduct, i.e., responsibilities and duties.	38	31
3. Enforcement procedures	0	5
4. Need, relevancy, and currency (why does a code exist?).	5	23
5. Rationale for specific prohibitions (justifications for specific rules).	9	5

ASCE Survey Results
(Percentage of YES responses)

CASE STUDY	Wisconsin	Illinois	Univ. of Maryland (Students)
1	19	37	48
2	52	71	97
3	67	43	74
4	93	67	81
5	3	5	14
6	67	89	31
7	74	46	41
8	28	33	52

TABLE 3

These results suggest topics or goals which should be included in any design course dealing with the ethical conduct of the professional if it is to address the concerns of the entering student.

THE TEACHING OF ETHICS

Martin (1981) suggests that ethics courses should improve the student's ability to

1. identify moral problems,

2. comprehend and critically assess arguments on opposing sides of a situation,

3. form consistent and comprehensive viewpoints based upon facts and moral considerations, and

4. express his views orally and in writing.

Some in industry have stated that the responsibility for teaching ethics lies with the university community, whereas those in educational institutions have suggested that industry has the primary responsibility for developing ethical (professional) behavior in engineers (Lee, 1975). It would appear that a combined effort involving both groups is necessary: university coursework and continuing education of the professional engineer in the industrial world (Smith, 1977a).

Coursework: Law schools have greater experience in offering coursework in professional conduct and codes than do engineering schools. Course methods can be categorized as either formal (single-course) offerings specifically concentrating in ethical behavior as a professional or pervasive (multiple-courses), in which ethical behavior and professional codes of conduct are included (to some extent) in all courses.

Law schools have found that the pervasive approach is not as successful as the formal specific-course procedure (Brown, 1981). (Of course, these approaches do not have to be mutually exclusive.) Formal training in ethics has been found to increase the overall ethical attitude of the (law school) participants by six percent (Smith, 1976).

Law schools have also discovered that the traditional teaching formats (lecture, Socratic, discussion) are not well-received by students (Smith, 1977a):

Role-playing, in which students play the characters in a hypothetical situation, and

Practitioner-involvement, in which professional attorneys interact closely with a small group of students.

Course formats and topics could include:

Guest (professional engineer) presentations (Urdang, 1968; Smith, 1977a)

Reviews of real and hypothetical cases (e.g., NSPE case studies (Urdang, 1968; Mitchell, 1975)

Discussion of current (ethical) engineering situations (Urdang, 1968; Huber, 1978)

Role-playing technique (Smith, 1977a)

Comparisons of different professional societies' codes of ethics

Discussions of the changes (and reasons for such changes) in professional societies' codes of ethics (Huber, 1978)

Team-teaching, in which interdisciplinary presentations of ethical issues in design courses (Martin, 1981)

Professional societies can provide support (as noted earlier) for these activities by publishing reviews of case studies (e.g., a consolidated, indexed version (Smith, 1977a) of NSPE Opinions of the Board of Ethical Review) which are periodically updated. In addition, interpretations of engineering codes of ethics could be provided - as is done in the legal profession (Smith, 1977a). Videotapes of panel discussions could also be provided.

Continuing education in ethical issues of professional engineers could be supported by both industry and the professional societies through videotapes, seminars, and publications. Workshops could be offered for both managerial and engineering personnel in

ASCE Survey - Significant Differences between professional and student responses?

CASE STUDY	Wisconsin vs. Students	Illinois vs. Students
1	Yes	No
2	Yes	Yes
3	No	Yes
4	No	No
5	Yes	No
6	Yes	Yes
7	Yes	No
8	Yes	No

TABLE 4

ASCE Survey Questions
Northeastern University Survey
Results (Percentage of YES responses)

CASE STUDY	Northeastern University Freshmen
1	78
2	70
3	30
4	60
5	50
6	40
7	60
8	48

TABLE 5

order to increase communication between these two groups with respect to professional/ethical behavior (Stilwell, 1975).

Finally, accreditation of engineering schools could include the requirement of course offerings in professional responsibility and ethics; licensing of professional engineers could include education in these areas as a requirement. (Such requirements are recent additions to the legal profession (Huber, 1978).)

As Smith notes (1976), students (and professional engineers) have ethics - but they need a working knowledge of what their profession will support ethical decisions.) Those of us in engineering education (and particularly in engineering design, wherein decisions and compromises in achieving specific goals must be considered) have a responsibility to help provide this working knowledge.

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The OSU Freshman Graphics and Programming Sequence

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When Autumn Quarter 1980 opened at The Ohio State University 240 freshmen engineering students began a new, experimental course sequence designed to add interactive computer graphics programming skills to their graphics and programming courses. They were followed Winter Quarter by another 120 students, bringing the total in the program to 360 of 1500 freshmen engineering students. The sequence, consisting of three 3-credit hour courses to be taken during consecutive quarters, would lead each of them to write a complete computer-aided interactive drafting package consisting of about 2000 lines of FORTRAN code using Tektronix PLOT10 graphics subroutine calls.

This new course sequence grew out of a perceived need to produce graduate engineers who are not only computer literate but are capable of contributing effectively in engineering departments of industrial firms that rely heavily on CAD/CAM to give them a competitive edge. In response to this need the Dean made development of interactive computing capability with graphics a top College priority. A computer planning committee was created and was chaired by the Associate Dean for Research and Administration with representation from every department of the College. The committee was charged with the task of planning for the rapid development of a comprehensive program to integrate interactive computing with graphics across the curriculum. Every department in the College began writing the use of interactive computing with graphics into their courses. Mechanical Engineering developed a computer aided design laboratory called the Advanced Design Methods Laboratory (ADML). This laboratory was configured around a DEC PDP 11/60 that has since been replaced with a VAX 11/750. Industrial and Systems Engineering established CAMSL (Computer Assisted Manufacturing and Systems Laboratory) that now uses a PDP 11/60, a PDP 11/34, and a PDP 11/23. Chemical Engineering replaced their aging PDP 11/15 with a VAX 11/780 for their Process Control Laboratory (PCL). Electrical Engineering replaced a Harris Datacraft with a VAX 11/780 and added a PDP 11/70 as well as a number of small minis and micros. The first serves research needs only while the others are for both research and teaching. Their department alone has over 30 separate CPU's. Every department in the college has stand-alone computing facilities, most with some graphics capability.

It became apparent very quickly that if the students were to be able to perform effectively in these new laboratories and courses they would need to receive formal training in programming and use of interactive computer graphics equipment.

The Department of Engineering Graphics had two required courses in the catalog for all engineering students. One was Engineering Graphics 110, a five credit hour one quarter course in engineering drawing and descriptive geometry normally taken at the freshman level. The other was Engineering Graphics 200, a three credit hour course in batch mode, structured FORTRAN programming with WATFIV normally taken at the sophomore or junior level. Since no other engineering department was teaching either graphics or computer programming to engineers on a formal basis, Engineering Graphics was asked to add both interactive computing and interactive computer graphics to its curriculum. Developmental work began and the first experimental course sequence was presented to a selected group of 120 students in 1978. The new sequence was numbered EG 294X, 294Y, and 294Z and consisted of three courses of three credits each (six contact hours). The numbers were experimental course numbers and have been replaced by EG 141, 142, and 143. It is intended that the sequence will be taken during the freshman year and, if necessary, could be completed early in the sophomore year.

produce graduate engineers who are literate and productive for firms that rely on CAD/CAM

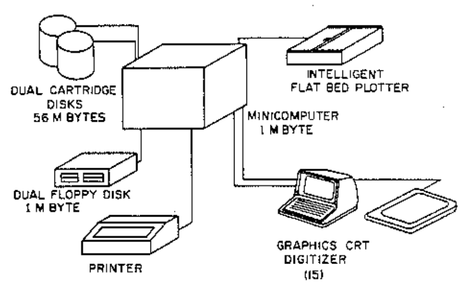
Equipment

The equipment available at the beginning of the program consisted of a Hewlett Packard 2115A CPU, a CalComp plotter, and a Tektronix 4010 graphics CRT. A dial-up line to the University's Instruction and Research Computer Center provided access to their Amdahl.

Using the experience gained from this first effort, a decision was made in the spring of 1979 to replace this equipment with a new pilot student laboratory consisting of four Tektronix 4052 stand-alone graphics CRT's multiplexed to a Tektronix hard copier to provide hard copy output. The course syllabus was revised and a total of 120 students enrolled in the program in 1979. A number of problems quickly surfaced. Chief among these was that the students were required to learn structured FORTRAN but the graphics equipment supported only BASIC. This meant that they also had to learn BASIC and had to use the two languages simultaneously in their course work. While learning and using two languages is not normally a serious problem it proved to be unworkable for freshmen level students with no previous programming experience. It became apparent that the department would have to standardize one language. A knowledge of FORTRAN would be required for the students' work in their chosen degree programs so the decision was made to standardize FORTRAN and PLOT10 as the programming and graphics languages respectively.

INTERACTIVE COMPUTER GRAPHICS LABORATORY
ENGINEERING GRAPHICS DEPARTMENT
THE OHIO STATE UNIVERSITY

HARDWARE CONFIGURATION



CPU - DEC PDP 11/44
DISKS - DUAL RK07 - CARTRIDGE, DUAL RX02 - FLOPPY
OPERATING SYSTEM - RSX-11M
GRAPHIC CRT - LEAR-SIEGLER ADM - 3A +
DIGITAL ENGINEERING RG-512 PC BOARD
TEKTRONIX COMPATIBLE
PLOTTER - HOUSTON INSTRUMENT DMP-4 SMART HIPLOT
DIGITIZER - HOUSTON INSTRUMENT HIPAD
PRINTER - PRINTRONIX P600 PRINTER/PLOTTER

FIGURE 1

A third generation pilot laboratory, to be called the Interactive Graphics Laboratory (IGL), was planned and configured around two Digital Equipment Corporation computers, a DEC 11/44 and a DEC 11/60 with dual RK07 hard disks, dual RX02 floppy disks and a Printronix printer. 15 Lear Siegler alphanumeric terminals equipped with Digital Engineering graphics boards that permitted them to emulate Tektronix 4010 terminals were selected for the student work stations. They were equipped with four-button control pads to drive the graphics crosshairs. Each of the 15 work stations was equipped with a Houston Instruments 11 in x 11 in (280 mm x 280 mm) digitizing tablet. These were connected to the auxiliary port on the terminals and used in point mode only. Figure 1 shows the schematic of the hardware configuration. See Figures 2-4 for photographs of the hardware. Five Houston Instruments 8.5 in x 11 in (216 mm x 280 mm) X-Y pen plotters were provided for shared use. By the end of Winter Quarter it was seen that additional work stations would be needed. 10 DEC VT100 alphanumeric terminals were added to provide added program preparation capability.

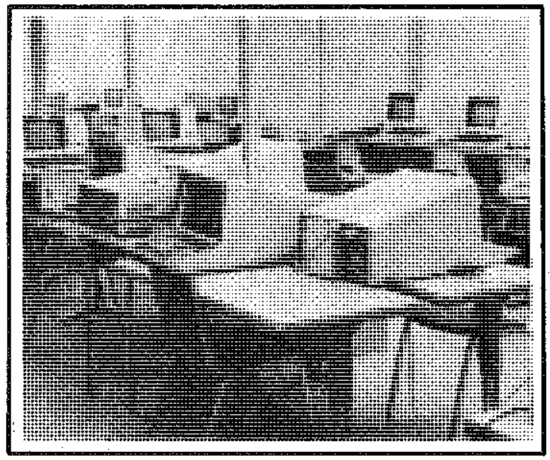


FIGURE 2

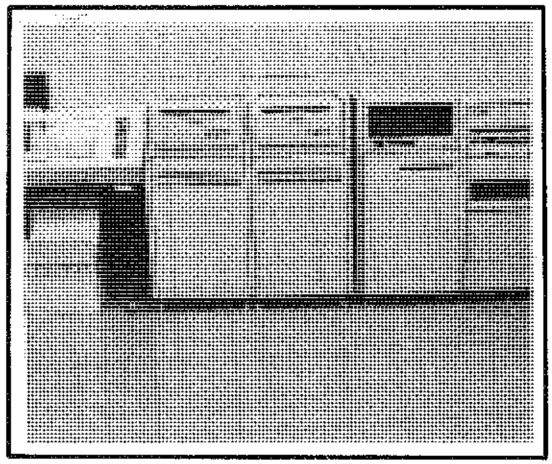


FIGURE 3

A severe restriction of the 11/34, 11/44, and 11/60 became apparent during the Spring Quarter in the third course of the sequence. These machines, operating under a multi-user operating system, RSX 11-M, limited available memory per user to 64K bytes. Students in the third course generally required more memory space, with the result that they were faced with consolidating their programs and, in many cases, were not able to complete their assignments.

That problem, coupled with the announcement by DEC of a small VAX (11/750) at an attractive price prompted the decision in late 1981 to convert to use of VAX hosts. Accordingly, when equipment money became available, an order was placed for a new VAX 11/750 and a second order was placed to upgrade the 11/44 to a VAX 11/750. The new 11/750 was delivered in time to be placed on line for use Spring Quarter 1982. Upgrade of the 11/44 was scheduled for the Summer Quarter 1982 so as to preclude having both hosts down at the same time.

During the Spring Quarter 1982, 14 terminals (10 with graphics) were available on the VAX and 15 terminals (all graphics) were available on the 11/44. For Autumn Quarter 1982 approximately 30 terminals will be available. The new terminals are DEC VT100's with graphics boards that offer the same resolution as the Lear Siegler terminals but can be repaired locally. They are also capable of being converted to standalone 16 bit microcomputers with the addition of a disk controller and disk drives.

The current cost of a work station is approximately $7000 to $10,000 depending on the terminal and computer. It is anticipated that the new 16 bit microcomputers will allow a network of microcomputers linked to minicomputers. This configuration should reduce the cost of the individual work station. The maintenance and operating costs are discussed below in the section on budget.

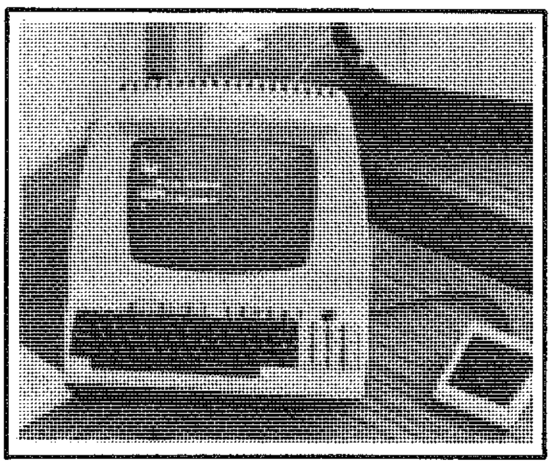


FIGURE 4

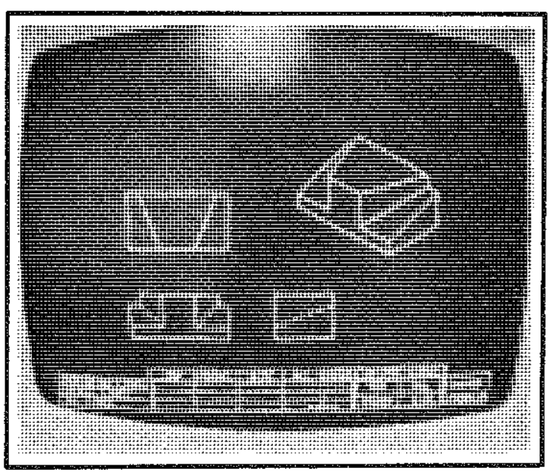


FIGURE 5

The Course Sequence

Autumn Quarter 1980 The entering students enrolled in Engineering Graphics 294X were divided into eight sections of 30 students each. During the first three weeks they concentrated on problem solving techniques. They were presented with elementary engineering problems in narrative form and were required to prepare a complete manual solution including a statement of the given information, what was required, an algorithm for manual solution including derivation of any needed equations, and finally the solution itself. The last seven weeks of the quarter were spent learning the FORTRAN language and analyzing, flow charting, and coding computer programs to solve problems similar to the ones they had solved manually. All programs were key punched and were run in batch mode on the Amdahl at IRCC.

Concurrently with problem solving and computer programming exercises, the students were given homework assignments designed to teach them to visualize and sketch three dimensional objects. Assignments included completion of missing-line problems, sketching isometric views given a three-view orthographic projection drawing, and producing an orthographic sketch given an isometric drawing. In order to use the system to help the students learn orthographic representation, a program was developed to display a pictorial and then to display the outline and details of the orthographic views of an object as the student selects it. See Figure 5. This program was written after the Autumn Quarter and was used during Winter Quarter.

Winter Quarter 1981 Of the original eight sections that started Engineering Graphics 294X in the autumn, seven sections or about 210 students went on to 294Y Winter Quarter. They were immediately faced with a number of new challenges. First, their programming experience to this point had all been on the Amdahl using punch cards for input and a line printer for output. They would now be working in the Interactive Graphics Laboratory, entering their programs from the keyboard of a CRT terminal. Consequently, they were required to learn an editor and file handling techniques as well as programming techniques to permit interactive communication from the keyboard during program execution. Second, they had to adapt to and learn the peculiarities of a different version of FORTRAN. They had learned structured FORTRAN with WATFIV in the autumn using the WATFIV compiler. Now they had to use DEC's FORTRAN IV PLUS without the constructs and other WATFIV extensions and diagnostic messages and with some variations in syntax. Additionally, they had to adapt to the use of a 16 bit word rather than the 32 bit word they had been using. Third, they had to learn the PLOT10 graphics commands. Fourth, in addition to computer graphics programming topics, they were taught descriptive geometry, orthographic projection, isometric drawing, dimensioning, and some graphical analysis. They completed a total of 93 plates of which 38 were sketches and the remaining 55 were done with instruments. The computer graphics portion of the syllabus included five programs. The first was a small nongraphics, interactive program that would read a set of three line length values from a file; analyze them to determine whether they could form a triangle and, if so, what class of triangle; print out the results of the analysis; and repeat for additional sets of values until the input file was exhausted. This program was designed to familiarize the student with the system and the editor. Consequently the code was supplied and had only to be keyed in, compiled, and run. The second program was an exercise in the use of MOVE and DRAW commands. The program was to read pairs of data points from a system file and, using them as arguments for MOVE and DRAW subroutines, to complete a simple drawing on the graphics screen.

The third program was to read in data consisting of coordinates of the center and one vertex along with the number of sides of each of several regular polygons and, using this data, to draw the polygons on the screen. In addition to drawing the polygons, the program was to draw a border and title block and was to fill in the title block with character information entered from the keyboard during program execution in response to prompts that were output to the screen by the program. Program structure had to be such as to obtain all title block information and then clear the screen prior to doing the drawing. Extra credit was allowed if the program correctly CLIPPED the polygons to preclude drawing into the title block.

Program number four was to draw a bar graph to present production data for a hypothetical firm. A separate bar was to be drawn for the data for each month of the year. The program was required to read all data and calculate a scale factor such that the longest bar would be the full height of the chart. Output had to be a complete chart including labeled and scaled axes, and a chart heading. Axis labels and the chart heading were read from a file during program execution.

The fifth program was a piecewise chart of up to five different sets of data. The data points for each set of data had to be uniquely identified with small geometrical shapes drawn around each point. As with program four, all necessary character information was read from files and output to the chart.

Spring Quarter 1981 A total of six sections or about 180 of the original group of 240 students enrolled in Engineering Graphics 294Z. The syllabus for this final course of the sequence covered three conventional graphics topics. They were dimensioning and tolerances, sections and conventions, and assembly drawings. In addition, the students were assigned in teams of five or six students to study open-ended multiple-solution problems, develop proposed solutions and present and defend their proposed solutions orally in class. They were to use appropriate visual aids including charts, diagrams, and drawings produced by the team. Their computer graphics assignment for the quarter was for each student to produce a complete computer aided interactive drafting package suitable for use by a nonprogrammmer. The program was to be menu driven, employing a main menu and eight sub-menus as specified in the problem description. All menu selections were to be made using the graphics crosshair. The eight sub-menus provided respectively, points, lines, a variety of polygons, various symbols such as arrow

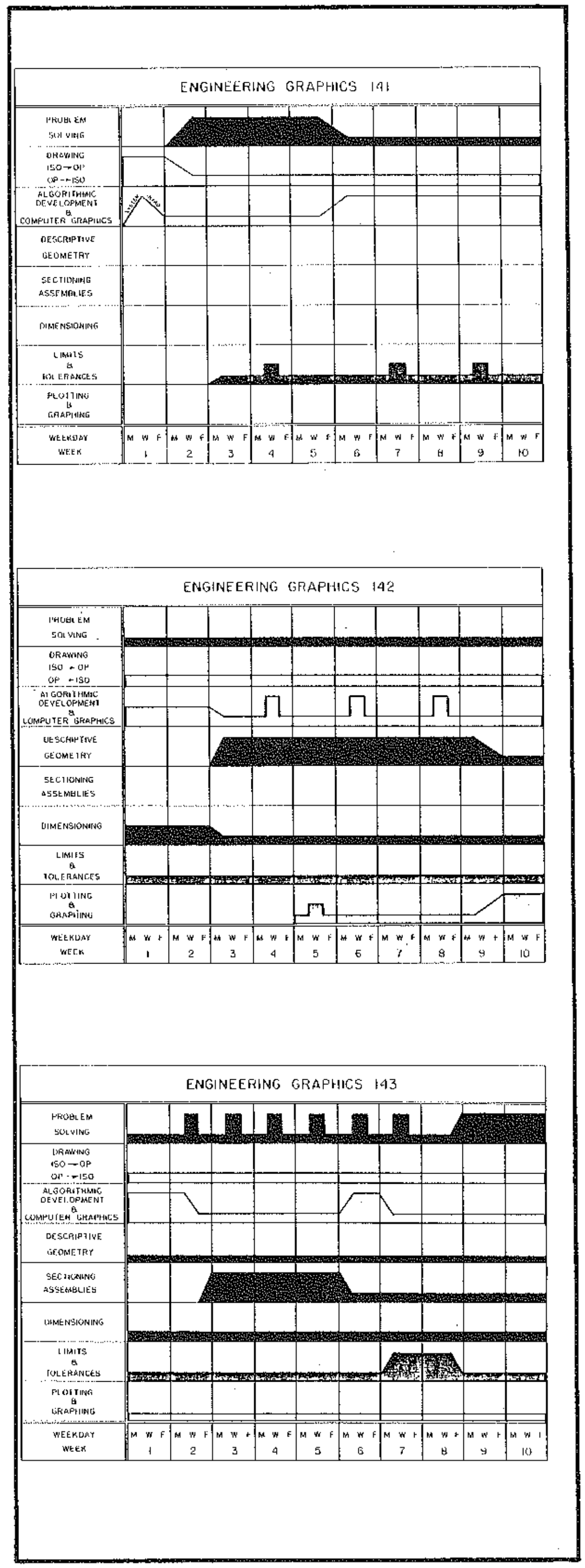


FIGURE 6

heads and circuit elements, a selection of different line types, a choice of dot grid backgrounds to serve as drawing aids, instructions and prompts, and plotter or printer-plotter output.

Data for all drawing elements was to be stored in arrays and the system was to be capable of duplicating or deleting any point, line, or figure and of erasing the entire screen and, using the stored data, re-displaying all material that had not been deleted.

The students were instructed in techniques for large program design including top-down programming, creation of efficient modular programs, and techniques for data storage and retrieval. Lecture topics also included techniques for identifying points, lines, polygons, or symbols using proximity search techniques.

Due to the size and complexity of the program it was anticipated that many of the students would not complete the entire package. This proved to be the case. While several did complete the package, the average student finished about 80 percent of the routines.

One reason for some students' inability to complete the entire package was seen in retrospect to be predictable, but was not anticipated at the outset. Many of the students' programs were too large to reside in the 64K of main memory to which they were limited due to the design of the DEC PDP 11 system. As a result they were not able to link all routines into a single task module for execution.

A number of factors contributed to their creation of outsized programs. Chief among them were

1. Inefficient program design and coding techniques that led to generation of large amounts of excess code. This can be expected of students at this level.

2. Dimensioning arrays larger than needed or using real rather than integer variables as array elements when integer variables would serve. Real variables on the DEC PDP 11's require four bytes per value while integers require only two bytes.

3. Using sequential access rather than direct access input files with the result that the entire file had to be read and stored in memory rather than reading individual records as needed. Additional instruction in use of direct access files would help to alleviate this problem.

4. Lack of instruction in overlaying large programs. The need for instruction in this area was not recognized in time to include it as a lecture topic. This instruction was added to the course syllabus but now has been removed because the VAX was installed.

The Second Year 1981-82

A complete review of the program was conducted at the end of the Spring Quarter and a number of changes was added to those that had been made during the year. Since the first two courses of the sequence had been taught twice by this time, there had been an opportunity to incorporate more changes into them than into the third course. The activity-time charts in Figure 6 show topics and where they are taught in the sequence. A line in the box means activity in a topic. A high line means daily instruction while a low line means assignments directly in or pertaining to a topic.

The primary changes made to the first course from the first year to the second year were to expand and strengthen the instruction in problem-solving techniques to include the effective use of flow charting and to introduce array variables and the use of subroutines earlier and in more depth. Compared to the pace in EG 110, the strength in the new sequence appears to be the slow, stepped approach in learning graphics and programming topics. As an example, three or four orthographic or isometric sketches are completed and graded each week during the first course. In EG 110 this topic is covered in four calendar days. The programming topics appear to benefit as well.

Changes made in the second course built on the additional array handling and subroutine use abilities of the students to develop more modular programming techniques. The top-down approach was stressed. Students were required to flow-chart all programming problems. In order to reduce the progamming effort, programming problems contained elements required for the problems in the third course.

Use of a digitizer tablet as an input device was incorporated into the third course by requiring that it be used for the program menu. Menu sheets were permanently affixed to the digitizers and the students were required to code routines to map the locations of the various menu boxes to a selection algorithm that would call the desired action subroutines, also written by the students, to perform the selected task. The menu is shown in Figure 7. As in the Spring Quarter, each student was required to write a complete menu-driven user oriented graphing package. Program sizes were reduced somewhat by eliminating features of the package that were largely repetitious and thus of less instructional value. The resulting programs would fit into the available memory in almost all cases.

A sign of the effectiveness of the restructuring of the entire sequence was that the students experienced less frustration and most of them completed their assignments.

When the individual student projects were completed, each class was organized into teams of five students. Each team was then given an opportunity to select a number of additional tasks to be completed as a team project and incorporated into one of the individual programs that had been done by a team member. The team decided which member's program to use. This approach proved effective since the teams selected what they were interested in working on. However, once again, program size outgrew memory available to the user. Consequently, it was necessary to give instruction in overlaying programs. The approach was to present a relatively simple type of overlay. The students, however, tended to have considerable difficulty with overlaying their programs. Upgrade to the laboratory host computers, mentioned earlier, solved that problem since the VAX hosts don't have the 64K per user limit.

Further reductions in program size were made by having the students do only points and lines routines as part of their menu driven programs. The students had written routines for rectangles, polygons, circles, and arcs in the second course. They were allowed to add these to their individual package for extra credit. However, prompts and mode indicators were required while they had been optional in prior quarters. The net effect was a program large enough to require top-down, modular programming and yet only provide enough repetition of a particular type of routine to reinforce concepts.

Operating Budget

The operating budget for the IGL has three main components: personnel, hardware maintenance, and supplies. During the first year of operation this budget was approximately $100,000. This was subdivided into 40% for hardware maintenance, 40% for personnel, and 20% for supplies and miscellaneous. Each additional station and its accompanying users increases the cost of running the laboratory. Each additional different station or computer operating system or graphics package increases the unit additional costs by at least 50% more than the cost of maintaining only one of each type. However, the rapid development of new and exciting software and hardware will cause every laboratory to face the problem of multiple systems. Minimizing the number of different systems or staying within a family of systems does help keep the costs to a reasonable level.

The operating budget for the second year was approximately $130,000. The budget for the third year is to be approximately $160,000 with the following percentages: personnel - 35%, hardware maintenance - 43%, and supplies and miscellaneous - 22%.

Summary

To date three groups of students have completed the entire sequence. Thus, the entire sequence has been taught three times. Changes were made in the sequence between the starting of the first and the second group. A complete review of the program was conducted at the end of Spring Quarter 1981 and a number of additional changes have been incorporated in the syllabi for 1981-82. Reviews are now underway for the 1982-83 version of the course sequence.

The sequence has been deemed successful and, while changes will continue to be made to fine-tune the program to the students' needs and abilities, most changes will be relatively minor and will be evolutionary in nature. The strength in the sequence is the longer time period available for absorption of information and reinforcement of topics. In the future more use will be made of user oriented programs now under development to provide additional experiences in graphing, descriptive geometry, and orthographic drawing.

The College has made a strong commitment to expand the new sequence to provide interactive computer graphics education to the entire freshman class of 1800 students annually. To do this it will be necessary to expand the current Interactive Graphics Laboratory to five times its present size. The cost of constructing, equipping, staffing, and operating a laboratory of that size is a budget item of major proportions in a period when funds for education are scarce. Perhaps the most difficult task, however, is recruitment of a strong computer graphics teaching faculty of the size necessary to meet the projected course load of 50 sections per quarter. The chosen alternative is to recruit faculty with strengths in one or two of the three areas of graphics, computer programming, and computer graphics. They are then provided time to audit and learn the new material or to strengthen a weak area.

POINT	LINE 2 END PT.	LINE N DEGREES	RECTANGLE	N-SIDED REGULAR POLYGONS	CIRCLE	ARC	→
ADD MODE	DELETE MODE	DOT MODE	CROSS MODE	LINE TYPE 1,2,3, OR 4	DOT GRID	REDISPLAY	STOP
1	2 3	4 5	6 7	8 9	0 •	END DIGITS	RETURN TO TERMINAL

FIGURE 7

The Geometry of an Oblique Osteotomy

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Introduction

This paper sets forth a geometrical solution for three-dimensional reorientation of the femoral head in Legg Calve Perthes disease. The problem was posed by the Head of the Orthopaedic Department of the Rothschild University Hospital in Haifa (Israel), Dr. D.G. Mendes. He and his colleagues, Dr. M. Rofman and Dr. S. Liberson, had been engaged in working out the methodology of an oblique osteotomy for the above mentioned disease.

Reorientation of the femoral head within the acetabulum in Legg Calve Perthes disease is often carried out by means of a femoral osteotomy and then confirmed by an antero-posterior (frontal) radiograph. The new concept is that such an osteotomy should be a three-dimensional one. A reorientation of the femoral head by means of a three-dimensional osteotomy should be carried out for the laterally (in profile) and anteriorly (frontally) displaced and uncovered femoral head. The aim here is to prevent deformation of the "biologically soft" femoral head due to the impingement on it of the acetabular rim (Figure 1). The desired three-dimensional correction for a given patient is determined pre-operatively under investigative fluoroscopy.

The new position of the femoral head can be achieved as a result of the following three successive forms of the hip:

1. flexion (or extension - in the opposite direction) in the sagittal (profile) plane to a certain angle;
2. abduction (or deduction - in the opposite direction) revolution in the frontal plane to a certain angle;
3. rotation - revolution about the loading axis of the femur to a certain angle.

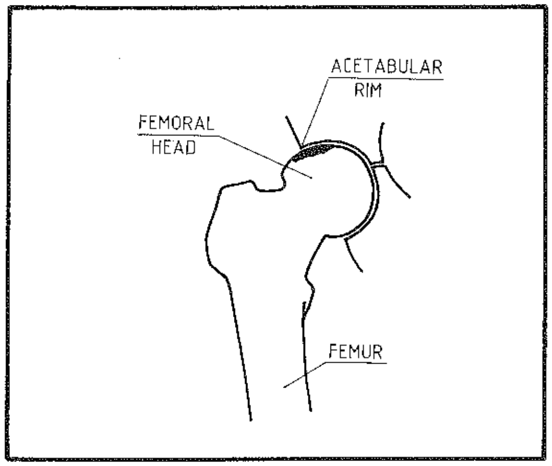


FIGURE 1

Antero-posterior (frontal) and lateral (in profile) radiographs should confirm that the desired coverage of the femoral head has taken place after these rotations have been performed. The correct selection of the three angles will thereby be confirmed.

The upper (proximal) part of the femur should be brought to this new desired position by means of:

a. a single cut (Figure 2) of the femur, spatially related to the long axis of the femur and the frontal, sagittal (profile) and transverse (horizontal) planes

b. rotation of the upper (proximal) part of the femur relative to the lower (distal) part of the femur through a certain angle about an axis perpendicular to the plane of the cut (designated 'screw axis')

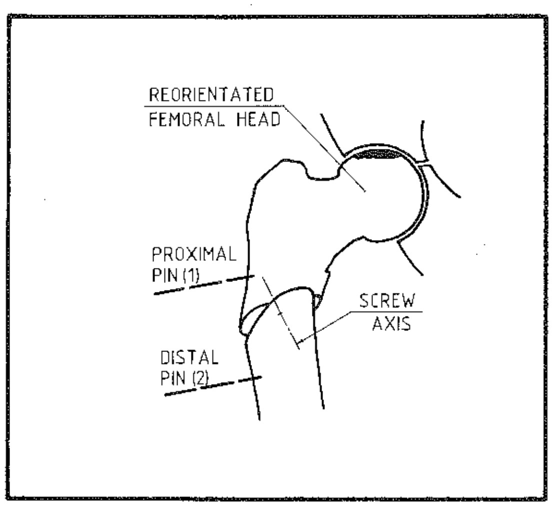


FIGURE 2

A single oblique cut eliminates the need for the removal of a wedge which is now an accepted procedure in femoral osteotomies. The oblique cut gives a good surface contact, which facilitates earlier bone union and reduces the shortening of the femur by comparison with the usual procedures.

Main Geometric Problems

Based on the above description of the desired three-dimensional reorientation, we can now formulate the following geometrical problems:

A. Given a solid body (the femur) in a certain position in space -

1. To find the intersection plane that cuts this body into two pieces so that the upper part, when rotated about an axis perpendicular to the intersection plane by a certain angle θ, will be in a predetermined position.

2. To find the required angle of rotation θ.

This predetermined position should be the final position of the upper part if it is flexed, abducted, and rotated through certain angles ϕ, ε, ρ, pre-operatively determined by the surgeon (see Introduction).

B. To facilitate the work of the surgeon during the operation, two auxiliary pins should first be drilled into the femure above and below the proposed cut. The lower (distal) pin should be perpendicular to the femur in a common frontal plane with its long axis. The problem is to determine the spatial position of the upper (proximal) pin so that after cutting and rotating the upper part of the femur (see Problem A) both pins will be parallel.

Geometrical Model

In a mathematical approach to the solution of the problems formulated we use a geometric model. Figure 3 shows the chosen model: a planar configuration ABECD formed by two coplanar triangles with a common apex E in the subtrochanteric area of the femur. Apex C of the upper triangle coincides with the center of the femoral head. The apexes A and B of the lower triangle are the femoral epicondyles. The plane of intersection should pass through the common apex E. The common median MN of the triangles ABE and CDE is here designated the long axis of the femur. The line joining the apex C with the lower endpoint of the median M is designated the loading axis of the femur (i). The angle between these two axes is the valgus angle of the femur.

Solution of Problem A

The initial position ABECD of the model is the frontal one. In Figure 4 the model is shown in orthographic projections; only the bases AB and CD and the common median MN containing the point E are drawn. The steps of the solution are as follows:

A. The first rotation of the model (flexion) to position $A^1B^1CD(E^1)$ takes place about an axis passing through point C perpendicular to the profile (sagittal) plane. The true angle ϕ of this rotation can be seen in the profile projection.

B. The second rotation of the model (abduction to position $A^2B^2CD^2(E^2)$ takes place about an axis passing through point C perpendicular to the frontal plane. The true angle, ε, of this rotation is shown on the frontal projection plane.

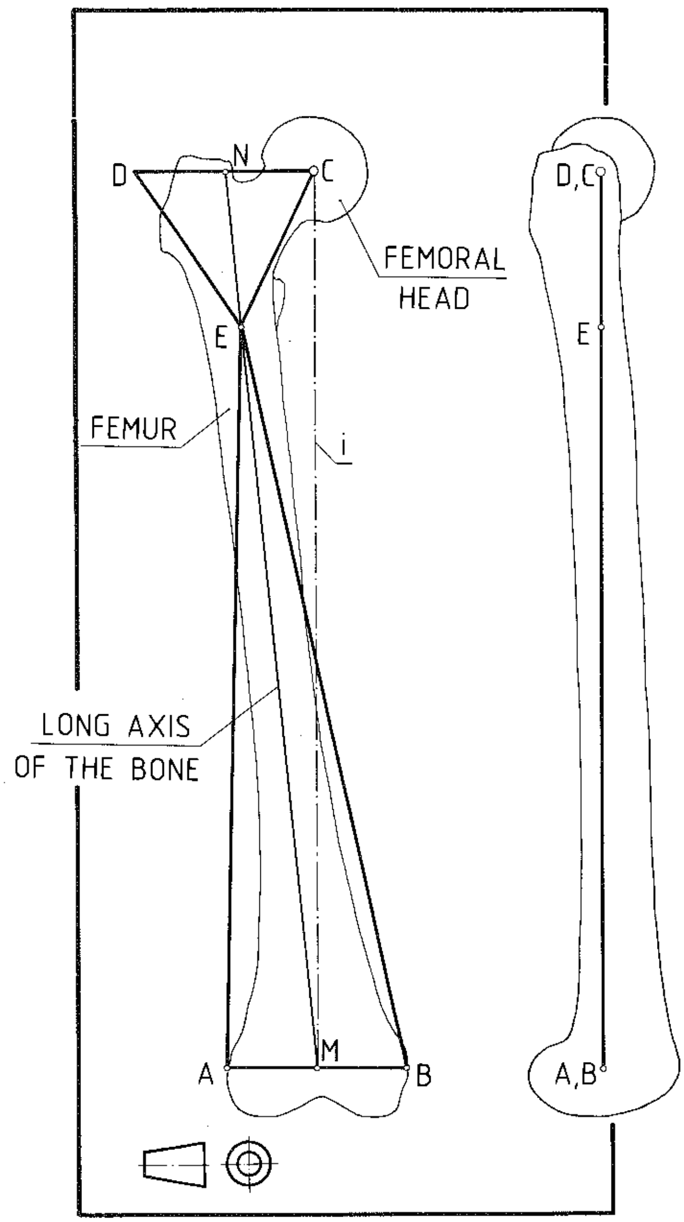


FIGURE 3

C. The third rotation to position $A^3B^3CD^3(E^3)$ takes place about the loading axis i. Two successive ausiliary projection planes are used to achieve this position. The true angle of this rotation is shown on plane 5. The final position $A^3B^3CD^3(E^3)$ corresponds to the position of the leg of the patient flexed, abducted and rotated to the pre-operatively determined angles ϕ , ε , and ρ .

D. Starting with point E^3 we now draw the dashed triangle $E^3A^4B^4$ which shows the lower triangle of the model in a frontal position (true size). This triangle models the lower part of the femur after the operation, i.e. after the femur has been cut and the parts rotated relative to each other into the desired new position; $\Delta E^3A^4B^4 \simeq \Delta EAB$.

$\Delta E^3A^4B^4$ will be seen to be a new position of $\Delta E^3A^3B^3$ after the latter has been rotated about a certain axis j. The skew segments A^3B^3 and A^4B^4 can be regarded as two positions of a generator of a ruled hyperboloid of revolution, and the points A^3, A^4 and B^3, B^4 as subsequent positions of points rotated in two parallel planes perpendicular to the axis (see Figure 5). The trajectories of these points (arcs of two circles) are located in these parallel planes. Two skew lines A^3A^4 and B^3B^4 (shown dotted in Figures 4 and 5) determine a singular pair of parallel planes which are the above mentioned trajectory planes. The axis of rotation j, therefore, should be perpendicular to the skew lines, i.e. to the parallel planes determined by them.

The orthographic projections of the axis j are obtained by drawing perpendiculars to the relevant projections of auxiliary horizontal and frontal lines located in one of the above

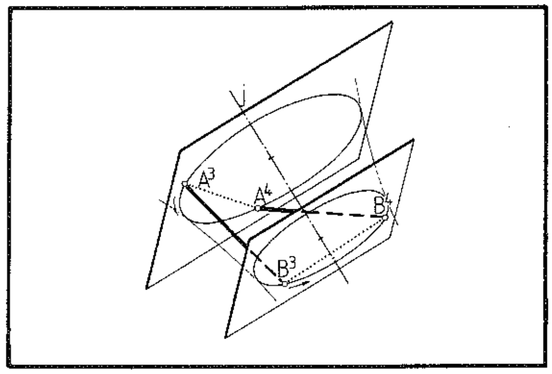


FIGURE 5

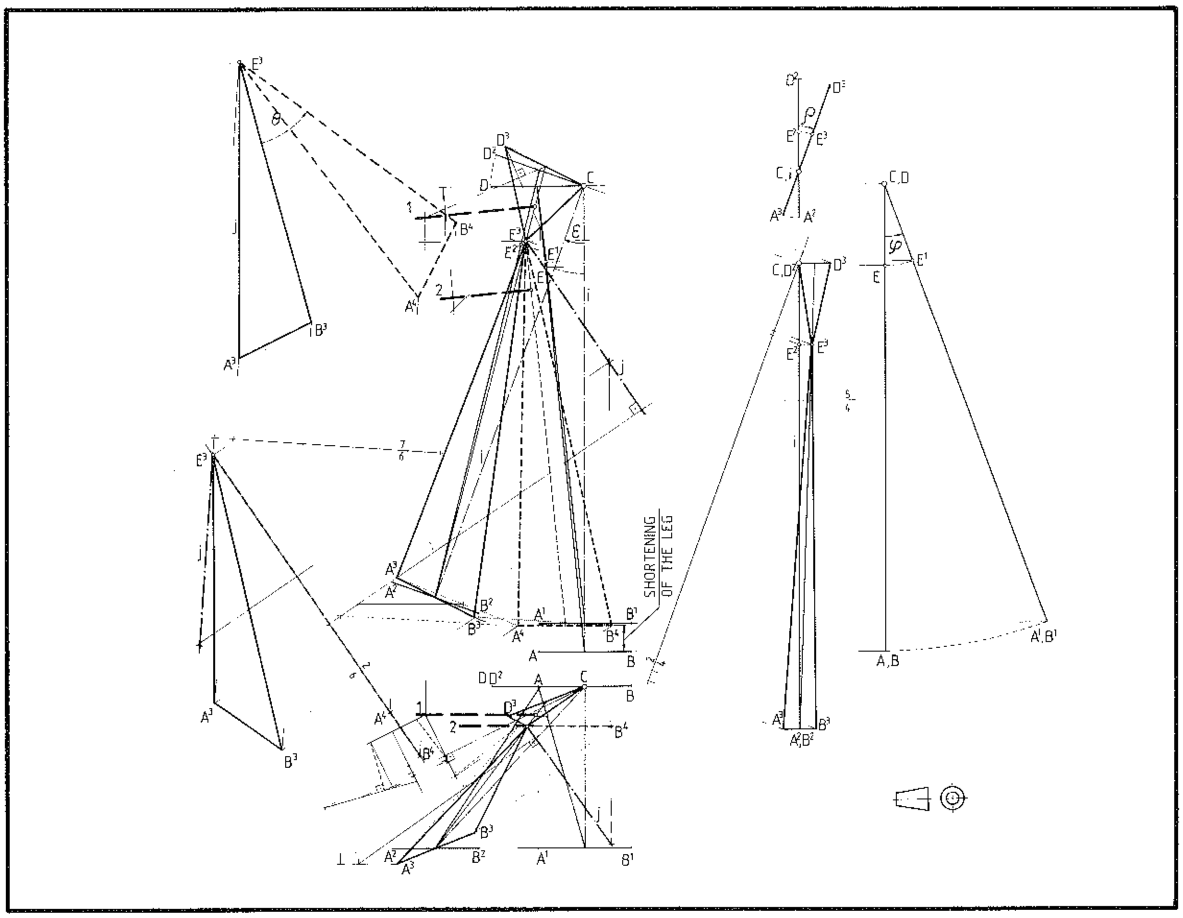


FIGURE 4

mentioned parallel planes, namely, that determined by the line A^3A^4 and the auxiliary line parallel to B^3B^4 passing through point A^3 (Figure 4).

The plane of intersection (cut) must be perpendicular to the derived axis j, so that both parts of the femur will remain in contact when rotated relative to each other.

To find out the true value of the angle θ to which $\Delta E^3A^3B^3$ should be rotated about the axis j to the position $\Delta E^3A^4B^4$ we use two successive auxiliary planes 6 and 7 respectively parallel and perpendicular to the axis j. On plane 7 we obtain the true angle θ. The projection on plane 7 is also used to check the accuracy of the graphical construction. The frontal projection of the $\Delta E^3A^3B^3$ is a result of many successful geometrical manipulations. The frontal projection of $\Delta E^3A^4B^4$ was drawn according to the original dimensions of the model. The projections of these two triangles onto plane 7 must be congruent.

The original drawing of Figure 4 was made to scale of 1,5:1 and the resulting accuracy was within 1%, which in this case is more than sufficient.

Solution of Problem B

To find out the position of the upper proximal pin (1) at the beginning of the operation we draw both pins in their final position in the orthographic projections: two parallel thick dashed lines 1 and 2, starting with points on the long axis of the femur (Figure 4). From an arbitrarily selected point on the upper pin (1) we drop an auxiliary perpendicular onto the ΔCD^3E^3, we fix the piercing point, and then find the true length of the perpendicular (Figure 4). Now we draw the model of the femur in its initial position, i.e. parallel to the frontal projection plane (true size) (Figure 6).

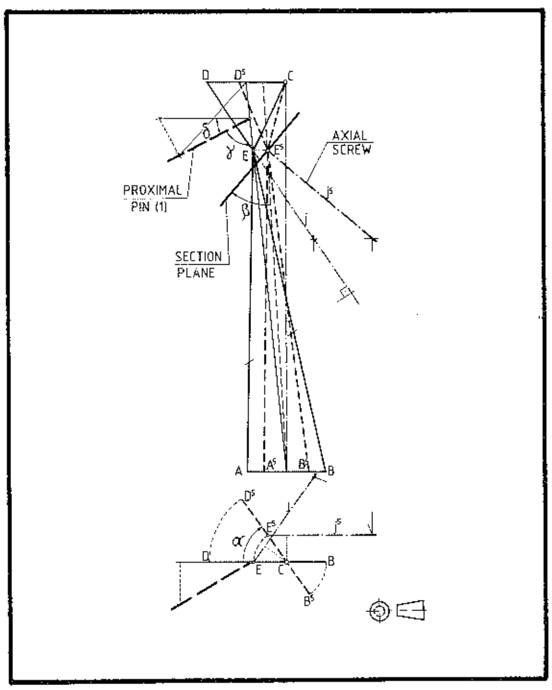


FIGURE 6

This position corresponds to the position of the hip of the patient at the start of the operation. Pin 1 is drawn in the above determined relation to ΔCDE by means of a perpendicular erected from the piercing point found earlier. The two angles γ, δ so obtained can be used to describe the direction of this pin (Figure 6).

Based on these angles a stainless steel jig is constructed to direct the drilling of both pins into the femur during the operation.

Determination of the Hip Position During the Operation

Surgeons prefer to cut the femur in a vertical plane. Therefore when the patient is lying on the operating table his leg should be rotated through a certain angle α to obtain a vertical position of the plane of section. This will happen if the leg is rotated to a position such that the axis j is parallel to the operating table. This angle α is obtained in true size on the horizontal projection (Figure 6) where the axis is shown in the original (transferred from Figure 4) and in rotated positions. The edge view of the plane of section is perpendicular to the projection j^5. We thus obtain the frontal projection β of the angle between this plane and the long axis of the model.

Practical Outcome

As a result of the proposed method, the surgical technique is based on only four angles: α, β, γ, δ. These angles will be taken from specially prepared tables according to the pre-operatively determined flexion, abduction, and rotation angles.

It should be noted that for the first time in the performance of this operation, the resultant shortening of the leg can be estimated beforehand (see Figure 4).

Experimental operations on bones twice carried out in the operating theatres of the Rothschild University Hospital in Haifa and in the General Hospital in Johannesburg. Some of the results of this paper were presented at the scientific seminars in the Orthopaedic Departments of the University Medical Schools in Haifa and Johannesburg.

A cut femur, together with drawings and pictures illustrating the proposed method were also exhibited in Atlanta (USA) at the 47th annual meeting of the American Academy of Orthopaedic surgeons 1980, and evoked great interest.

The first operations following the described method took place on 25th March and 23rd May 1981 at the Coronation Hospital in Johannesburg. The patients, six and five year old boys repectively, suffered from Legg Calve Perthes disease. Femoral osteotomies based on the above theoretical procedure, were performed by the surgeon Dr. M.Rofman in collaboration with the author of this paper, with most satisfactory results.

Industrial Models: a team project approach in teaching engineering graphics

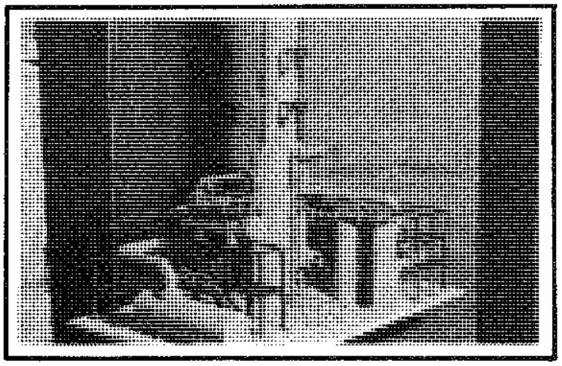


Figure 1.

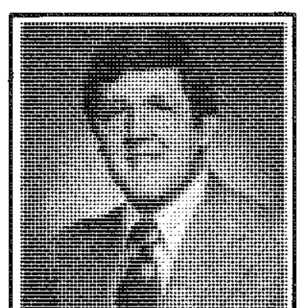
ABSTRACT

This paper describes an instructional approach which was developed to introduce advanced technical drawing students at Athens Drive Senior High School in Raleigh, N. C. to organizing and conducting a simulated engineering team project. The drawings and resulting industrial model (figure 1.), all produced by students, served as a medium and focal point for the project. Since this method was concerned with orienting advanced students to the engineering field and exposing them to the team approach, it may have potential for use in engineering graphics programs.

RATIONALE & OBJECTIVES

Many of us can recall the fascination of laying out the surfaces of geometric shapes at the drawing board and then developing cardboard models of pyramids, cones, pipe elbows, intersections or transition pieces from the patterns. In this regard, there is nothing new about model building as an integral part of engineering drawing courses. Model building has long been established as a valuable instructional aid in relating three-dimensional visual thinking to two-dimensional surfaces. Student experiences in building models serve to clarify the relationships between the drawing and the finished product. In the opinion of the author, learning experiences of this type play a key role in influencing many students to choose, or stay with, engineering as a career goal.

Models are widely used in industry and although most observers find their miniaturized, toy-like appearance intriguing, few fully appreciate their value as engineering tools in project design, planning, and construction. Examples of their increasing use may be found in material handling and process operations involving petroleum, chemicals, mining, foods, and natural gas. Because models vividly portray complex 3-dimensional concepts, they are universally understood. Large firms frequently organize specialized engineering teams or "task forces" for projects involving both drawings and models. After the project is completed the model may still be useful for planning future modifications and expansion or it may "retire" as an attractive public display.



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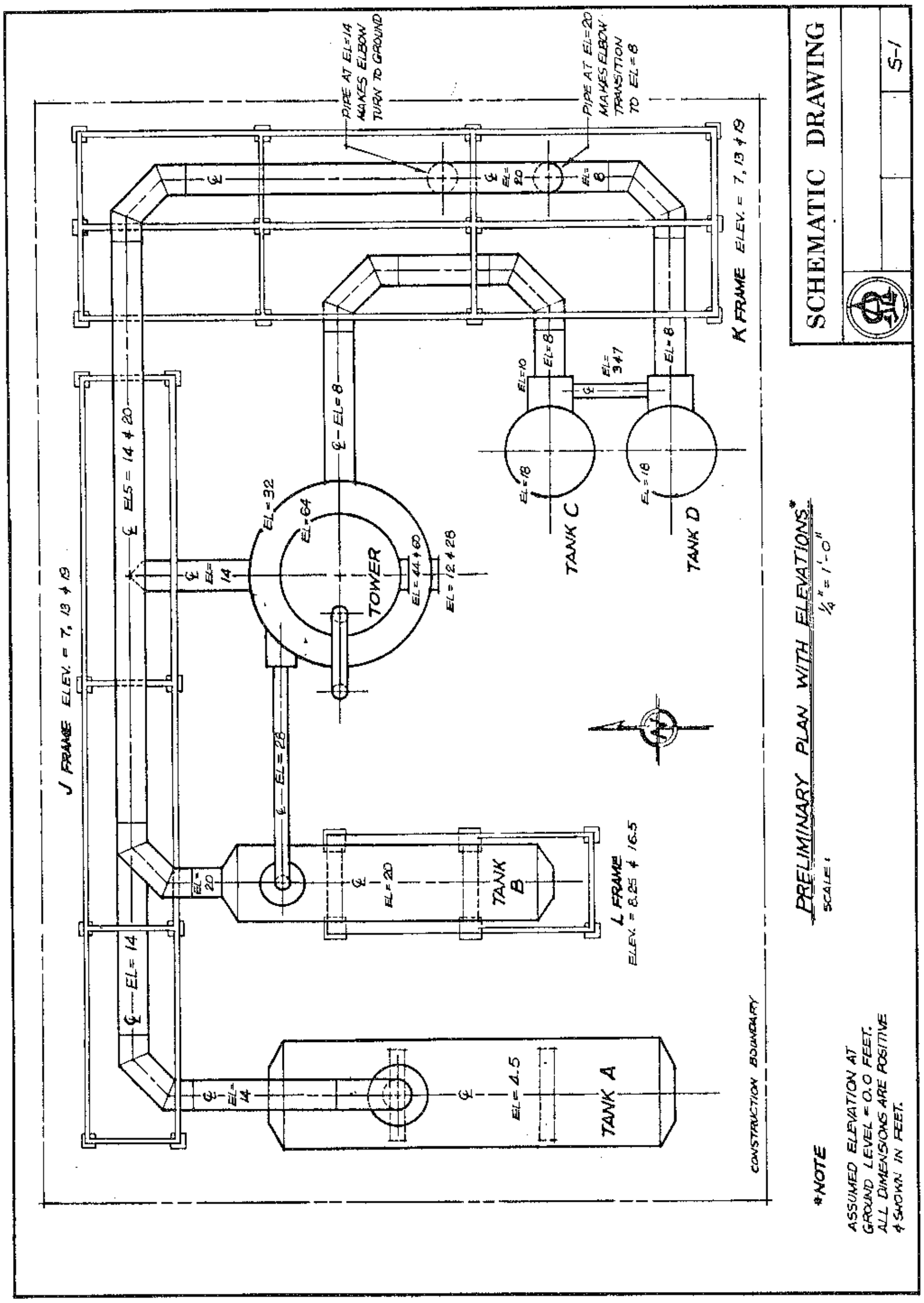
SCHEMATIC DRAWING
S-1
PRELIMINARY PLAN WITH ELEVATIONS*
SCALE: 1/4" = 1'-0"
*NOTE
ASSUMED ELEVATION AT GROUND LEVEL = 0.0 FEET. ALL DIMENSIONS ARE POSITIVE & SHOWN IN FEET.
PIPE AT EL=14 MAKES ELBOW TURN TO GROUND
PIPE AT EL=20 MAKES ELBOW TRANSITION TO EL=8
J FRAME ELEV. = 7, 13 & 19
K FRAME ELEV. = 7, 13 & 19
L FRAME ELEV. = 8.25 & 16.5
CONSTRUCTION BOUNDARY
TOWER
TANK A
TANK B
TANK C
TANK D

Figure 2.

Few students are exposed to model building in their formal education. Traditionally, lack of class time, relative instructional value, facilities, cost, available instructional materials and background of instructor are some of the factors which limit the use of a drawing-model building approach. Additionally, industrial model building is thought of as a highly specialized and technical field outside of the scope of most drawing courses. This is unfortunate because there is much potential here for introducing drawing students to engineering and teamwork while, most importantly, relating the project to the development of graphical skills and visual thinking ability.

The statements and observations mentioned thus far served as a rationale for developing the following objectives to be realized in utilizing the drawing-model building team approach.

1. To improve 3-dimensional visual thinking ability and drawing skills.

2. To involve students in organizing and conducting a simulated engineering team project requiring them to interact and cooperate in achieving a common goal.

3. To expose students to industrial models as a visual design tool used in engineering.

PREPARATION FOR THE PROJECT

The underlying instructional problem was to incorporate the above broad goals into an instructional package which matched student ability as well as one which was concise, economical, realistic and compatible with the scope and sequence of a drawing course. Following is a summary of the major items considered as prerequisites to initiating a learning experience of this type:

1. Student Preparation: Students involved in these projects were enrolled in Technical Drafting II and had previously completed at least one year of basic technical drawing. Students received a unit of instruction in intersection and development drawing prior to the project and each student had at least one experience in constructing a cardboard model of an elbow or transition piece.

2. Project Selection and Scope: An industrial system was chosen which could be easily identified by students and one which could be broken down into geometric components. Specialized disciplines of engineering likely to be involved in the design and construction of the system, such as mechanical, structural, piping, chemical and civil were described to the students and served as a basis for organizing students into teams. In carrying out the project, however, greater emphasis was placed on "visual thinking" and geometric form than on function. The project had to be realistic and complex enough to challenge and involve all students, yet simple enough to be understood and completed in a relatively short time. The refinery project shown here (see figure 3.) involved 18 students and required approximately 42 hours of class time.

3. Schematic Drawing: A preliminary plan view of the entire system (figure 2.) was drawn to determine the size and scale of the model. This initial drawing was prepared by students from sketches furnished by the instructor and included key elevation heights for tanks, frames and pipe center lines. The schematic drawing was then used to prepare a list of all required drawings, elevations, plans, details and patterns sufficient to visually describe the system layout in detail. This list of required drawings also served as a basis for assigning drawings to teams and individual students. A total of 27 drawings were required to describe this system.

4. Project Schedule: A project progress schedule was prepared next (figure 3.). The reader should note that this schedule is similar to standard bar charts as used in construction projects. All phases of the project, the sequence of activities and projected deadlines are listed. The schedule was highly useful throughout the project for it enabled students and instructor to monitor each phase and activity of the project.

5. Materials and Facilities: Wood and cardboard were chosen as model building materials because of their availability and economy. The total cost of this project, including all accessories such as glue, paint and hobby knives, was approximately $40.00. Other than the usual classroom drafting equipment and supplies, the only special facility required was the school's woodshop in order to cut and dress wooden strips to scale for structural shapes.

CONDUCTING THE PROJECT

Possibly, the most important phase of this project was orienting and involving students. Explaining the problem clearly, organizing teams and spreading the workload fairly were among factors to be considered. Each student needed to feel a positive sense of responsibility to a "team" whose overall objective could only be accomplished through interaction and group effort. Specific activities and deadlines listed on the "Project Schedule", figure 3, served as an outline for conducting and monitoring the project. The instructor's role throughout the project was that of project manager, resource person, facilitator, and sometimes, arbitrator. Throughout the project, it was found especially important for the instructor to be flexible in adjusting the project's schedule and in keeping student workloads balanced.

The final stages of the project are illustrated in figures 4, 5, and 6. Figures 4 and 5 show students involved in checking drawings and working on model components. The photos also serve to depict the relative size of the model as well as the drawings. After all model components were checked for accuracy, they were laid out prior to final assembly as shown in figure 6. Figure 7 shows one corner of the finished model and illustrates the importance of having all 18 students working together to make drawings agree so that model components would inter-relate and fit.

PROJECT SCHEDULE

TITLE & DESCRIPTION: REFINERY SYSTEM, Design Model & Drawings

*One Class Period = 100 minutes

PHASE	ACTIVITY	DATE DUE	1st Week *	2nd	3rd	4th	5th
I. IMPLEMENTATION	A. Schematic Drawing, Description of Project and Objectives	Proposed / Actual					
	B. Engineering Teams Organized & Duties Assigned						
II. DRAWING	A. Drawings of Overall System; Elevations & Plan						
	B. Drawings of Individual, Component Systems						
	1. Piping System & Valves						
	2. Structural Frames, Supports, Catwalks & Ladders						
	3. Storage Tanks & Refractory Tower						
	C. Pattern Drawings						
	1. Piping & Elbows						
	2. Storage Tanks & Refractory Tower						
III. MODEL BUILDING	A. Construction of Model Components						
	1. Base & Structural Frames						
	2. Pipe Lengths & Elbows						
	3. Storage Tanks & Refractory Tower						
	4. Catwalks, Hand-railing, Ladders & Valves						
	B. Trial Assembly, Modifications, & Drawing Revisions						
	C. Painting, Primer and Finish Coats						
IV. EVALUATION	A. Print & Compile Complete Set of Drawings						
	B. Final Assembly of Model & Clean Up						
	C. Evaluation, Feedback & Discussion						

Figure 3.

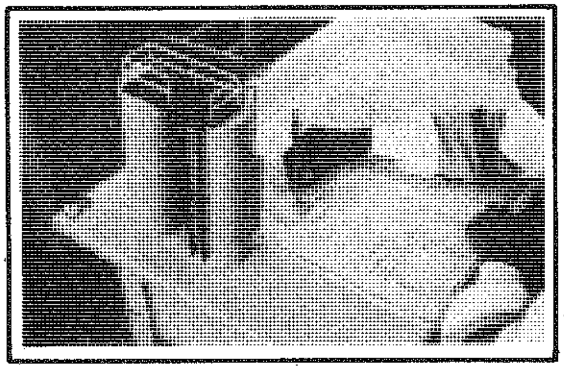

Figure 4.

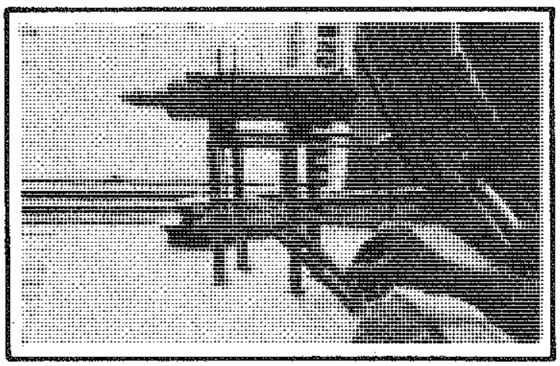

Figure 5.

REACTION AND ASSESSMENT

The reaction of students involved in this project was highly positive once they understood their role in the overall project. The time frame imposed on students plus the required interaction and teamwork helped to create a cooperative and dynamic classroom atmosphere. Since all drawings and model had to fit together as a system, nearly all classroom activity was engrossing and required much attention to detail. An indicator of the interest generated is the fact that on several occasions, students had to be run out of the classroom.

An evaluation of student achievement was conducted at the close of the project. Evaluation was based two-thirds on individual drawings and model components and one-third on teamwork, participation, interaction and meeting deadlines. Evaluation of "teamwork" was largely subjective and, therefore, difficult.

Even though this project provided an engaging learning experience, the author does not mean to imply that industrial model projects are a panacea for all engineering drawing courses. Following is a partial listing of advantages and disadvantages observed in using this instructional method:

ADVANTAGES

1. Expanded students' knowledge of drawing and visual thinking into a broad new area.

2. Required students to meet deadlines, much as would be expected in industry.

3. Organized and compressed a complex activity into a feasible time frame, divided major tasks into shared responsibilities and required interaction and teamwork.

4. Emphasized engineering drawing as a realistic and necessary activity in project planning.

5. Resulted in a tangible finished product which was both visible and interesting.

6. Introduced students involved in making career choices to the field of engineering.

DISADVANTAGES

1. Preparation for the project, especially the first one, was time-consuming.

2. Students required prequisite experience in intersection and development drawing and construction of cardboard models from patterns.

3. It was difficult to keep all students equally involved, due partly to the sequence of activities.

4. The project had to be designed to fit the level of student and sequence of instruction.

5. Availability and cost of materials somewhat limited the scope of the project.

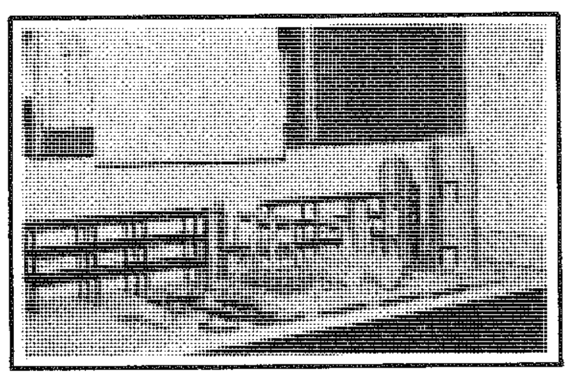

Figure 6.

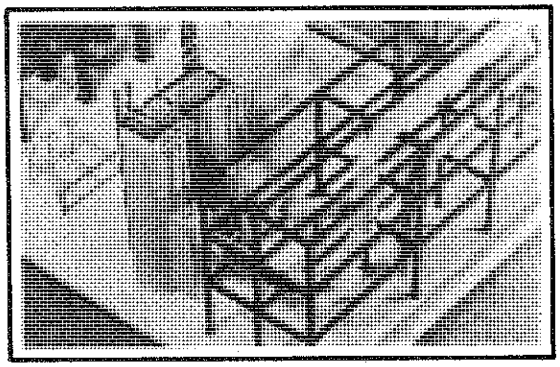

Figure 7.

DISCUSSION AND CONCLUSION

The development of this article was intended only to report on an innovative teaching method. The scope of this project, and the two that preceded it, was too broad, and the number of students too small, to furnish much useful data or to draw any meaningful conclusions. A follow-up of graduates does reveal that of the 44 students who participated in these projects, over a three-year period, 17 went on to 4-year engineering or related schools, 12 went into 2-year technical schools, and 15 went directly into the job market or military service.

It should be re-emphasized that this project was designed to visually orient high school students to an industrial system with less emphasis placed on the actual function of the system. Students at the post secondary level should certainly be more involved in functional design in addition to the graphical layout of the system being modeled. For anyone considering development of a technically correct industrial model, kits, some educational material, and a wide array of plastic components are available commercially for constructing piping process models. For instructional purposes and economy, all components in the model described here were developed from patterns and handmade.

Although not directly appropriate for a first course in engineering graphics, a project of this type might easily be integrated into a second course. It has the potential to be developed into a design project where students are required to develop a proposal, design a functional industrial system, produce design layout drawings, and prepare a project schedule and cost analysis. To quote Dr. Lee Harrisberger from his article titled "Developing the Complete Engineer" in the Spring 1980 edition of Engineering Design Graphics Journal, "there is little room or inclination in current engineering education to be concerned about the personal and psychological development of the engineering student to prepare him/her to cope with real-world interactions." Since group interaction and organization are involved, a project of this type provides one method for those involved in teaching engineering graphics to take the initiative in introducing their students to the engineering process.

Regardless of the merits of this particular method, instructional approaches which develop team skills through the application of engineering drawing are worth considering. When carefully designed and executed, realistic learning experiences do stimulate student interest and involve them seriously in their education. When this happens, everyone benefits, especially the student.

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Computational Geometry

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Introduction

One of the most important areas emerging from computer science, electrical engineering, operations research, and related disciplines has come to be known as Computational Geometry (Forrest, 1971; Shamos, 1975, 1978; Preparata, 1977). Computational Geometry is concerned with the design and analysis of computer algorithms for solving geometric representation, construction, and design problems. These geometric problems include all the classical Euclidean construction problems plus many others which have emerged from computer graphics, computer aided design, and other engineering design applications. These can generally be placed into one of the following categories:

1. Location
   - nearest neighbor
   - spatial organization
   - network design
2. Inclusion
   - area/volume calculations
   - polygon inclusion
   - statistical clustering
3. Intersection
   - polygon intersection
   - interference/hidden surface
   - combinatorial optimization

With the increasing importance of the field of Computer-Aided Design and Computer-Aided Manufacturing (CADCAM), the influence of Computational Geometry is obviously becoming more important. For example in finite element analysis, the type of triangulation of an object can have a major impact on the number of computations and the accuracy of the ensuing analysis. Some research has shown that the Delaunay triangulation is perhaps the "best" triangulation to use in finite element analysis (Sibson, 1978). Another major impact is emerging in Very Large Scale Integration (VLSI) which concerns the miniaturization of components and the packing of these components on an electronic chip. One critical problem in VLSI design is to minimize the overlapping of the rectangular components on the chips. This has come to be called the "rectangle intersection" problem (Bentley, 1979; Six, 1980). Thus, as we can see, the influence of Computational Geometry on the future of engineering design and graphics is far-reaching indeed.

What we intend to do in this article is present an overview of the literature of Computational Geometry, introduce the reader to some of its basic principles, and outline the eventual impact this field should have on engineering design and graphics in the future.

Areas of Polygons

To begin this discussion, let us consider the area calculations of plane, convex polygons with N vertices. This problem and its surprisingly difficult counterpart in three dimensions is a significant recurring problem in computer-aided design. The classical approach to this problem is to use the following formula:

$$\text{Area} = \left| 1/2 \sum_{i=1,N} x_i (y_{i+1} - y_{i-1}) \right|$$

The computations above require N multiplications and 2N – 1 additions or substractions, for a total of 3N – 1 arithmetic operations.

Another set of relationships has been advanced by Shamos (1978) which results in (4N – 5) operations if N is odd and (4N – 9) operations if N is even. The two formulae are:

$$\text{(N odd)} \qquad \text{Area} = \left| 1/2 \sum_{i=1,N-1} (x_i - x_N)(y_{i+1} - y_{i-1}) \right|$$

$$\text{(N even)} \qquad \text{Area} = \left| 1/2 \sum_{i=2,N/2} (x_{2i-1} - x_1)(y_{2i} - y_{2i-2}) + (x_{2i-2} - x_N)(y_{2i-1} - y_{2i-3}) \right|$$

In the case of triangles, quadrilaterals, and six-sided figures, Shamos' formula results in fewer arithmetic operations than the classical method. For design applications requiring thousands of area computations of these modular figures, a significant savings in computer time could be realized.

Example subroutines coded in FORTRAN-IV for the computation of these odd and even polygonal figures are given below in Figure 1.

```
      SUBROUTINE ODD(N,X,Y,SUM)

      DIMENSION X(10),Y(10)

      SUM = 0.0

      M = N - 1
      DO 1 I = 1,M
         IPLUS = I + 1
         IMINUS = I - 1
         IF(  (I + 1) .GT. N) IPLUS = (I+1)-N
         IF(  (I - 1) .LE. 0) IMINUS = (I-1)+N
1     SUM = ( X(I)-X(N)) * (Y(IPLUS)-Y(IMINUS)) + SUM
      RETURN

      END



      SUBROUTINE EVEN(N,X,Y,SUM)

      DIMENSION X(10),Y(10)

      SUM = 0.0

      NBY2 = N/2
      DO 2 I = 2,NBY2
       IM = 2*I - 1
       IP = 2*I - 2
2        SUM = (X(IM)-X(1)) * (Y(2*I)-Y(IP)) +
               (X(IP)-X(N)) * (Y(IM)-Y(2*I-3)) + SUM

      RETURN
      END
```

FIGURE 1

These programs are presented as subroutines since the main program which would call these programs may have special input/output features which differ with various mini and large computing facilities unique to the reader's system capability. One rule which must be observed in examining plane figures to be computed by these formulae is that the points should be read in sorted clockwise or counter-clockwise order, otherwise, the programs will not compute the correct area calculations. The sub-programs require not only the number of vertices N but the sorted Cartesian coordinates of the vertices of the plane polygon.

Computational Complexity

When one analyzes a computer algorithm, we like to measure its computational complexity. This complexity is basically measured on two separate dimensions:

1. computer running time
2. computer storage space.

Further, this complexity is a function of the size of the input problem which the algorithm is intended to solve. The size of the input problem is usually defined in terms of the number of vertices of the object, the number of edges of the object, the number of faces of the object, or some combination thereof. The variable used to define the input size is usually: N.

Given this, one would like to have some formula, usually a polynomial which is a function of N, f(N), whose growth rate as $N \rightarrow \infty$ gives one a sense of the worst case time or space which the algorithm will take in order to solve a given problem of size N. To be more specific here, let's define the following terminology. We say that an algorithm has complexity "big oh" of g(N):

$$f(N) = O(g(N)) \text{ as } N$$

if the algorithm is run on some computer, then the running time and space required by the computer will approximately require time and space proportional to g(N).

For example, we recently showed, with the formula for computing areas of convex figures, that the exact polynomial function for each algorithm is as follows for the classical and Shamos' formula respectively:

$$f(N) = 3N - 1$$

$$f(N) = \begin{cases} 4N - 5 \text{ (if N is odd)} \\ 4N - 9 \text{ (if N is even)} \end{cases}$$

Thus, according to our above notations, we can simply say that each algorithm is:

$$f(N) = O(N)$$

or in other words, that each of them is "linear" in the size of N. The "big oh" notation drops the leading constant, so that we have a rough approximation of the complexity of the algorithm as a function of N.

Most of the algorithms are O(logN), O(NlogN), $O(N^2)$, etc. which are some polynomial function of N. In general, if an algorithm is polynomial in time or space, it is classified as a "good" algorithm (Edmonds, 1965; Lawler, 1976). The references included in the reference section elaborate on this in greater detail than we will in this article, since some of these concepts are quite complex, thus transcending the intended purpose of this article.

Of particular importance here is that the problems we solve and the algorithms designed to solve them be polynomially bounded. In this regard it is important to know beforehand the "intractability" or "difficulty" of a problem in relation to other problems for which polynomially bounded algorithms exist. To this end, we can borrow a problem classification recently developed in the theory of combinatorial optimization which provides a useful guideline for the problems and algorithms we wish to study.

Figure 2 illustrates the relationships between these various combinatorial optimization problems: P, NP, NP-complete, and NP-hard. For further details, the reader is encouraged to see the following references: Reingold, 1977; Horowitz and Sahni, 1979; Garey and Johnson, 1979.

P: The class of all problems for which a worst-case polynomial time algorithm exists. Polynomial time algorithms are usually described as O(logN), O(NlogN), or O(N). Examples of problems in this class are: shortest path problems, assignment problems, certain network flow problems.

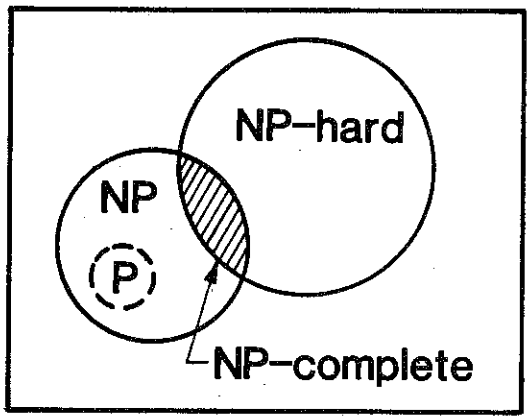

FIGURE 2

NP: The class of problems for which no polynomial time algorithm exists. For example, Khachian's algorithm for Linear Programming (LP) showed that the LP problem itself is in the class P and not the class NP (Aspvall and Stone, 1979).

NP-complete: Those problems which are the most difficult to solve in the NP class are in a special sub-class called the NP-complete class. These problems are called NP-complete because through a translation process they can be reduced to one central problem called the satisfiability problem (Cook, 1971; Karp, 1972, 1975). Typical of the problems in this class is the problem of deciding whether an undirected graph has a Hamilton cycle.

NP-hard: This final class contains problems that are even more difficult than those in the NP-complete class. Certain mathematical optimization problems fall into this class. An example is determining the optimal Hamilton cycle of all possible Hamilton cycles in a graph.

Summary and Conculsion

In this article, we have attempted to introduce the reader to some of the basic concepts of Computational Geometry, outlining the scope of the subject and introducing some example applications. We have also included a summary list of references through which the interested reader can delve much deeper into this fascinating area of theoretical graphics.

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The Perception of Auxiliary and Principal Planes of Projection

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This article is a bit like Columbus trying to explain the shape of the earth to the people of his time. That is, it is not a very comfortable position to be in when one makes statements contrary to what the authorities say and to overwhelming popular belief and practices. Nevertheless, it is the author's belief that the overwhelming majority of engineering graphics texts are not accurate in the usage of reference planes any more than the belief in Columbus' day that the world was flat. In fact, the same premise is in question here; should an orthographic view be viewed as flat or three dimensional in nature? That is, should we teach just relationships between two dimensional views, or should we use every available tool necessary to encourage three dimensional visualization?

The "Flattened out" method (Figure 1) is the method used in most texts. Figure 2 is the method the author feels should be taught, not only because of its true 3D presentation, but also because of its direct application to 3D visualization. The following comments have been made by faculty members who do not support this premise.

1. The reference lines are merely aids to an end.

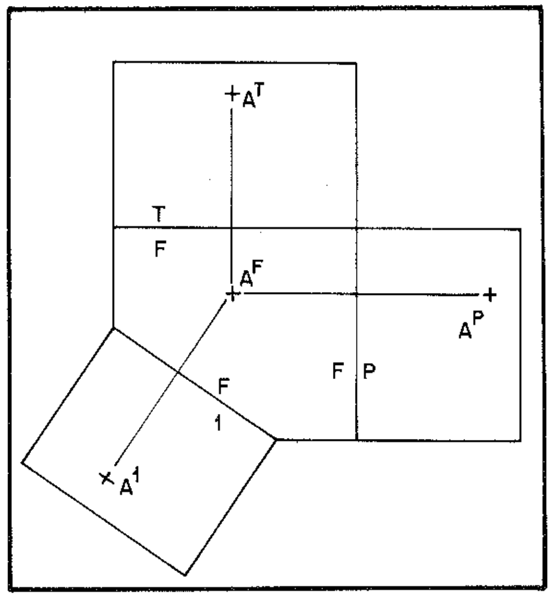

FIGURE 1 - Planes of Projection "Flattened out"

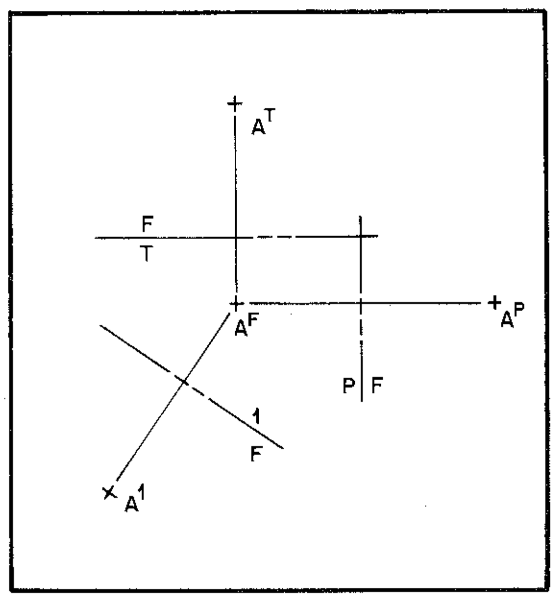

FIGURE 2 - Planes of Projection shown in three dimensional space

2. I just tell my students to count two views back.

3. It doesn't really matter what they are called as long as the student understands what they are.

The point is, DO the students really understand what they are doing or are the faculty speaking of themselves and their colleagues? When a faculty or practicing engineer solves a descriptive geometry problem, there is a reasonable chance they understand what they are doing. However, a student in class may mimic the instructor in rote rules and not have the foggiest idea of what is going on. The students will reflect their teacher sufficiently to receive an acceptable grade. But, when it is necessary to apply this learning to actual problems, great difficulty is encountered because they cannot recognize when or where what they have "learned" applies.

Other counter-arguments to the planes of projection being viewed as edges are:

1. We have always done it that way.

2. It seems more natural to label them as flattened out planes.

3. The textbook does it that way, and the students seem to understand it.

4. Reference lines are just that, a line of reference that can be looked at anyway one chooses.

5. When one is looking at the object in our current direct method in the third quadrant, there really are no planes of projection.

By now you may have guessed that the author is not concerned with convenience or tradition, but how to get the student to view and visualize orthographic projections in their natural placement. Hopefully this will present to the new student a true three dimensional viewing, visualizing, and understanding of 3D graphical problem solving.

The flattened method has all of the reference lines in the front view labeled F. In that case, why label them at all? Labeling the point A^F tells one that the plane of projection and its edges are the Front plane. It appears that the only purpose of the reference "line" is to give one the direction of the next projection. This is the easy part. The part the students have trouble with is the distance one must measure to get to the point in the next projection. When the student is told the plane of projection seen as an edge is a surface to be measured from, not only is this an accurate description of what is going on, but it also forces the student to view each multiview as a three dimensional object. This should increase their visualization capabilities.

Why is the author so adamant as to the labeling of what most consider to be trivial "bookkeeping" on a drawing? Primarily because looking at these reference "lines" as planes on edge exercises the students virtual space imagination (Duff, 1979). The developing of this virtual space concept is of paramount importance if we expect our students to develop the right side of their brain (Hanks & Belliston, 1980) where the spatial visualization takes place.

"TO VISUALIZE BETTER IS TO THINK BETTER" (DeJong, 1981). Do we not agree to the importance of inner visualization as being critical in the design process as well as an important tool in graphically communicating these thoughts and creative ideas? If so, why do we allow our textbooks to foster the development of non-virtual space by using the flat planes of projection method. As stated by Jon M. Duff (1979),

> "These individuals see the symbols of objects in virtual space as flat, two-dimensional diagrams. The representational image is lost and the drawing takes on the visual vitality of a tic-tac-toe diagram."

Yes, we have been dismissing an important visualization tool, the reference planes, as a trivial tool for measurement for too long. Visualization is too important a skill not to use every available resource to teach and fortify it in every way we can.

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Computerized Descriptive Geometry

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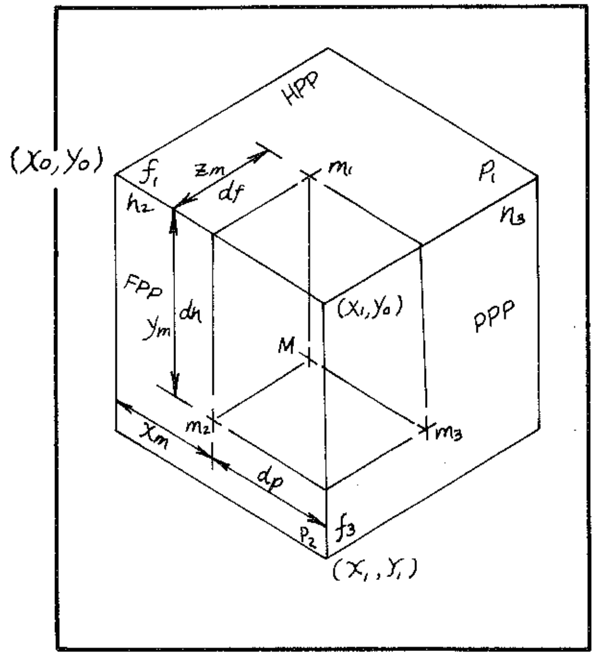


FIGURE 1
Notations used.

Introduction

Euclid had for "ground rules" the requirement that geometry problems be solved only with straight-edge and compass. Monge probably had crude drafting instruments, perhaps T-square and triangle, and more recent draftsmen have had universal drafting machines.

Computerized descriptive geometry, making use of the interactive computer instead of ruler and compass or more sophisticated drafting devices, is probably one of the most interesting topics in the computer era.

In this article a package of descriptive geometry programs is presented. It covers most of the point, line, and plane work of that course. As a matter of fact, this paper is a blend of computerized analytical and descriptive geometry.

Comparing a system of notation used in Descriptive Geometry and the coordinate system in computer programming

Figure 1 shows a point M in space projected to the jorizontal projection plane (HPP) as m_1, projected to the frontal projection plane (FPP) as m_2, and projected to the profile projection plane (PPP) as m_3. Figure 2 is the unfolded orthographic version of the pictorial representation of Figure 1. Note that in computer programming, instead of the transfer dimensions d_h, d_f, and d_p, the Cartesian coordinate notation x_m, y_m, and z_m is used to match the coordinate system of the monitor screen. Using the left end of the f_1 h_2 fold line as an origin, the coordinates of the fold line are x_o and y_o at the left end, and x_1 and y_o at the right end. The coordinates of the lowest end of fold line p_2 f_3 are x_1 and y_1. The coordinates for point M are inputted to the computer as follows: (See Figure 2)

$x_m = x_o + x_m$

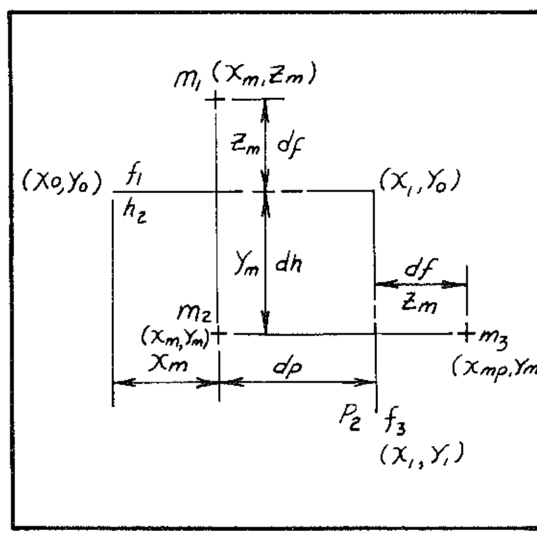


FIGURE 2
Relationship between three principal views and coordinates system.

$$y_m = y_o + y_m$$
$$z_m = y_o - z_m$$

and for profile view:

$$x_{mp} = x_1 + z_m$$
$$y_{mp} = y_o + y_m$$
$$(\text{or } y_{mp} = y_m)$$

True length view of an oblique line, adjacent to top view

A view of the line projected to an auxiliary projection plane parallel to the line shows the line true length. Figure 3 shows the geometric relationship between b_1 and a point A on the auxiliary fold line follows:

$$x_a = x_b - \text{HSIN}(\alpha)$$
$$y_a = y_b - \text{HCOS}(\alpha)$$
$$\text{where } \alpha = tg^{-1}((y_c - y_b)/(x_c - x_b))$$

and H, the distance between the auxiliary fold line and the top view $b_1 c_1$, is a constant number arbitrarily selected. From point A any other point on the fold line can be calculated by using the same method as above. For example, the coordinates of point M are

$$x_m = x_a - \text{DCOS}(\alpha)$$
$$y_m = y_a + \text{DSIN}(\alpha)$$

where D is the distance between point A and M. Obviously the coordinates of point b_4 and c_4 can be calculated in the same way by using the transfer dimensions y_b and y_c.

Figure 4 shows examples of true length views of an oblique line adjacent to the top view, as output on the printer, from the program of Figure 5.

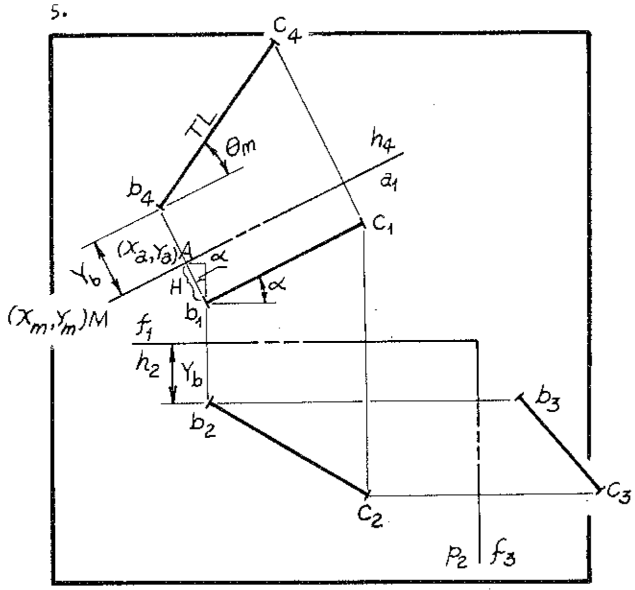
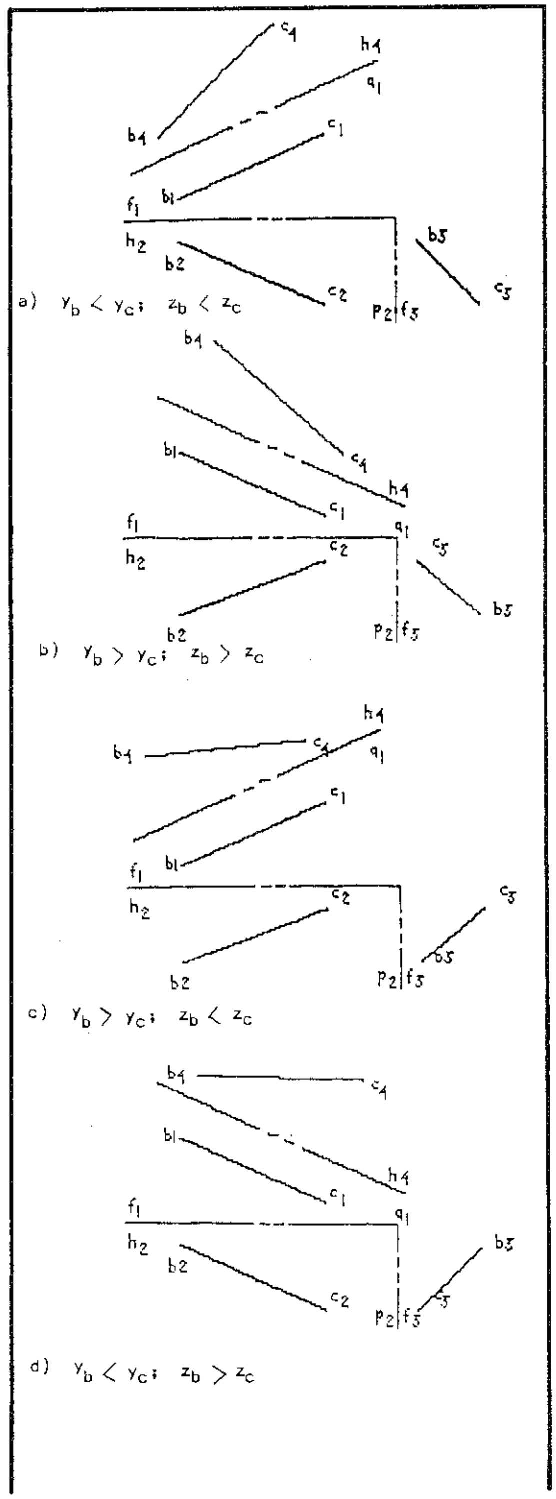


FIGURE 3
True length of an oblique line.

In Figure 4 from a to d the outputs are for different inputs. For example, a) is for $y_b > y_c$; $z_b > z_c$; and b) is for $y_b > y_c$; $z_b > z_c$.



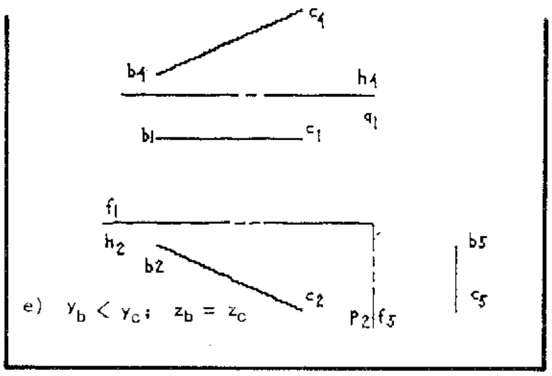


FIGURE 4
Computer output 3 views and true length view of an oblique line.

If the input is for $z_b = z_c$, the line is not an oblique line but rather an inclined frontal line. In that case the output e) shows both the front and rear views as true length views.

The true length program calculates and outputs the numerical values of the true length of the line, the true angle between the line and HPP (θ_h or slope), and the grade of the line as well.

The program causes this information to be printed on the text screen under the graphics screen.

```
10  REM  THIS PROGRAM MAY BE USED TO DETERMINE TRUE LENGTH OF A LINE
20  HGR : HCOLOR= 3: SCALE= 1
30  DIM X(20),Y(20)
40 XO = 50:YO = 110:X1 = 180:Y1 = 160: HPLOT XO - 20,YO TO 100,YO: HPLOT 1
     04,YO TO 109,YO: HPLOT 112,YO TO 117,YO: HPLOT 120,YO TO X1,YO
50  HPLOT X1,YO TO X1,YO + 12: HPLOT X1,YO + 15 TO X1,YO + 19: HPLOT X1,YO
     + 22 TO X1,YO + 26: HPLOT X1,YO + 29 TO X1,Y1
60  DRAW 16 AT XO - 15,YO - 10: DRAW 1 AT XO - 13,YO - 8: DRAW 18 AT XO -
     18,YO + 5: DRAW 2 AT XO - 12,YO + 10
70  DRAW 26 AT X1 - 12,Y1 - 10: DRAW 2 AT X1 - 6,Y1 - 7: DRAW 16 AT X1 + 6
     ,Y1 - 10: DRAW 3 AT X1 + 9,Y1 - 8
80  PRINT "THE COORDINATES OF POINT B": PRINT "XB=": INPUT XB: PRINT " YB=
     ": INPUT YB: PRINT "ZB=": INPUT ZB
90  PRINT "THE COORDINATES OF POINT C": PRINT "XC=": INPUT XC: PRINT "YC="
     : INPUT YC: PRINT "ZC=": INPUT ZC
100 X(1) = XO + XB:Y(1) = YO + YB:X(2) = XO + XC:Y(2) = YO + YC:X(3) = X1 +
     ZB * 7 / 6:Y(3) = Y(1)
110 X(4) = X1 + ZC * 7 / 6:Y(4) = Y(2):X(5) = X(1):Y(5) = YO - ZB:X(6) = X
     (2):Y(6) = YO - ZC
120 ALPHA =  ATN ((Y(5) - Y(6)) / (X(2) - X(1)))
130 C = 20 *  COS (ALPHA):S = 20 *  SIN (ALPHA)
140 X(7) = X(5) - S:Y(7) = Y(5) - C
150 X(8) = X(7) - C:Y(8) = Y(7) + S
160 K = .5: IF X(2) - X(1) > 60 THEN K = 1.5
170  IF X(2) - X(1) > 76 THEN K = 2
180 X(7) = X(7) + K * C:Y(7) = Y(7) - K * S
190 X(9) = X(5) - (20 + YB) *  SIN (ALPHA)
200 Y(9) = Y(5) - (20 + YB) *  COS (ALPHA)
210 X(10) = X(6) - (20 + YC) *  SIN (ALPHA)
220 Y(10) = Y(6) - (20 + YC) *  COS (ALPHA)
230 X(11) = X(6) - S:Y(11) = Y(6) - C
240 X(12) = X(11) - C:Y(12) = Y(11) + S
250 X(11) = X(11) + K * C:Y(11) = Y(11) - K * S
260 T = 5 *  SIN (ALPHA):D = 5 *  COS (ALPHA)
270  FOR L = 12 TO 16
280 X(L + 1) = X(L) - D
290 Y(L + 1) = Y(L) + T
300  NEXT L
310  FOR J = 1 TO 16 STEP 2
320  HPLOT X(J),Y(J) TO X(J + 1),Y(J + 1)
330  NEXT J
340  DRAW 12 AT X(1) - 6,Y(1) + 6: DRAW 2 AT X(1),Y(1) + 8: DRAW 13 AT X(2
     ) + 6,Y(2) - 8: DRAW 2 AT X(2) + 9,Y(2) - 6
350  DRAW 12 AT X(5) - 8,Y(5) - 5: DRAW 1 AT X(5) - 3,Y(5) - 3: DRAW 13 AT
     X(6) + 6,Y(6) - 6: DRAW 1 AT X(6) + 10,Y(6) - 4
360  DRAW 12 AT X(3) + 8,Y(3) - 6: DRAW 3 AT X(3) + 14,Y(3) - 4: DRAW 13 AT
     X(4) + 12,Y(4) - 9: DRAW 3 AT X(4) + 14,Y(4) - 7
370  DRAW 12 AT X(9) - 16,Y(9) - 5: DRAW 4 AT X(9) - 8,Y(9) - 3: DRAW 13 AT
     X(10) + 8,Y(10): DRAW 4 AT X(10) + 12,Y(10) + 2
380  DRAW 11 AT X(11) - 2,Y(11) + 8: DRAW 1 AT X(11) + 1,Y(11) + 10: DRAW
     18 AT X(11) - 8,Y(11) - 12: DRAW 4 AT X(11) + 1,Y(11) - 10
390  HPLOT 1,1 TO 279,1 TO 279,159 TO 1,159 TO 1,1
400 T1 =  SQR ((X(3) - X(4)) ↑ 2 + (X(1) - X(2)) ↑ 2):T2 = Y(1) - Y(2):TL =
     SQR (T1 ↑ 2 + T2 ↑ 2)
410 TH =  ATN (T2 / T1) / .0174533:TH =  ABS (TH): PRINT "TL=";TL;"    THE
     TA=";TH;"-D"
420 G =  ABS ( TAN (TH * .0174533) * 100): PRINT "GRADE=";G;"%"
430  END
```

FIGURE 5
Program for plotting true length of an oblique line.

Edge view of a plane

To show a plane in its edge view is important in the dimensional location of the plane in space, and its relationship to other points, lines, and planes. A horizontal line on a plane will show true length in the top view. An auxiliary view showing the horizontal line as a point will show the plane as a line. Figure 6 shows an example of the edge view of a plane. Its program is shown in Figure 11, which is programmed fully interactively. When running, each step calls for the user to answer a question displaying on the screen, such as "input the coordinates of point B -- BX, BY, and BZ", etc. In answering, the user inputs the requeted data through the keyboard of the graphics terminal. In answering, Once the coordinates of point B, C, and D have been inputted, the program is executed immediately and the final solution appears on the terminal screen.

True size and shape view of a plane

Figure 7 shows the output of the true size view of a plane. The top, front, and first auxiliary views are identical to those of Figure 6. The true size view is obtained by using the same algorithm as in the true length line program.

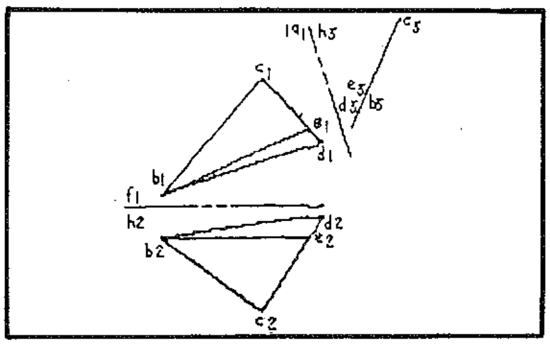


FIGURE 6
Edge view of a plane.

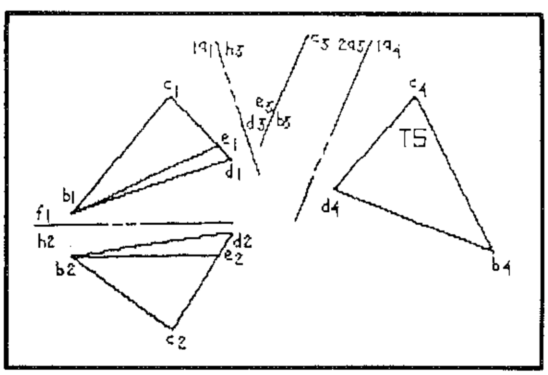


FIGURE 7
True size view of a plane.

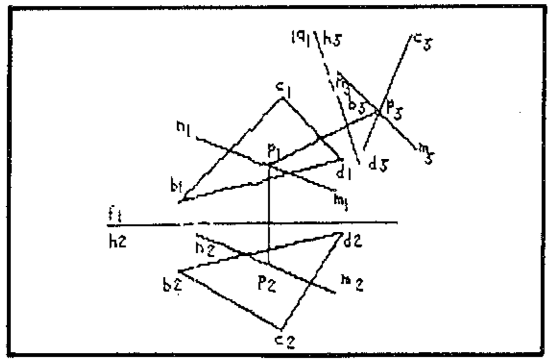


FIGURE 8
Piercing point of a line and a plane (auxiliary view method).

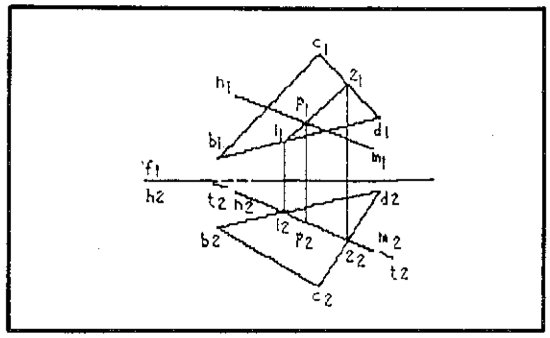


FIGURE 9
Piercing point of a line and a plane (two view method).

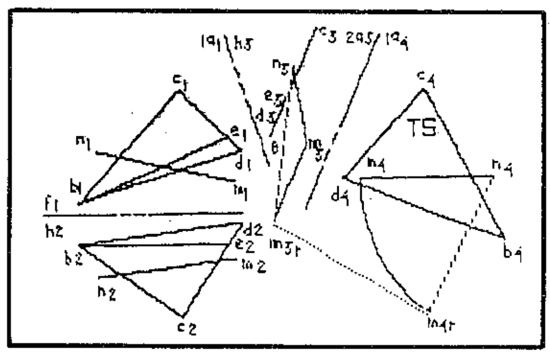


FIGURE 10
True angle between any line and any plane by rotation.

```
10   REM  PROGRAM FOR PLOTTING EDGE VIEW OF PLANE
20   HGR : HCOLOR= 3: SCALE= 1
30   PRINT "INPUT XB,YB,ZB": INPUT XB,YB,ZB
40   PRINT "INPUT XC,YC,ZC": INPUT XC,YC,ZC
50   PRINT "INPUT XD,YD,ZD": INPUT XD,YD,ZD
80   REM  PLOT FOLD LINE --F1 & H2
90 X = 10: HPLOT X,100 TO X + 40,100: HPLOT X + 43,100 TO X + 48,100: HPLOT
     X + 51,100 TO X + 56,100: HPLOT X + 59,100 TO X + 110,100
100  DRAW 16 AT X + 4,92: DRAW 1 AT X + 7,93
110  DRAW 18 AT X + 2,104: DRAW 2 AT X + 7,106
120 XB = XB + 30:XC = XC + 30:XD = XD + 30
130 YB = 100 + YB:YC = 100 + YC:YD = 100 + YD
140 ZB = 100 - ZB:ZC = 100 - ZC:ZD = 100 - ZD
150  REM    PLOT FRONT & TOP VIEW OF TRIANGLE
160  HPLOT XB,YB TO XC,YC TO XD,YD TO XB,YB
170  HPLOT XB,ZB TO XC,ZC TO XD,ZD TO XB,ZB
180 S = (YD - YC) / (XD - XC):YE = YB:XE = XD + (YE - YD) / S: HPLOT XB,YB
      TO XE,YE
190 S1 = (ZD - ZC) / (XD - XC):ZE = ZC + (XE - XC) * S1: HPLOT XB,ZB TO XE
     ,ZE
200  DRAW 12 AT XB - 8,YB + 2: DRAW 2 AT XB - 2,YB + 4: DRAW 13 AT XC,YC +
     3: DRAW 2 AT XC + 4,YC + 4
210  DRAW 14 AT XD + 4,YD: DRAW 2 AT XD + 7,YD + 2
230  DRAW 13 AT XC,ZC - 7: DRAW 1 AT XC + 4,ZC - 5: DRAW 14 AT XD,ZD + 2: DRAW
     1 AT XD + 4,ZD + 4
240  DRAW 12 AT XB - 4,ZB - 12: DRAW 1 AT XB + 1,ZB - 10
250  DRAW 15 AT XE + 6,YE - 2: DRAW 2 AT XE + 10,YE: DRAW 15 AT XE + 5,ZE -
     5: DRAW 1 AT XE + 10,ZE - 3
260 S2 = (ZE - ZB) / (XE - XB): IF S2 > 0 THEN 270: IF S2 < 0 THEN 280
270 SL =  ATN ((XE - XB) / (ZE - ZB))
280 SL =  ATN ( - (XE - XB) / (ZE - ZB))
290 ST = 3.14159 / 2 - SL:Z = ZE - 6:X = XE -  TAN (SL) * (Z - ZE):Z1 = Z +
     20:Z2 = Z - 12:X1 = X +  TAN (ST) * (Z1 - Z):X2 = X +  TAN (ST) * (Z2
     - Z)
300 Z3 = Z2 - 3:Z4 = Z3 - 5:Z5 = Z4 - 3:Z6 = Z5 - 5:Z7 = Z6 - 3:Z8 = Z7 -
     12
310 X3 = X +  TAN (ST) * (Z3 - Z):X4 = X +  TAN (ST) * (Z4 - Z):X5 = X +  TAN
     (ST) * (Z5 - Z):X6 = X +  TAN (ST) * (Z6 - Z):X7 = X +  TAN (ST) * (Z
     7 - Z):X8 = X +  TAN (ST) * (Z8 - Z)
320  REM  PLOT AUXILIARY FOLD LINE -- A1 & H3
330  HPLOT X1,Z1 TO X2,Z2
340  HPLOT X3,Z3 TO X4,Z4: HPLOT X5,Z5 TO X6,Z6: HPLOT X7,Z7 TO X8,Z8
350  DRAW 1 AT X8 - 12,Z8: DRAW 11 AT X8 - 6,Z8: DRAW 1 AT X8 - 3,Z8 + 2
360  DRAW 18 AT X8 + 6,Z8: DRAW 3 AT X8 + 12,Z8 + 2
370 A =  TAN (ST):B =  -  TAN (SL)
380 DZ = (X - XD + B * ZD - A * Z) / (B - A):DX = XD + B * (DZ - ZD)
390 BZ = (X - XB + B * ZB - A * Z) / (B - A):BX = XB + B * (BZ - ZB)
400 CZ = (X - XC + B * ZC - A * Z) / (B - A):CX = XC + B * (CZ - ZC)
430 C =  COS (SL):D =  SIN (SL):YB = YB - 100:YC = YC - 100:YD = YD - 100
440  REM  PLOT EDGE VIEW OF TRIANGLE
450 X2 = DX + YD * D:Z2 = DZ - YD * C:X4 = CX + YC * D:Z4 = CZ - YC * C: HPLOT
     X2,Z2 TO X4,Z4
460 X3 = X + YB * D:Z3 = Z - YB * C
480  DRAW 14 AT X2 - 4,Z2 - 14: DRAW 3 AT X2,Z2 - 12: DRAW 13 AT X4 + 5,Z4
     : DRAW 3 AT X4 + 8,Z4 + 2
490  DRAW 12 AT X3 + 4,Z3 - 3: DRAW 3 AT X3 + 8,Z3 - 1
500  DRAW 15 AT X3 - 6,Z3 - 10: DRAW 3 AT X3 - 2,Z3 - 8
510  HPLOT 1,1 TO 279,1 TO 279,159 TO 1,159 TO 1,1
520  END
```

FIGURE 11

Program for plotting edge view of a plane.

Piercing point of a line and a plane

The piercing point program is based on the program for plotting the edge view of a plane. The only difference is in the calculation of the intersection of a line and the plane in the auxiliary view. The same algorithm is used to project the piercing point p_3 back to p_1 and p_2 on $m_1 n_1$ and $m_2 n_2$ respectively, as shown in Figure 8. The piercing point of a line and a plane by the two view or cutting plane method is shown in Figure 9. The program for both methods is shown in Figure 12. There is a special switch at line 80 and line 320. The user can make a choice of one of those methods by inputting a value for variable J, if J = 1 then auxiliary view method is used and J = 2 the two view method will be the output.

True angle between any line and any plane by rotation

Figure 10 illustrates the computer generation of the true angle between any line and any plane by rotation. Obviously the program is closely related to the true size view of a plane.

Conclusion

There are four principal reasons for constructing views, either principal or auxiliary. They are:

1. to show a line true length
2. to show a line as a point
3. to show a plane as a line
4. to show a plane true size

Programs presented in this article can accommodate all of these principal reasons for constructing views.

There are a variety of approaches to solving three-dimensional descriptive geometry problems using computer graphics. The approach presented in this paper has proven to be a most simple and valuable learning experience for students.

Computer graphics is a very powerful learning and teaching tool for a course to supplement descriptive geometry. In such a course the student reinforces his knowledge of descriptive geometry efficiently, and is motivated to further study and research in CAD/CAM.

```
10  REM  THIS PROGRAM MAY BE USED TO DETERMINE PIERCING POINT OF A LINE AN
     D A PLANE
20  HGR : HCOLOR= 3: SCALE= 1
30  PRINT "INPUT XB,YB,ZB": INPUT XB,YB,ZB
40  PRINT "INPUT XC,YC,ZC": INPUT XC,YC,ZC
50  PRINT "INPUT XD,YD,ZD": INPUT XD,YD,ZD
60  PRINT "INPUT XM,YM,ZM": INPUT XM,YM,ZM
70  PRINT "INPUT XN,YN,ZN": INPUT XN,YN,ZN
80  PRINT "INPUT J =1 OR 2": INPUT J
90  REM  PLOT FOLD LINE --F1 & H2
100 X = 40: HPLOT X,100 TO X + 40,100: HPLOT X + 43,100 TO X + 48,100: HPLOT
     X + 51,100 TO X + 56,100: HPLOT X + 59,100 TO X + 160,100
110  DRAW 16 AT X + 4,92: DRAW 1 AT X + 7,93
120  DRAW 18 AT X + 2,104: DRAW 2 AT X + 7,106:X = 60
130 XB = XB + X + 20:XC = XC + X + 20:XD = XD + X + 20:XM = XM + X + 20:XN
     = XN + X + 20
140 YB = 100 + YB:YC = 100 + YC:YD = 100 + YD:YM = 100 + YM:YN = 100 + YN
150 ZB = 100 - ZB:ZC = 100 - ZC:ZD = 100 - ZD:ZM = 100 - ZM:ZN = 100 - ZN
160  REM  PLOT FRONT & TOP VIEW OF TRIANGLE & LINE
170  HPLOT XB,YB TO XC,YC TO XD,YD TO XB,YB: HPLOT XM,YM TO XN,YN
180  HPLOT XB,ZB TO XC,ZC TO XD,ZD TO XB,ZB: HPLOT XM,ZM TO XN,ZN
190 S = (YD - YC) / (XD - XC):YE = YB:XE = XD + (YE - YD) / S
200 S1 = (ZD - ZC) / (XD - XC):ZE = ZC + (XE - XC) * S1
210  DRAW 12 AT XB - 8,YB + 2: DRAW 2 AT XB - 2,YB + 4: DRAW 13 AT XC,YC +
     3: DRAW 2 AT XC + 4,YC + 4
220  DRAW 14 AT XD + 4,YD: DRAW 2 AT XD + 7,YD + 2: DRAW 23 AT XM + 4,YM -
     8: DRAW 2 AT XM + 12,YM - 5
230  DRAW 24 AT XN,YN + 4: DRAW 2 AT XN + 6,YN + 6: DRAW 24 AT XN - 10,ZN -
     8: DRAW 1 AT XN - 4,ZN - 6
240  DRAW 13 AT XC,ZC - 7: DRAW 1 AT XC + 4,ZC - 5: DRAW 14 AT XD,ZD + 2: DRAW
     1 AT XD + 4,ZD + 4
250  DRAW 12 AT XB - 4,ZB - 12: DRAW 1 AT XB + 1,ZB - 10: DRAW 23 AT XM,ZM
     + 2: DRAW 1 AT XM + 6,ZM + 4
260 S2 = (ZE - ZB) / (XE - XB): IF S2 > 0 THEN 270: IF S2 < 0 THEN 280
270 SL =  ATN ((XE - XB) / (ZE - ZB))
280 SL =  ATN ( - (XE - XB) / (ZE - ZB))
290 ST = 3.14159 / 2 - SL:Z = ZE - 6:X = XE -  TAN (SL) * (Z - ZE):Z1 = Z +
     20:Z2 = Z - 12:X1 = X +  TAN (ST) * (Z1 - Z):X2 = X +  TAN (ST) * (Z2
     - Z)
300 Z3 = Z2 - 3:Z4 = Z3 - 5:Z5 = Z4 - 3:Z6 = Z5 - 5:Z7 = Z6 - 3:Z8 = Z7 -
     12
310 X3 = X +  TAN (ST) * (Z3 - Z):X4 = X +  TAN (ST) * (Z4 - Z):X5 = X +  TAN
     (ST) * (Z5 - Z):X6 = X +  TAN (ST) * (Z6 - Z):X7 = X +  TAN (ST) * (Z
     7 - Z):X8 = X +  TAN (ST) * (Z8 - Z)
320  IF J = 2 THEN 610
330  REM  PLOT FIRST AUXILIARY FOLD LINE
340  HPLOT X1,Z1 TO X2,Z2
350  HPLOT X3,Z3 TO X4,Z4: HPLOT X5,Z5 TO X6,Z6: HPLOT X7,Z7 TO X8,Z8
360  DRAW 1 AT X8 - 12,Z8: DRAW 11 AT X8 - 6,Z8: DRAW 1 AT X8 - 3,Z8 + 2
370  DRAW 18 AT X8 + 6,Z8: DRAW 3 AT X8 + 12,Z8 + 2
380 A =  TAN (ST):B =  -  TAN (SL)
390 DZ = (X - XD + B * ZD - A * Z) / (B - A):DX = XD + B * (DZ - ZD)
400 BZ = (X - XB + B * ZB - A * Z) / (B - A):BX = XB + B * (BZ - ZB)
410 CZ = (X - XC + B * ZC - A * Z) / (B - A):CX = XC + B * (CZ - ZC)
420 MZ = (X - XM + B * ZM - A * Z) / (B - A):MX = XM + B * (MZ - ZM)
430 NZ = (X - XN + B * ZN - A * Z) / (B - A):NX = XN + B * (NZ - ZN)
440 C =  COS (SL):D =  SIN (SL):YB = YB - 100:YC = YC - 100:YD = YD - 100:
     YN = YN - 100:YM = YM - 100
450  REM  PLOT FIRST AUXILIARY VIEW OF TRIANGLE & LINE
460 X2 = DX + YD * D:Z2 = DZ - YD * C:X4 = CX + YC * D:Z4 = CZ - YC * C: HPLOT
     X2,Z2 TO X4,Z4
470 X3 = X + YB * D:Z3 = Z - YB * C
480 X5 = MX + YM * D:Z5 = MZ - YM * C:X6 = NX + YN * D:Z6 = NZ - YN * C: HPLOT
     X5,Z5 TO X6,Z6
```

FIGURE 12
Program for determining piercing point of a line and a plane (auxiliary view method and two view method)

```
490  DRAW 14 AT X2 + 6,Z2 + 3: DRAW 3 AT X2 + 10,Z2 + 5: DRAW 13 AT X4 + 5
     ,Z4: DRAW 3 AT X4 + 8,Z4 + 2
500  DRAW 23 AT X5 + 2,Z5 - 3: DRAW 3 AT X5 + 6,Z5 + 2: DRAW 24 AT X6,Z6 +
     3: DRAW 3 AT X6 + 5,Z6 + 6
510  REM  CALCULATE THE COORDINATES OF PIERCING POINT IN ALL THE VIEWS
520 E = Z6 - Z5:F = Z4 - Z2:G = X4 - X2:H = X6 - X5
530 ZK = (Z2 * E * G - Z5 * F * H + (X5 - X2) * E * F) / (E * G - F * H):X
    K = G * (ZK - Z2) / F + X2:M = ZN - ZM:N = XN - XM
540 X1 = (XM * B * M / N + B * (ZK - ZM) - XK) / (B * M / N - 1):Z1 = ZK -
    (XK - X1) / B
550 YM = 100 + YM:YN = 100 + YN
560 Y1 = ((X1 - XM) * (YN - YM) + YM * N) / N: HPLOT XK,ZK TO X1,Z1 TO X1,
    Y1
570  DRAW 26 AT XK + 5,ZK - 5: DRAW 3 AT XK + 10,ZK - 1: DRAW 26 AT X1,Z1 -
     10: DRAW 1 AT X1 + 5,Z1 - 8: DRAW 26 AT X1 - 5,Y1 + 5: DRAW 2 AT X1,Y
     1 + 8
580  DRAW 12 AT XK - 16,ZK - 7: DRAW 3 AT XK - 10,ZK - 4
590  GOTO 710
600  REM  PLOT CUTTING PLANE T2-T2
610 A = (XM - XN) / (YM - YN):YT = YN - 1.5:XT = XN + A * (YT - YN):TY = Y
    N - 4:TX = XN + A * (TY - YN): HPLOT XT,YT TO TX,TY
620 YJ = YM + 1.5:XJ = XM + A * (YJ - YM):JY = YM + 4:JX = XM + A * (JY -
    YM): HPLOT XJ,YJ TO JX,JY
630  DRAW 30 AT TX - 2,TY + 5: DRAW 2 AT TX + 3,TY + 8: DRAW 30 AT JX,JY +
     3: DRAW 2 AT JX + 5,YJ + 8
640 G = XM - XN:E = YB - YD:F = YM - YN:H = XB - XD:Y1 = (YN * E * G - YD *
    F * H + (XD - XN) * E * F) / (E * G - F * H):X1 = G * (Y1 - YN) / F +
    XN:Z1 = (X1 - XD) * (ZB - ZD) / (XB - XD) + ZD: HPLOT X1,Y1 TO X1,Z1
650 E1 = YC - YD:H1 = XC - XD:Y2 = (YN * E1 * G - YD * F * H1 + (XD - XN) *
    E1 * F) / (E1 * G - F * H1):X2 = G * (Y2 - YN) / F + XN:Z2 = (X2 - XD
    ) * (ZC - ZD) / H1 + ZD: HPLOT X2,Y2 TO X2,Z2
660  HPLOT X1,Z1 TO X2,Z2:E2 = Z1 - Z2:F2 = ZM - ZN:H2 = X1 - X2:ZP = (ZN *
     E2 * G - Z2 * F2 * H2 + (X2 - XN) * E2 * F2) / (E2 * G - F2 * H2)
670 XP = G * (ZP - ZN) / F2 + XN:YP = (XP - XN) * F / G + YN: HPLOT XP,YP TO
     XP,ZP
680  DRAW 26 AT XP - 5,ZP - 12: DRAW 1 AT XP,ZP - 9: DRAW 26 AT XP - 5,YP +
     5: DRAW 2 AT XP,YP + 8
690  DRAW 1 AT X1 - 4,Y1 + 4: DRAW 2 AT X1 - 1,Y1 + 6: DRAW 1 AT X1 - 5,Z1
      - 8: DRAW 1 AT X1 - 2,Z1 - 6
700  DRAW 2 AT X2,Y2 + 6: DRAW 2 AT X2 + 6,Y2 + 9: DRAW 2 AT X2 + 2,Z2 - 6
     : DRAW 1 AT X2 + 7,Z2 - 4
710  HPLOT 1,1 TO 279,1 TO 279,159 TO 1,159 TO 1,1
720  END
```

Three Point Perspective Transformation and Diagram Construction

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When an object is placed so that none of its principal edges are parallel to the picture plane, the resulting view is a three point perspective. Each of the three sets of parallel lines will converge to its vanishing point, and the graphical construction becomes more involved. Therefore, three point perspective is not often used in engineering drawing. However, three point perspective is the most realistic form of pictorial. It is effective for realistic illustration for tall structure and for bird's-eye views where the heights of the objects are to be emphasized for special effects.

The graphical projection method of a simple three point perspective is illustrated in Fig. 1. In Fig. 1 the drawing of the perspective is divided into five steps as follows:

1. Draw the plan view of the object which has been turned θ ° counterclockwise. The station point (SP_h) is located, and the line of center of vision (CV) and the ground line (GL) are drawn.

2. The view of step 1 is turned so that the ground line appears in a vertical position.

3. The elevation of the object is drawn looking parallel to the ground line. The SP_f is located at any desired height. The elevation view of the center of vision is drawn from the SP_f at ϕ ° with the horizontal line. The PP is then drawn through the end view of the GL and perpendicular to the CV. The vertical vanishing point (VVP) of all vertical lines is located at the intersection of the PP and the vertical line drawn from the SP_f.

4. Construct the view perpendicular to the SP_f of step 3. From SP_h, lines are drawn at angles θ and α to intersect the horizon line (HL) to locate the right vanishing point (RVP) and the left vanishing point (LVP). Draw the left wall horizon by connecting LVP with VVP, and the right wall horizon by connecting RVP with VVP. The two measuring points for horizontal dimensions MR and ML are then located by making LVP to MR = LVP to SP_h and RVP to ML = RVP to SP_h. The vertical measuring point MVR is located on the right wall horizon by making VVP to MVR = VVP to SP_f taken from step 3. This completes the diagram of the three vanishing points and three measuring points needed for the construction of a three point perspective by the graphical projection method.

5. From the intersection of the center line and the ground line, measure the distance A taken from the plan of step 1 on the ground line to locate the corner B of the perspective view. The horizontal dimensions are laid out on the ground line and then connected to MR and ML to obtain the perspective projection. The height dimensions are set off along the height measuring line drawn from point B parallel to the right wall horizon. For a detailed explanation of the graphical method of three point perspective, refer to Martin (pp. 86-93) or Pare (pp. 312-314).

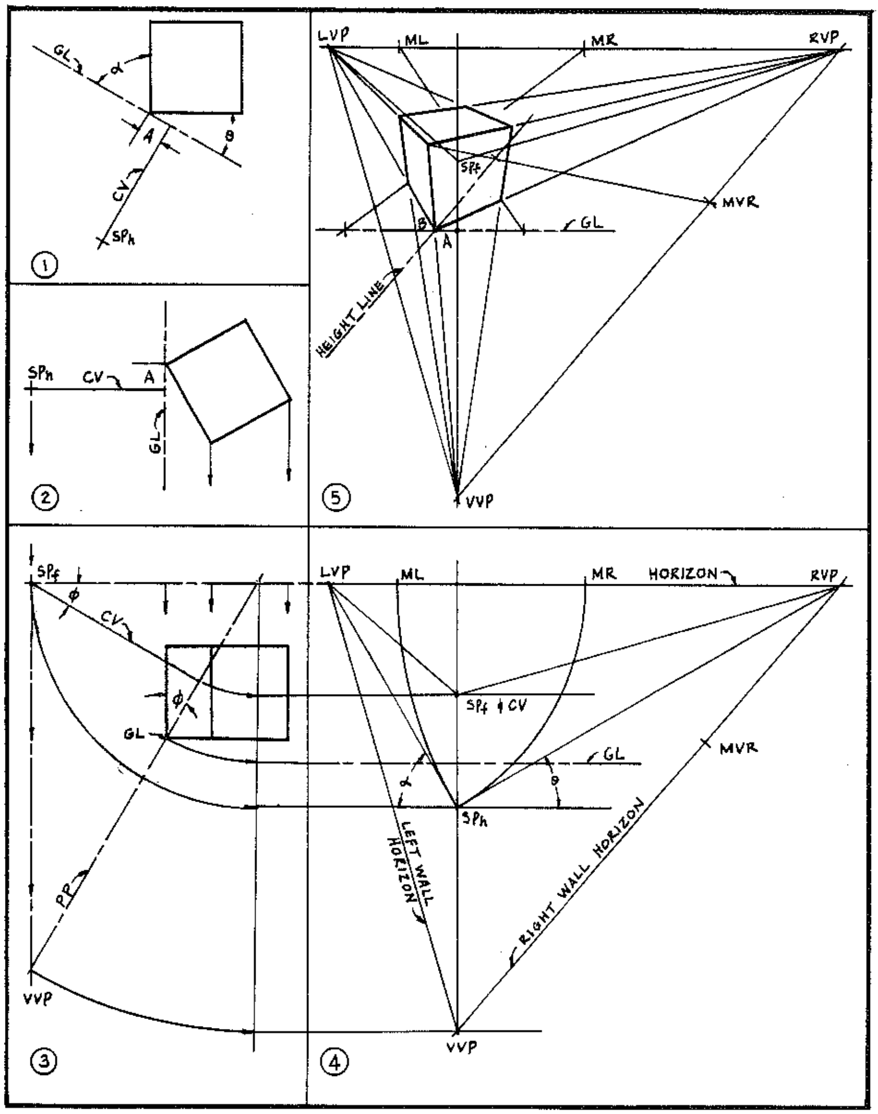

FIGURE 1

It can be seen from the above steps that it is quite tedious to construct the diagram of a three point perspective. Thus, there are short cut methods of perspective projection to shorten the work in constructing three point perspectives. One such method is the Black's formula (Black, p. 146) in which the perspective proportion of a three point perspective axis is determined by the formula X = R x Y / R + Y. R is the radius of the large construction circle and X is the radius of the small limiting circle. Distance Y is measured from the center of the construction circle to the vanishing point, and should be at least six times R. See Fig. 2.

The resulting three point perspective views by the short cut methods tend to be symmetrical and rigid. The completely constructed perspective is still the most certain way of producing an accurate and truthful representation of the object. The process of the diagram construction can be shortened by means of matrix transformations with the same accurate results as the graphical method.

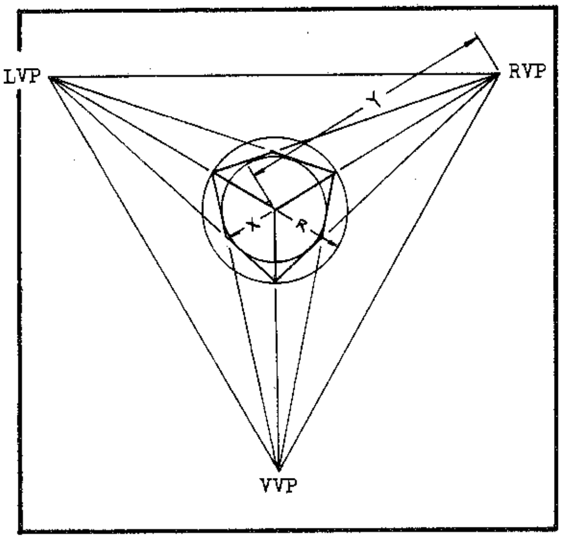

FIGURE 2

Following similar logic as we do in axonometric transformations (Land, pp. 34-37), a three point perspective can be produced by first performing rotation about two different axes following by a perspective transformation. As an example, we will perform the perspective transformation of the unit cube shown in Fig. 3. First, we will translate the cube from the origin to the point (-j -m -n) by the following matrix:

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -j & -m & -n & 1 \end{pmatrix} \quad \ldots\ldots\ldots \ (1)$$

We will then consider a rotation of $\theta°$ about the Y-axis, followed by a rotation of $\phi°$ about the X-axis:

$$\begin{pmatrix} \cos\theta & 0 & -\sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\phi & \sin\phi & 0 \\ 0 & -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad \ldots \ (2)$$

A three point perspective is obtained by concatenation of a perspective transformation followed by a projection onto a two-dimensional picture plane. Assuming that observer is located at a distance of K from the origin on the Z-axis and the perspective is projected onto the Z = 0 plane, the following transformation matrix is used (Giloi, p. 101):

$$\begin{pmatrix} 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{K} \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad \ldots\ldots\ldots \ (3)$$

A complete set of transformations on a unit cube to obtain a three point perspective is then:

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -j & -m & -n & 1 \end{pmatrix} \begin{pmatrix} \cos\theta & 0 & -\sin\theta & 0 \\ 0 & 1 & 0 & 0 \\ \sin\theta & 0 & \cos\theta & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos\phi & \sin\phi & 0 \\ 0 & -\sin\phi & \cos\phi & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & -\frac{1}{K} \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$= \begin{pmatrix} \cos\theta & \sin\theta\sin\phi & 0 & \frac{1}{K}\sin\theta\cos\phi \\ 0 & \cos\phi & 0 & -\frac{1}{K}\sin\phi \\ \sin\theta & -\cos\theta\sin\phi & 0 & -\frac{1}{K}\cos\theta\cos\phi \\ -j\cos\theta - n\sin\theta & -m\cos\phi + (n\cos\theta - j\sin\theta)\sin\phi & 0 & 1 - \frac{m\sin\phi + j\sin\theta + n\cos\theta}{K} \end{pmatrix} \quad ..(4)$$

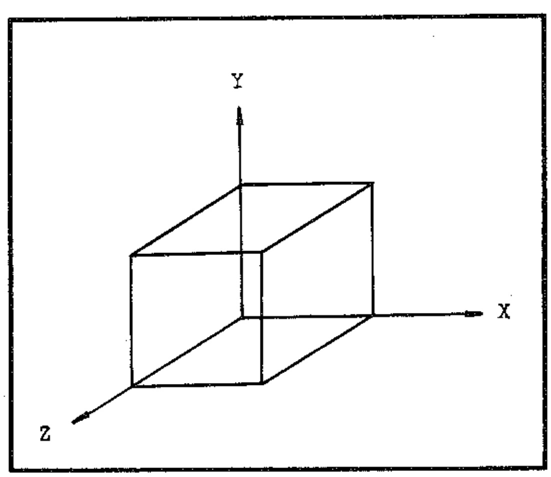

FIGURE 3

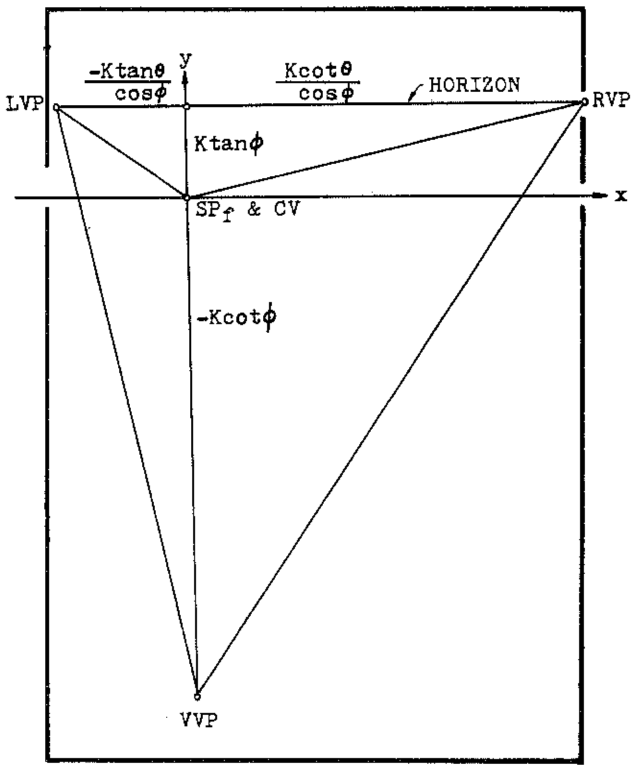

FIGURE 4

Then, since the vector in Eq. (4) is the homogeneous coordinate representation of the projected points, the Cartesian coordinates are obtained by dividing the first three components by its fourth component (Giloi, p. 102):

$$\begin{bmatrix} x & y & z & 1 \end{bmatrix} = \begin{bmatrix} \frac{X}{H} & \frac{Y}{H} & 0 & 1 \end{bmatrix} \quad \ldots\ldots\ldots (5)$$

We will next consider three points given by (1 0 0 0), (0 1 0 0), and (0 0 1 0). These vectors represent points at infinity on the X-, Y-, and Z-axes respectively. Now performing the three point perspective transformation given by Eq. (4):

$$\begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} \text{Eq. (4)} \end{bmatrix}$$

$$= \begin{bmatrix} \cos\theta & \sin\theta\sin\phi & 0 & \frac{1}{K}\sin\theta\cos\phi \\ 0 & \cos\phi & 0 & -\frac{1}{K}\sin\phi \\ \sin\theta & -\cos\theta\sin\phi & 0 & -\frac{1}{K}\cos\theta\cos\phi \end{bmatrix} \quad \ldots\ldots (6)$$

Thus, the point at $X = \infty$ transforms to

$$x = \frac{\cos\theta}{\frac{1}{K}\sin\theta\cos\phi}, \qquad y = \frac{\sin\theta\sin\phi}{\frac{1}{K}\sin\theta\cos\phi}$$

or

$$x = \frac{K\cot\theta}{\cos\phi}, \qquad y = K\tan\phi \quad \ldots\ldots\ldots (7)$$

This is the right vanishing point (RVP) in Fig. 1. The point at $Y = \infty$ transforms to

$$x = 0, \quad y = \frac{\cos\phi}{-\frac{1}{K}\sin\phi}$$

or

$$x = 0, \quad y = -K\cot\phi \quad \ldots\ldots\ldots\ldots (8)$$

This is the vertical vanishing point (VVP) in Fig. 1. The point at $Z = \infty$ transforms to

$$x = \frac{\sin\theta}{-\frac{1}{K}\cos\theta\cos\phi}, \qquad y = \frac{-\cos\theta\sin\phi}{-\frac{1}{K}\cos\theta\cos\phi}$$

or

$$x = \frac{-K\tan\theta}{\cos\phi}, \qquad y = K\tan\phi \quad \ldots\ldots (9)$$

This is the left vanishing point (LVP) in Fig. 1.

To further clarify the application of Equations (7), (8), and (9), we again consider the three point perspective diagram shown in Fig. 1. The line of center of vision (CV) in step 3 is the Z-axis, and the distance from SP_f to the picture plane is K. The picture plane is the Z = 0 plane on which the perspective view is projected. Angle θ in step 1 is the angle of rotation about Y-axis, and angle ϕ in step 3 is the angle of rotation about X-axis. Thus, in any three point perspective projection, when the distance K from station point (SP) to picture plane (PP), and the angles of rotation θ and ϕ are determined, the diagram of the three vanishing points can be constructed easily by using equations (7), (8), and (9). See Fig. 4 and follow these steps:

1. Locate SP and CV. Draw horizontal x-axis and vertical y-axis.

2. Measure a distance of Ktan along the y-axis to locate the horizon (HL).

3. The RVP is located by measuring a distance of $\frac{K \cot\theta}{\cos\phi}$ along the horizon.

4. The LVP is located by measuring a distance of $\frac{- K \tan\theta}{\cos\phi}$ along the y-axis.

5. The VVP is located by measuring a distance of $-K\cot\phi$ along the y-axis.

Once the perspective diagram is completed, the three point perspective projection can be constructed easily by using the measuring points as described in step 5 of Fig. 1 or referring to any standard text such as Giesecke et al (pp.555 - 558).

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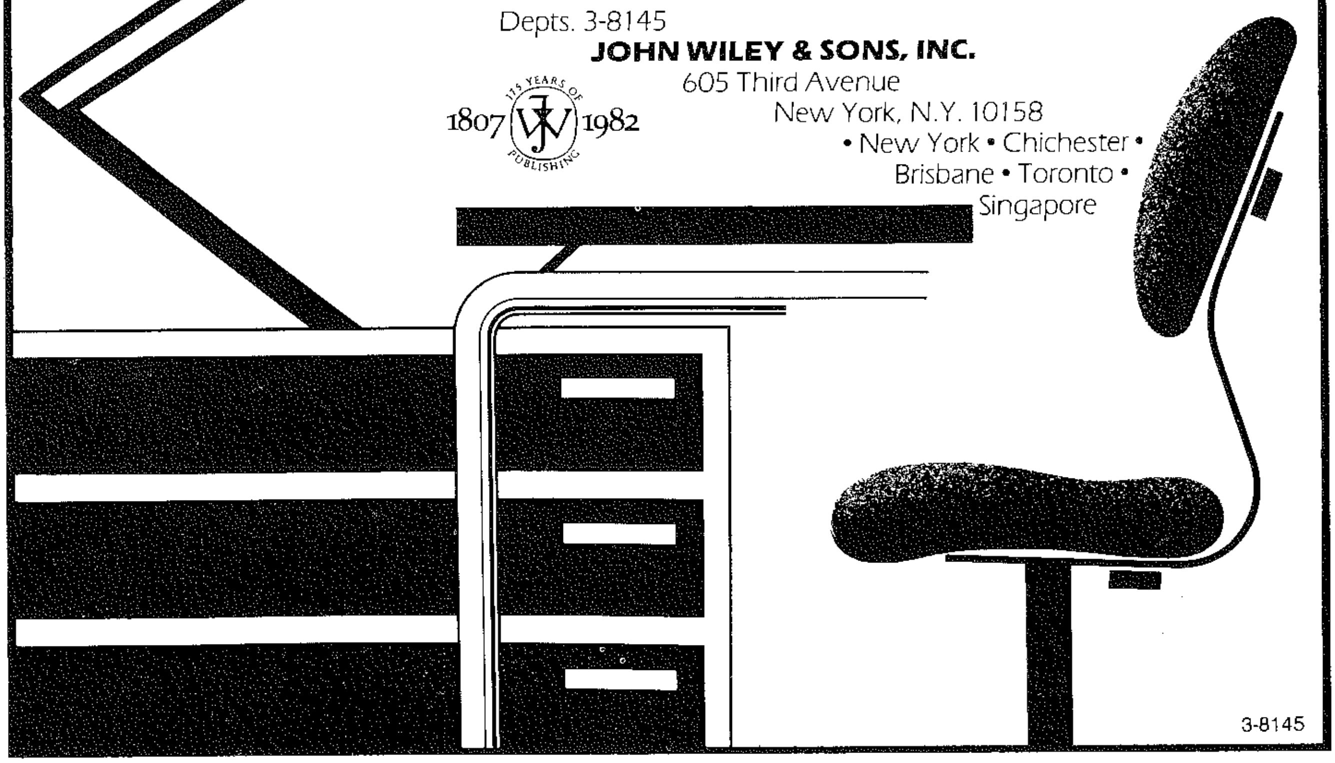

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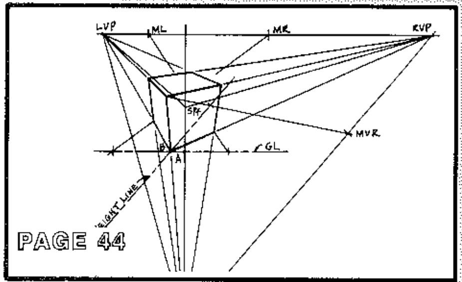

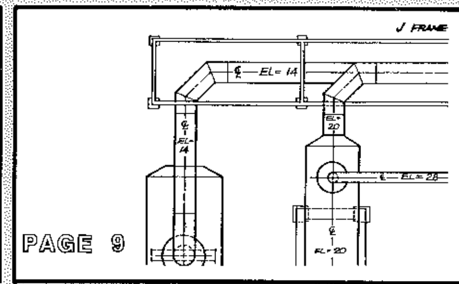

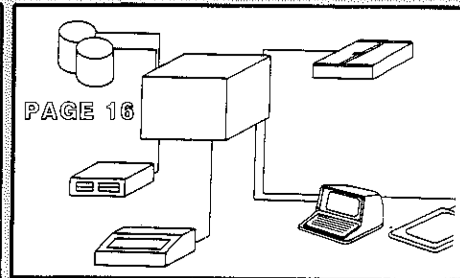

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