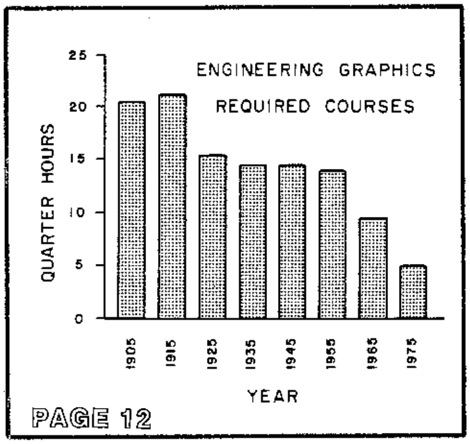
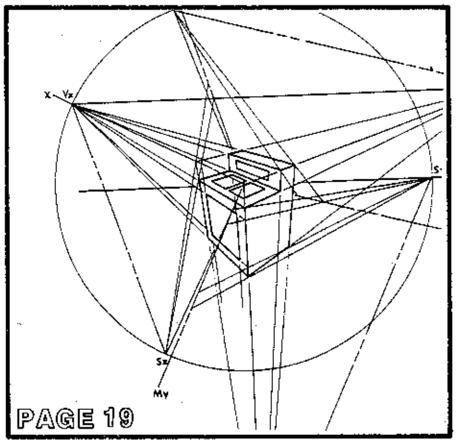
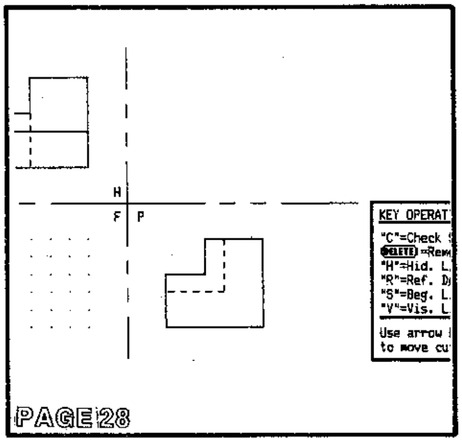


PAGE 12



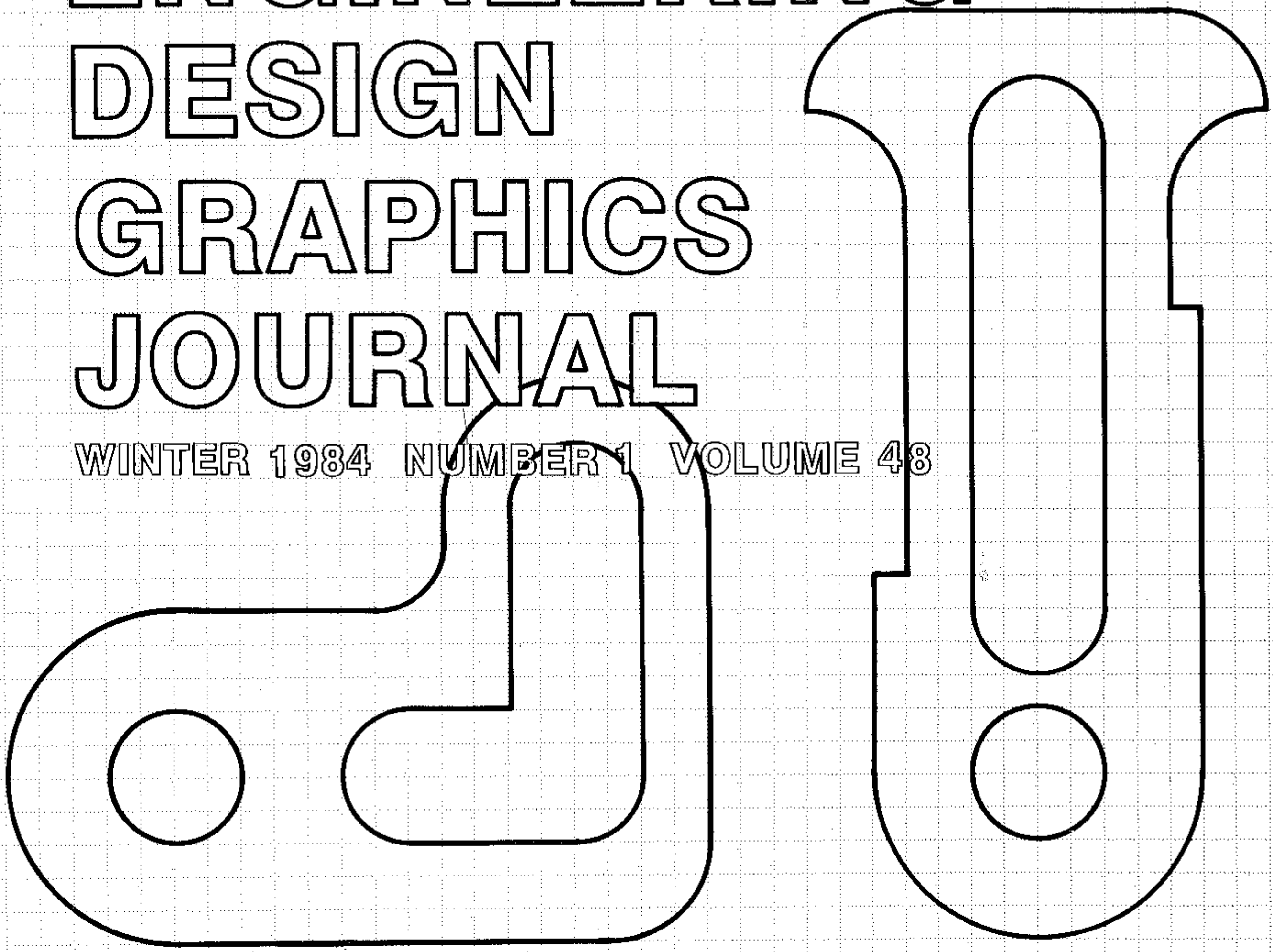
PAGE 19



PAGE 28

ENGINEERING DESIGN GRAPHICS JOURNAL

WINTER 1984 NUMBER 1 VOLUME 48



C&R ☐

	SCALE	NAME			DWG
		INSTR	TABLE	HOUR	

ENGINEERING DESIGN GRAPHICS DIVISION

Brooks/Cole Engineering Division

Texts for Now and the Future

The Brooks/Cole Engineering Division is a publisher of authors and ideas.

Because we are a smaller publisher with a growing new list in Engineering, our sales staff is able to give closer attention to each individual title. And because we are a division of Wadsworth, Inc., we are able to provide stability and strength for our family of authors.

We hope that you as a reviewer of our new materials will consider joining us in achieving our goal of producing high quality learning materials for Engineering students.

EXPERIENCES IN VISUAL THINKING, 2nd Edition

Robert H. McKim,
Stanford University.
210 pages. 11 x 8½.
Kivarbound. 1980.

Through exercises and strategies, this book revitalizes inherent powers of observation and imagination for improving perception, creative thinking, visualizing, imagining, and idea sketching. This fresh apporach to engineering design innovation directly challenges stereotypical thinking.

COMPUTER PROGRAMMING FOR GRAPHICAL DISPLAYS

Daniel L. Ryan,
Clemson University.
288 pages. 11 x 8½.
Kivarbound. 1983.

This engaging text or supplement for any course introducing computer graphics techniques encourages students to get on line as quickly as possible. There are many sample programs and practice problems for a variety of settings and disciplines.

COMPUTER GRAPHICS PROBLEMS MANUAL

Daniel L. Ryan,
Clemson University.
Paperbound. 1983.

This workbook gives students experience with the practical side of computer graphics.

INDUSTRIAL TECHNICAL ILLUSTRATION

Jon M. Duff,
Ohio State University.
200 pages. 11 x 8½.
Kivarbound. 1982.

Here at last is a current and carefully prepared treatment of the fundamentals of technical illustration that shows both the traditional drawing aspects of technical illustration as well as the new technologies such as photodrawing and computer drafting. This text is filled with helpful hints and suggestions for upgrading average illustrations to illustrations of superior quality.

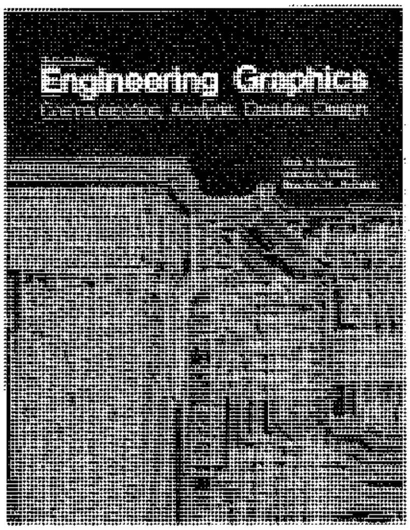
PROBLEMS IN INDUSTRIAL TECHNICAL ILLUSTRATION

Jon M. Duff,
Ohio State University.
200 pages. 11 x 8½.
Paperbound. 1983.

This valuable workbook for technical illustration includes examples, practice problems, and complete worksheets.

For further information or for examination copy requests, please write us.

Ray Kingman, Editor
Brooks/Cole Engineering Division
555 Abrego Street, Monterey, California 93940


Engineering Graphics

CALENDAR

ASEE ANNUAL CONFEENCES

1984 - Salt Lake City, Utah

1985 - Atlanta, Georgia

EDGD MID-YEAR MEETINGS

1985 - Kansas City, Missouri

1986 - West Lafayette, Indiana

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, Design Graphics, and Creative Design.

YEARLY SUBSCRIPTION RATES:

U.S., Mexico, Canada	
ASEE-EDG members	$ 1.50
ASEE but not EDG members	$ 3.00
Non-members	$ 5.00
Foreign subscribers	$10.00

SINGLE COPY RATES:

U.S., Mexico, Canada	
ASEE-EDG members	$ 1.00
ASEE but not EDG members	$ 1.50
Non-members	$ 2.00
Foreign subscribers	$ 3.50

BACK ISSUES are available at single copy rates (prepaid) and limited in general to numbers published within the past six years.

Subscription expiration date (last issue) is printed in upper right corner of mailing label, W83 for Winter 1983, S83 for Spring 1983, etc.

ENGINEERING DESIGN GRAPHICS JOURNAL OBJECTIVES:

The objectives of the JOURNAL are:

1. To publish articles of interest to teachers and practitioners of Engineering Graphics, 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 the quality of and modernize instruction and courses.
4. To encourage research, development, and refinement of theory and application of engineering graphics for understanding and practices.

DEADLINES FOR AUTHORS AND ADVERTISERS

The following deadlines for submission of article, 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 style 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, double spaced, 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 graphics, 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. Enclosed 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, Department of Engineering Graphics, The Ohio State University, 2070 Neil Avenue, Columbus, Ohio 43210.

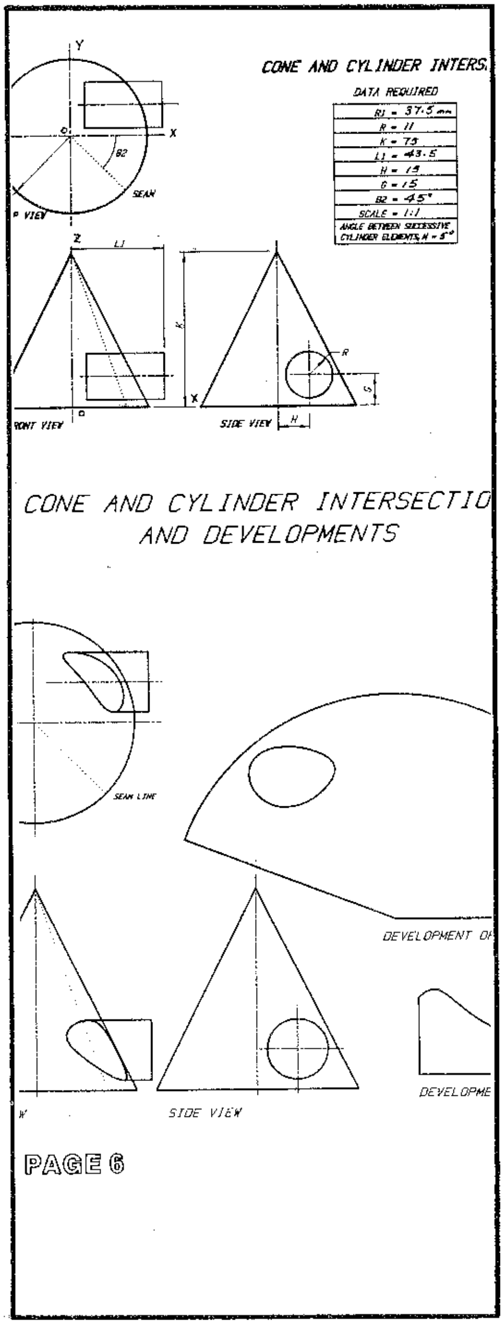
REVIEW OF ARTICLES

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 acepted at the discretion of the editors.

AMERICAN ASSOCIATION FOR ENGINEERING EDUCATION

ENGINEERING DESIGN GRAPHICS JOURNAL

WINTER 1984 VOLUME 48 NUMBER 1



PAGE 6

DEPARTMENTS

FEATURES

EDITOR'S PAGE

There was some talk at the EDGD Mid-Year Meeting concerning "software trading" being an important activity in the future. Beginning in the Spring 1984 issue, space will be reserved for readers who wish to share software that is not copyright protected. I suggest that you list what you want to share by providing the following information:

NAME: Software name or function

LANGUAGE: Programming language (i.e. AppleSoft, Microsoft, Fortran 77)

MACHINE: Computer the software is known to run on; the configuration of that machine

comments: How you use the software, which classes; which students

---

oppenheimer award ⟶

JOBS POSTED

SEARCH FOR ENGINEERING GRAPHICS FACULTY

The College of Engineering, Clemson University, invites applications for two tenure-track positions in Engineering Graphics at the assistant/associate professor level. General responsibilities will include undergraduate teaching, course development, R & D, and public service. The teaching area will include traditional engineering graphics subjects, but special emphasis is being placed on computer-aided graphics and design to support the expansion of the College's computer-graphics program. A MS degree in engineering or a related field is required. The PhD degree, PE registration, and/or industrial experience will be considered as additional desirable qualifications. Rank and salary will be commensurate with qualifications. Applications will be accepted until the positions are filled with a projected hire date of August 15, 1984. Send letter of application, resume, and references to Professor Vera B. Anand, Search Committee Chairman, Department of Engineering Technology, Clemson University, Clemson, SC 29631, PHONE (803) 656-2406. An Affirmative Action/Equal Opportunity Employer.

See JOBS page 18

DIVISION NEWS

CRITERIA FOR OPPENHEIMER AWARD

Each of the following five areas carry equal weight and will be evaluated on a 1 to 5 scale, with 1 being poor; 5 excellent.

Paper Content: Appropriateness of technical content and level to the discipline and audience.

Organization: Evidence of careful sequencing of materials, adherence to time limit.

Delivery: Poise, confidence, voice projection, (including microphone effectiveness).

Audience Interaction: Extent to which speaker is aware of and involves audience; questions, remarks, jokes, observations.

Visual Aids: Extent and effectiveness of use of audio, video, computer media; may include use of handouts.

ENGINEERING DESIGN GRAPHICS WORKSHOP

The Engineering Graphics Department of The Ohio State University will present a workshop on Interactive Computer Graphics August 20 - 24, 1984. The workshop is co-sponsored by the Engineering Design Graphics Department of ASEE.

This workshop is designed to introduce educators and individuals from industry to the use of microprocessor computing systems in computer aided drafting and computer aided design in industry and education. Various types of microprocessors, plotters, graphics tablets and other peripheral devices will be discussed and demonstrated.

There are no prerequisites of previous experience in either programming or computer graphics for enrollment in the workshop. For additional information contact

Louise Larew
Continuing Education
Fawcett Center for Tomorrow
2400 Olentangy River Road
Columbus, OH 43210

NATIONAL MEETING

The University of Utah will host the 1984 ASEE Annual Conference June 24-28, 1984 in Salt Lake City. Richard Latimer will chair the graphics program: "Engineering Graphics Preparation for Automation." Look for a CAD/CAM exhibit!

MID-YEAR MEETING

The 1984-85 EDGD Mid-Year Conference will be held November 25-28, 1984 in Kansas City, Missouri. Betty Butler is Conference Chairwoman; Jerry Smith is Program Chairman. Direct paper abstracts to him at Purdue University, Department of Technical Graphics, West Lafayette, Indiana, 97907.

IN REVIEW

INTERACTIVE COMPUTER GRAPHICS APPLIED TO MECHANICAL DRAFTING AND DESIGN

Jerome C. Lange
and
Dennis P. Shanahan
John Wiley & Sons, p. 345
1984

INTERACTIVE COMPUTER GRAPHICS APPLIED TO MECHANICAL DRAFTING AND DESIGN, by Lange and Shanahan, offers a comprehensive introduction to computer-aided drafting techniques. The text emphasizes that the computer is a tool and demonstrates the available graphic capabilities. The authors present typical engineering graphics and CAD topics. In addition, step-by-step examples and practice problems are included. The format of the text makes it possible to teach CAD techniques without "hands-on" experience. A basic drafting background, however, is necessary to use the text successfully.

The authors begin with an overview of interactive computer graphics and an introduction to system components. Discussion covers various input/output devices and the purpose of each. A generic menu, which is the basis of all the commands defined and illustrated, is used throughout the text. Commands are demonstrated through a series of visuals which include input instructions, before and after diagrams, and an explanation of the procedure.

Some of the engineering graphics topics covered are geometric constructions, descriptive geometry, dimensioning and tolerances. The units on geometric constructions and descriptive geometry use a standard diagrammatic technique to explain the concept, as well as a description of the procedure used to generate the construction with the computer. CAD topics include display manipulations such as zoom, scroll and rotate. Utility options include mirror, move and duplicate. The concept of a data base is explored along with the editing and filing capabilities. Most chapters conclude with a complex example which illustrates a step-by-step application of the graphic commands. These examples reinforce the idea that the computer is a production tool. The tasks of problem-solving and the implementation procedures remain the responsibility of the operator.

Reviewed by Judy A. Watson
Department of Technical Graphics
Purdue University

INTERSECTIONS

COMPUTER AIDED DRAWING OF INTERSECTION AND DEVELOPMENTS USING POSITION VECTORS

G.F. Pearce, Professor
Mechanical Engineering
University of Waterloo

Introduction

Position vectors provide a convenient method of obtaining equations for use in the computer-aided drawing of the intersection of two objects and their developments. The essence of the method is to equate the position vector of a point on one object with a point on the other. The resulting vector equation is then solved for the intersection points. The developments are readily computed from true lengths involving the intersection points.

Intersection of a Cone and Cylinder

Consider a right circular cone and an intersection cylinder as shown in Figure 1. First it is necessary to decide on an origin for the cartesian axes system used for the vectors. In the case of a right circular cone the apex is one convenient position. An alternate position could be the center of the base. In this case we will use the apex of the cone.

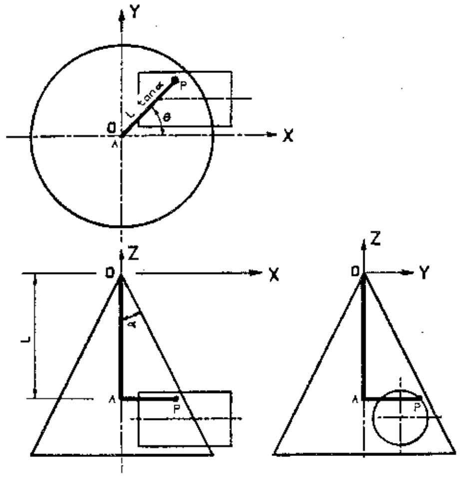


Figure 1

After the origin has been decided upon, the position of a point P on the surface of the cone is defined by its position vector $\bar{P}$. It can be seen from Figure 1 that:

$$\bar{P} = -L\bar{k} + L\tan\alpha\cos\theta\, i + L\tan\alpha\sin\theta\,\bar{j}$$

where α is known for any particular problem and L and θ are unknown variables.

Now we next obtain the position vector of a point Q on the surface of the cylinder, see Figure 2. The point Q can be reached by the path OCDEQ. The position vector of Q can therefore be written as:

$$\bar{Q} = -S\bar{k} + H\bar{j} + M\bar{i} + R\cos\phi\, j + R\sin\phi\,\bar{K}$$

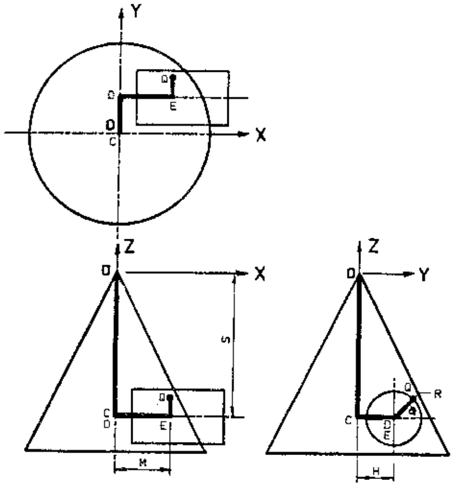


Figure 2

where S, H and R are known for any particular problem and M is an unknown, while ϕ is varied from 0° to 360° in known increments.

At a point of intersection $\bar{P} = \bar{Q}$. Equating like terms:

$$L\tan\alpha\cos\theta = M$$
$$L\tan\alpha\sin\theta = R\cos\phi + H$$
$$-L = -S + R\sin\phi$$

For a computer solution let vary from 0 to 360° in small steps and calculate the x, y and z coordinates of each intersection point. In this case:

$$x = L\tan\alpha\cos\theta$$
$$y = L\tan\alpha\sin\theta$$
$$z = -L$$

This data can then be plotted, the x and y coordinates forming the top view and the x and z dimensions forming the side view.

As a numerical example this problem was solved for a cylinder and cone with dimensions as shown in Figure 3. The resulting intersection is shown in the three orthographic views in the left hand portion of Figure 4. Note that a hidden line routine was not used in this example as the development was considered to be of more interest at this time.

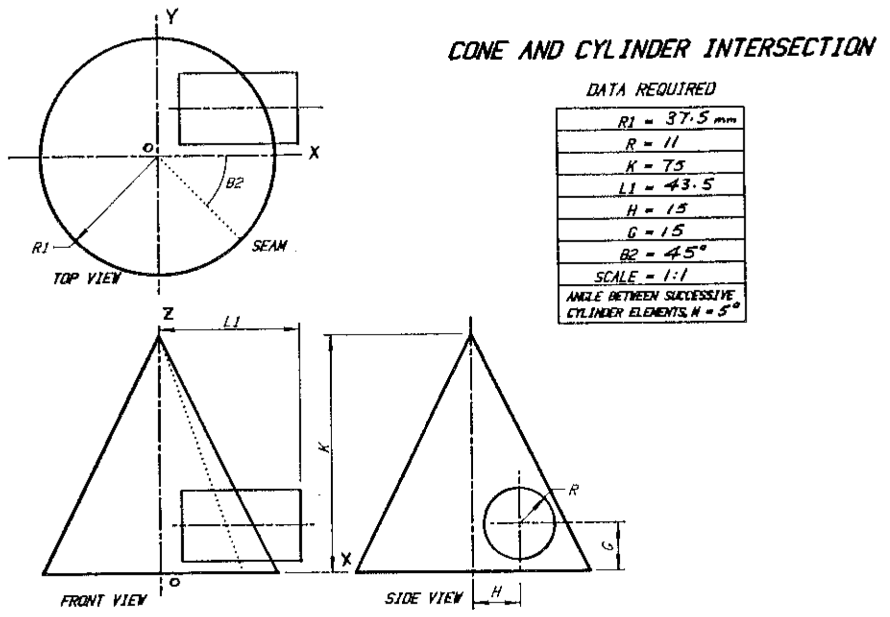


Figure 3

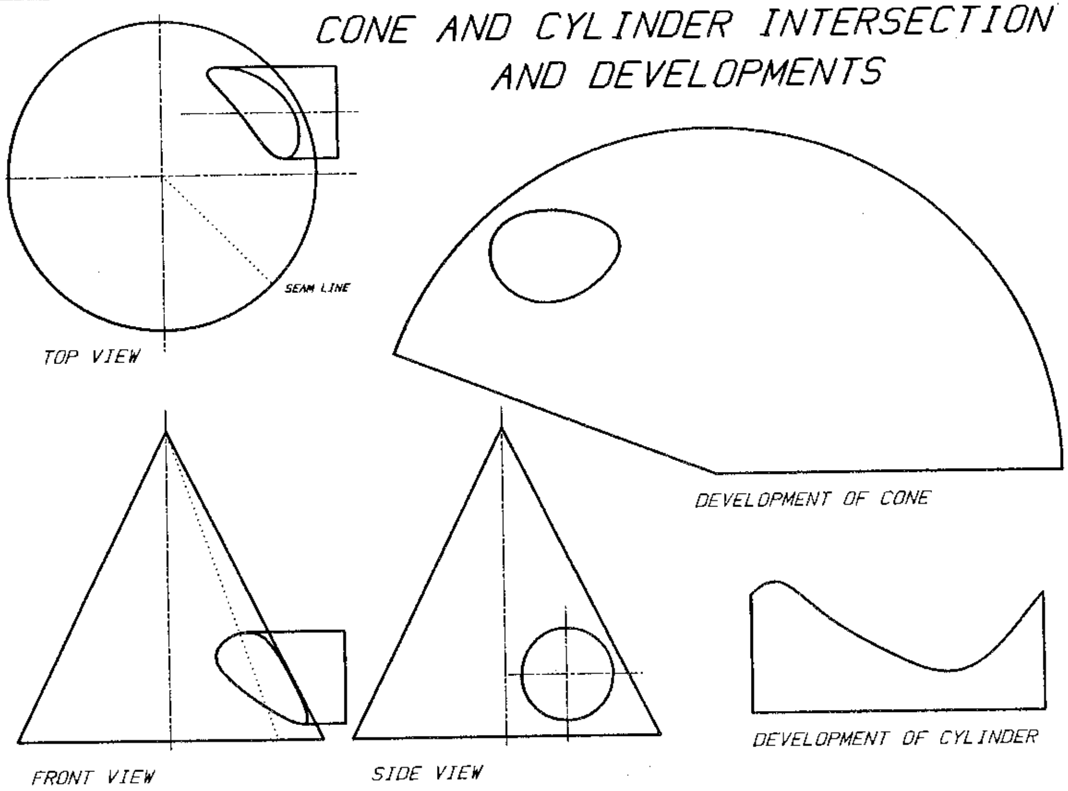


Figure 4

Development of a Cone and Cylinder

A development is primarily a true shape of the surfaces making up an object. In the case of a cone and a cylinder the developments can be obtained from the true length of a series of lines on the surfaces.

A development of a general cone is sketched in Figure 5. The length OR is equal to the slant height. The angle β can be found by the fact that the arc length RST is equal to the circumference of the base of the cone. That is

$$\beta = \frac{\text{cone circumference}}{\text{slant height}} = \frac{2\pi(R1)}{R1/\sin\alpha}$$

$$= 2\pi \sin\alpha \text{ radians}$$

where R1 = radius of the base of the cone and α is 1/2 the projected apex angle, Figure 1.

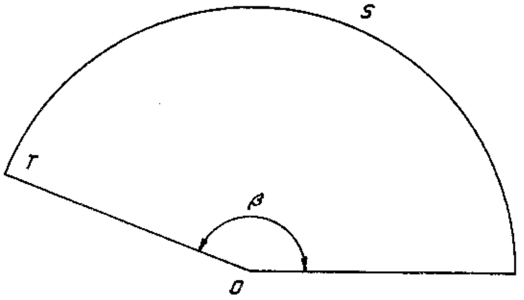


Figure 5

With β known it is a simple matter to draw the outline of the cone development because the slant height is known.

The development of the hole in the cone is obtained by obtaining the true length of a series of lines from the apex to the intersection points. In the case of the origin at the apex the true lengths are

$$T.L = (x^2 + y^2 + z^2)^{1/2}$$

where x,y,z are coordinates of an intersection point. The position of each intersection point on the development is determined by calculating its angular position using the relation developed for determining the angle β. Any angle, θ, on the top view of the cone becomes θ times $\sin\alpha$ on the development. Thus the hole can be drawn on the development since $\theta = \tan^{-1} y/x$ where x and y are the known coordinates of the intersection points found previously.

HOLE COORDINATES ORIGIN AT A		CYLINDER COORD. ORIGIN AT B	
X	Y	X	Y
-26.83	61.48	0	28.47
-24.59	60.05	1.96	30.26
-23.04	58.4	3.92	31.4
-22.36	56.53	5.89	31.73
-22.55	54.52	7.85	31.23
-23.44	52.44	9.81	30.12
-24.82	50.41	11.78	28.64
-26.5	48.49	13.74	27.01
-28.38	46.75	15.7	25.36
-30.39	45.24	17.67	23.78
-32.51	43.99	19.63	22.3
-34.69	43.02	21.59	20.94
-36.92	42.35	23.56	19.68
-39.18	42.01	25.52	18.51
-41.44	41.99	27.48	17.39
-43.65	42.31	29.45	16.32
-45.78	42.96	31.41	15.27
-47.78	43.92	33.37	14.24
-49.59	45.18	35.34	13.23
-51.17	46.68	37.3	12.27
-52.47	48.4	39.26	11.38
-53.45	50.27	41.23	10.61
-54.06	52.23	43.19	9.99
-54.27	54.22	45.16	9.58
-54.07	56.18	47.12	9.41
-53.44	58.04	49.08	9.52
-52.39	59.75	51.05	9.94
-50.93	61.25	53.01	10.68
-49.07	62.51	54.97	11.76
-46.86	63.48	56.94	13.17
-44.35	64.14	58.9	14.88
-41.57	64.47	60.86	16.86
-38.62	64.49	62.83	19.07
-35.56	64.18	64.79	21.44
-32.49	63.56	66.75	23.88
-29.53	62.65	68.72	26.28
-26.83	61.48	70.68	28.47

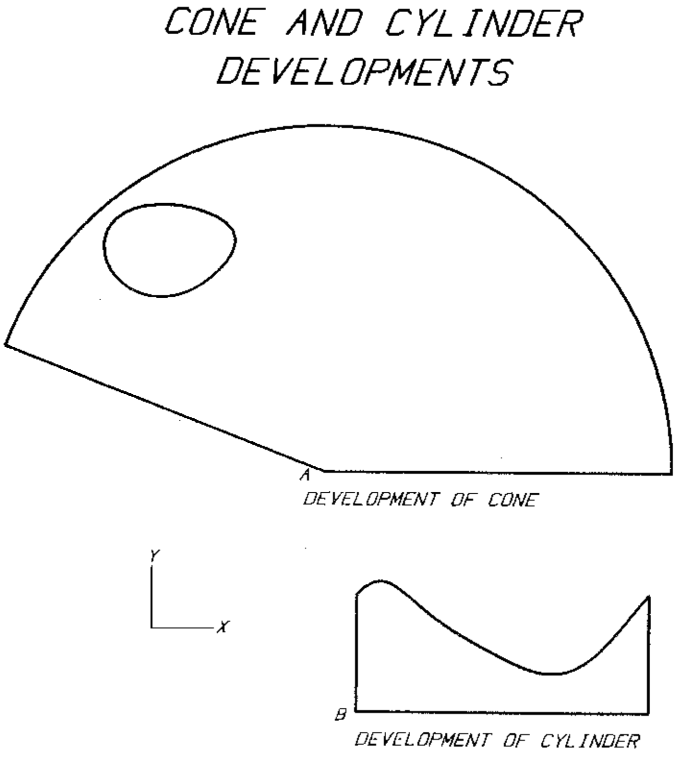


Figure 6

For the same numerical example as previously used, the developments are shown on the right hand side of Figure 4.

The development of the cylinder is very simple and requires no explanation for readers of this journal.

Numerical Results

For manufacture, perhaps the drawing of the developments only is required together with supporting data. This can be produced from the same computer program since the required information has been generated by the program. An example of this type of drawing, using the same sized cone and cylinder as in the first example, is shown in Figure 6.

Numerical Example 2 - Intersection only

Determine the intesection of the cone and vertical cylinder shown in Figure 7.

Solution

The position vector of a point P on the cone is

$$\bar{P} = L\bar{j} + L\tan\alpha\cos\sigma\,\bar{i} + L\tan\alpha\sin\sigma\,\bar{K}$$

The position vector of a point Q on the cylinder is

$$\bar{Q} = H\bar{i} + L\bar{j} + R\cos\phi\,\bar{i} + R\sin\phi\,\bar{K} - S\bar{k}$$

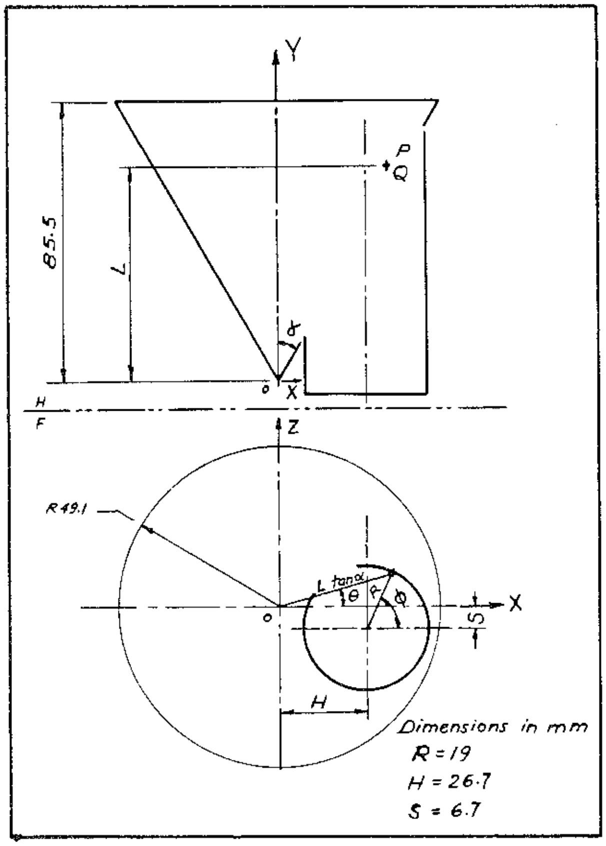


Figure 7

Equating like terms

$$L\tan\alpha\cos\sigma = H + R\cos\phi \qquad (a)$$
$$L\tan\alpha\sin\sigma = -S + R\sin\phi \qquad (b)$$

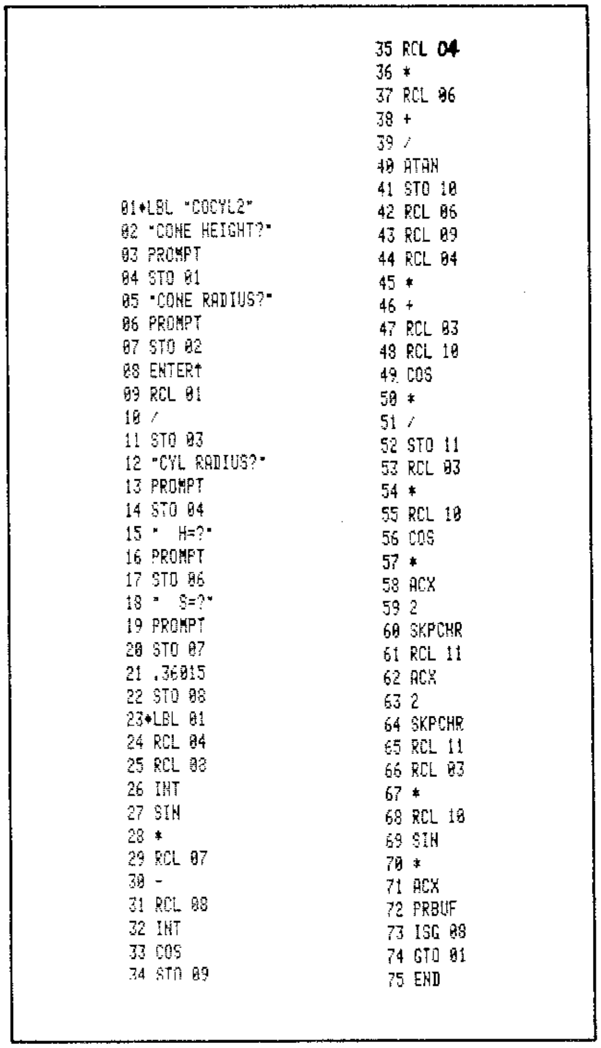
Divide (b) by (a); $\tan = \dfrac{-S + R\sin\phi}{H + R\cos\phi}$

Find σ, substitute into (a)

$$L = \frac{H + R\cos\phi}{\tan\alpha\ \cos\theta}$$

Intersection points are
$X = L\tan\alpha\cos\sigma$
$Y = L$
$Z = L\tan\alpha\sin\sigma$

The program shown below was written for the HP-41 calculator. The angle ϕ goes from 0 to 360° in steps of 15°. The results are printed out and hand plotted on Figure 8.



```
01♦LBL "COCYL2"
02 "CONE HEIGHT?"
03 PROMPT
04 STO 01
05 "CONE RADIUS?"
06 PROMPT
07 STO 02
08 ENTER↑
09 RCL 01
10 /
11 STO 03
12 "CYL RADIUS?"
13 PROMPT
14 STO 04
15 "  H=?"
16 PROMPT
17 STO 06
18 "  S=?"
19 PROMPT
20 STO 07
21 .36015
22 STO 08
23♦LBL 01
24 RCL 04
25 RCL 08
26 INT
27 SIN
28 *
29 RCL 07
30 -
31 RCL 08
32 INT
33 COS
34 STO 09
35 RCL 04
36 *
37 RCL 06
38 +
39 /
40 ATAN
41 STO 10
42 RCL 06
43 RCL 09
44 RCL 04
45 *
46 +
47 RCL 03
48 RCL 10
49 COS
50 *
51 /
52 STO 11
53 RCL 03
54 *
55 RCL 10
56 COS
57 *
58 ACX
59 2
60 SKPCHR
61 RCL 11
62 ACX
63 2
64 SKPCHR
65 RCL 11
66 RCL 03
67 *
68 RCL 10
69 SIN
70 *
71 ACX
72 PRBUF
73 ISG 08
74 GTO 01
75 END
```

Numerical Example 3 - Development only

Draw the development of a truncated cone as shown in Figure 9. Check the program using the following values:
H1 = 90, H2 = 75, H3 = 30, H4 = 20,
R1 = 37.5.

Solution

This problem can be solved by more than one method. This solution will follow the usual graphical procedure of finding the true length of a series of lines on the surface of the cone. One such line is shown as CB at angle θ as shown. A series of such lines is obtained by letting θ vary from 0 to 360° in a series of known small steps.

The first problem to be solved is to find the location of the end points C and B. First we will consider the point B and its location in the frontal projection. The X and Z components can be found by finding the intersection of two lines, line $o_F a_F$ and line $h_F j_F$.

Line $o_F a_F$, Point a_F : $X = R1 \cos\theta$, $z = -H1$

Point oF : $X = o$, $z = o$

Line $h_F j_F$, Point h_F : $X = -R1$, $z = -H1$

Point j_F : $X = H2 \tan\alpha$, $z = -H2$

We can find the intersection point of these two lines using an easily developed computer program. This program will therefore produce values for the x and z coordinates of B. The y coordinate can be found to be equal to the x coordinate multiplied by tan θ as can be seen from the horizontal projection.

In a similar manner the coordinates for the point C can be found. With these two points known we can find the true lengths of OC and OB.

Another method of finding the coordinates of points B and C would be to find the intersection of the line OA with the inclined planes which truncate the cone.

The final step is to lay out the development. This can be done in several ways. One way is to find the magnitude of the angle $\Delta\psi$ on the development which corresponds to the angle $\Delta\theta$ between the lines in the horizontal view. We can use the relation between an arc and its subtended angle $s = r\theta$. In the case of the development, the arc is the length of the circumference of the base cone, $2\pi R1$. The radius is the slant height of the cone $= R1/\sin\alpha$

$$\text{total } \psi = \frac{s}{r} = \frac{2\pi R1 \sin\alpha}{R1} = 2\pi \sin\alpha$$

X	Y	Z
45.7	80.4	-6.7
45.1	78.5	-1.8
43.2	75.3	2.8
40.1	70.9	6.7
36.2	65.3	9.8
31.6	58.7	11.7
26.7	51.2	12.3
21.8	43.0	11.7
17.2	34.4	9.8
13.3	25.9	6.7
10.2	18.5	2.8
9.3	14.9	-1.8
7.7	17.8	-6.7
8.3	24.9	-11.6
10.2	33.4	-16.2
13.3	42.0	-20.1
17.2	50.2	-23.2
21.8	57.8	-25.1
26.7	64.5	-25.7
31.6	70.2	-25.1
36.2	74.8	-23.2
40.1	78.2	-20.1
43.2	80.3	-16.2
45.1	81.0	-11.6
45.7	80.4	-6.7

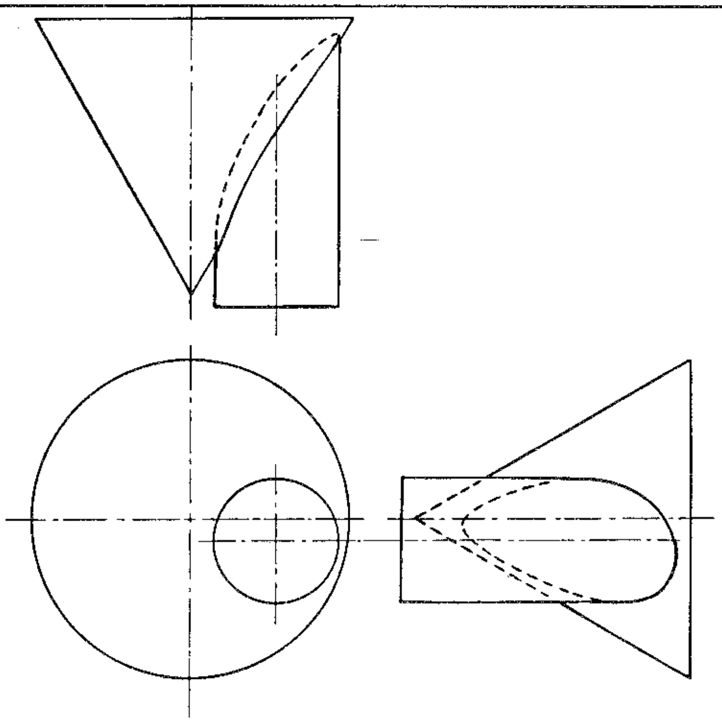


Figure 8

If the number of lines on the surface which were originally chosen to make the development were N, then

$$\Delta\psi = \frac{2\pi \sin\alpha}{N} \quad \text{radians}$$

The coordinates of any point defining the edges of the development can be found as follows, see Figure 10.

$$x = r\cos\psi \ , \ y = r\sin\psi$$

where r is the true length of a line on the surface.

These results are plotted on Figure 11.

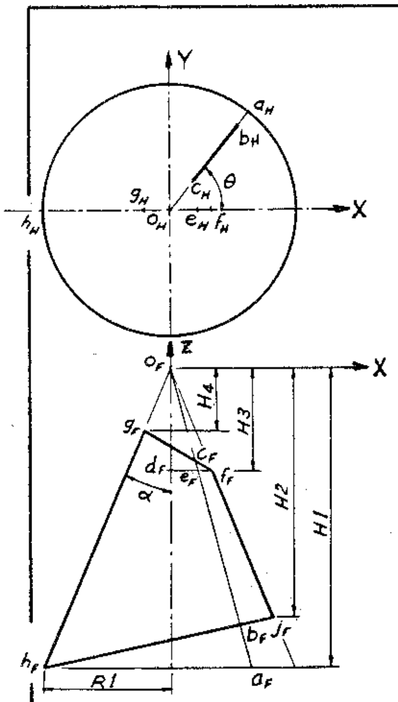


Figure 9

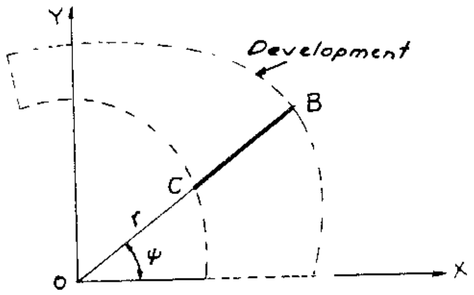


Figure 10

CONE DEVELOPMENT

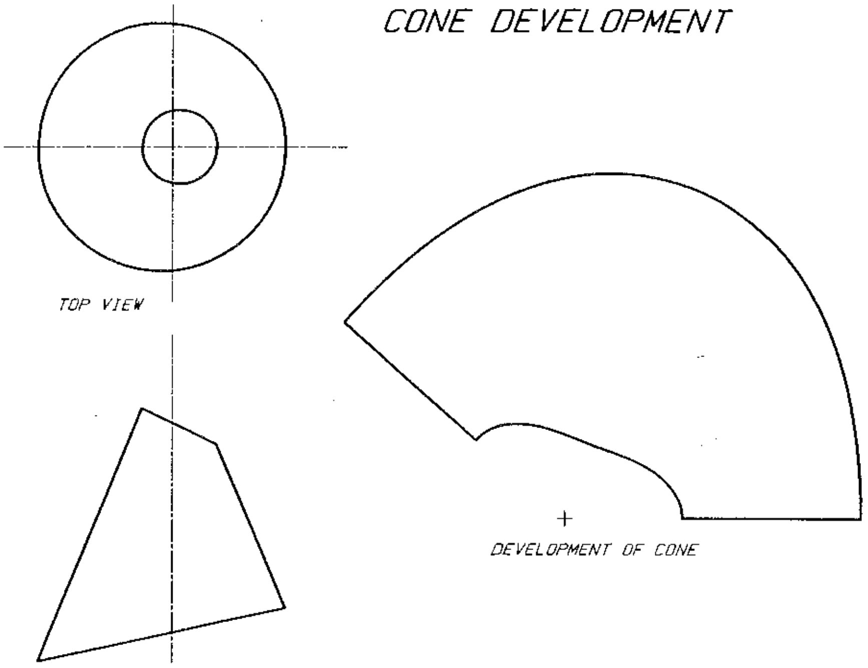


Figure 11

CHANGES

ENGINEERING GRAPHICS TAKES A NEW DIRECTION

Josann W. Duane
Department of Engineering Graphics
The Ohio State University

The role of graphics in the engineering curriculum is changing. Engineering graphics faculty members at Ohio State recently became a part of this change as a result of: 1) The development of an undergraduate course sequence that integrates computer programming and engineering graphics through the common medium of computer graphics, and 2) the initiation of graduate level instruction in computer graphics for engineering design and analysis. This paper summarizes the thinking that has governed these recent changes in Ohio State's engineering graphics curriculum and presents the new direction we see this discipline taking.

While critiquing the status of engineering graphics within both our university and general engineering practice, we noted that two opposing points of view exist: some faculty and practicing engineers view graphics as peripheral while others deem it a fundamental part of an engineer's education. In attempting to find out why this divergence dominates current thinking, we discovered that these opposing points of view are rooted in engineering graphic's historical development.

Prior to the 1920's, engineering graphics occupied a sizable portion of an engineer's education. For example, Charles Mann's 1918 report (1) on engineering education commissioned by the Carnegie Foundation for the Advancement of Teaching recommended that theory and practice be taught simultaneously (2). He suggested that students execute practical engineering projects early in their education and also argued that skill in drafting was important to understanding more theoretical graphics concepts such as descriptive geometry. Mann's philosophy coincided with the educational philosophy of the time, as is evident from the engineering curricula of that era at major universities such as Ohio State.

The Department of Engineering Drawing at Ohio State, founded in 1906 by its first chairman Professor Thomas E. French, offered a curriculum that was centered around graphics' importance in engineering practice and that was designed so that students would achieve skill in technical drafting (3). As freshmen, engineering students studied freehand and geometrical drawing and lettering. As sophomores, they learned about projection systems, descriptive geometry, and shades and shadows. As juniors, students studied photography and gained skill in professional drafting (4).

During the 1920's, educators' interpretation of engineering graphics' place in the engineering curriculum began to change. William Wickenden (5) outlined this new interpretation after conducting an extensive study of engineering education at the request of the Society for the Promotion of Engineering Education, a predecessor of the American Society for Engineering Education (ASEE). In his report, Wickenden distinguished between a technological and a collegiate engineering education. He suggested that technical schools should be responsible for teaching the practice of engineering while colleges and universities should teach the theory underlying the practice. This division in educational objectives was in part a by-product of growth in the sciences and mathematics. Both mathematics and sciences, in their applied forms, offered engineers new tools. However, mastering both the practice of engineering and the effective application of mathematics and science required more than the four years then allotted undergraduate education.

Wickenden's position was reflected in the Ohio State graphics curriculum by a gradual reduction in the number of credit hours of required instruction in engineering practice. For example, graphics topics such as lettering and photography were deemed to be engineering practice, and as such were eliminated from the curriculum. An advanced course in descriptive geometry, which is the theoretical basis for drafting's practice, was added to the curriculum.

The technological advances made during World War II, which demonstrated the strength of mathematics and science applied through engineering, substantially influenced L. E. Grinter's report, commissioned in 1955 by the ASEE (6). Grinter called for further "strengthening of work in the basic sciences" at universities with a corresponding reduction in the time devoted to engineering practice. Because the bulk of engineering graphics was interpreted to be engineering practice, and additional courses in basic sciences and mathematics needed to be added to an already full curriculum, the study of engineering graphics was reduced at most universities, but remained an important element in the technical school curriculum. Although it was not Grinter's intent, graphics courses at some schools were eliminated entirely. In fact, Grinter specifically refers to the importance of graphics as a fundamental of engineering by "an insistence upon the development of a high level of performance in the oral, written and graphical communication of ideas."

At Ohio State, in the decade following World War II, courses teaching detailed drafting of working drawings were dropped from the curriculum. By this elimination, study of engineering drawing required of all engineering students could be confined to the freshman year. At Ohio State, Grinter's Report was not interpreted as a call for eliminating graphics entirely from the curriculum, but rather a shift in priorities. Specialized and advanced courses teaching graphics' use as an analytical tool were still offered to seniors and graduate students.

During the 1960's, engineering educators again began reinterpreting the role of graphics in the engineering curriculum. In the 1968 ASEE Goals Committee's final report (7) engineering graphics was considered "a critical but controversial element of engineering education." Some schools had eliminated it entirely. Among subjects recommended for the future in engineering curricula, it ranked below middle. The report states that,

> "teachers of engineering drawing and engineering graphics have often seemed separated from the mainstream of thought and development in engineering education. Recently, however, interest in this important area has been renewed as a result of the expanded use of the computer as a graphical tool applicable to problems in space, as well as a device for storing and retrieving information heretofore available only in the form of engineering drawings. Hopefully, these developments will stimulate and attract the vigorous and creative teachers needed in this important field."

Like Grinter's report a decade earlier, the Goals Committee's report reflected educator's desire to incorporate new developments into the education received by young engineers. Now, however, the new developments revolved around the computer.

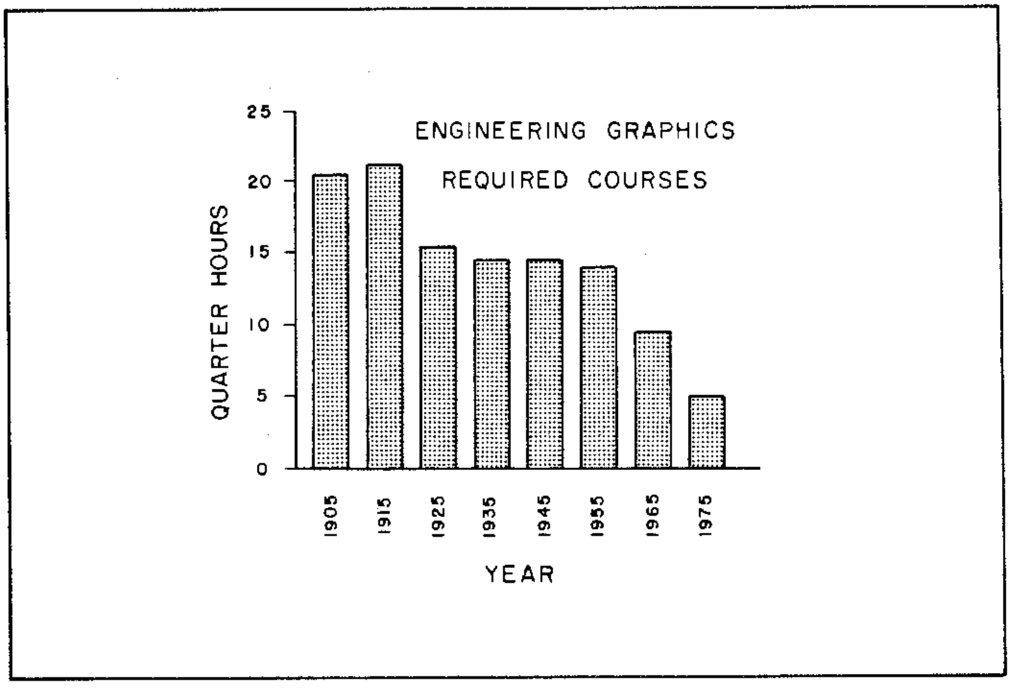


Figure 1. Required Engineering Graphics Curriculum for Civil, Electrical, and Mechanical Engineering at The Ohio State University for the Year 1900 through 1980 based on reference (4).

Before the Goals Committee's report was published, Ohio State Graphics Professors Richard I. Hang and Clyde H. Kearns had begun experimenting with computer generated graphics. Keeping abreast of the latest technology, Hang and Kearns used FORTRAN addressable graphics calls in programs run on the IBM 1620 to produce binary cards which drove a Calcomp drum plotter. Later, the Graphics department obtained an HP 2100 series minicomputer which when linked to the Calcomp plotter permitted on-line plotting. This acquisition was followed by a Tektronix 4010 terminal which displayed PLOT10 graphics run on the host IBM 360 computer.

In these early years, Ohio State's Engineering Graphics Professor Robert D. LaRue also saw engineering graphics' potential. In an interview published in the April, 1966 issue of Engineering Graphics (8), LaRue responded to a question on how computer based engineering would change teaching methods by stating,

> "if automation becomes economically feasible, certain areas of work that are now done by draftsmen will be eliminated. However, it would seem that the main effect of automation will be to eliminate or reduce those portions of a draftsman's work that are tedious and boring and leave the draftsman more time to devote to more challenging, creative work. This may, of course, require that the "draftsman" be trained at a higher level."

In 1972 the engineering Graphics Department offered the first formal course in computer-based engineering graphics. In teaching this course, Professor LaRue began to enhance the importance of graphics in the collegiate curriculum.

During these same years industry demonstrated the power of graphics through the medium of computers. Turnkey drafting systems, which reduced the cost of producing and revising drawings, permitted greater use of graphics in design and manufacturing. In his work with AIDES (Automated/ Interactive Design Engineering System), Charles A. Fritsch (9) at Bell Laboratories in Columbus, Ohio, found that computer-aided design systems eliminate so much of drafting's tedious tasks that it became easier for engineers to prepare drawings than to communicate information to technicians and check their work. Having engineers intimately involved in the graphical representation put them in direct control of the design process, ultimately improving the product.

Industry is now developing a new kind of engineering graphics. An importㅤtant eample of this is pre- and post-processing programs for finite element analysis. Graphics for analysis has evolved sufficiently that it has taken on a form fundamentally different from traditional graphics. This graphics has become so intermeshed with the analytical method it supports that it has become part of the analytical technique.

The finite element method's strength lies in generating numerical solutions to problems with complex boundary conditions and material properties. For example, to analyze the stress distribution in a culvert, the culvert drawing is subdivided into a mesh of small elements. Each element in the mesh is analyzed. The solutions at the boundary of adjacent elements are matched at a finite number of discrete points. The analyst can control solution accuracy by altering the mesh of element's design. To achieve the optimum solution, the analyst must visualize the mesh of element's geometry and display numerical results. For structural analysis, this is done by interactive display of stress contours and distorted geometry superimposed on the mesh.

When interviewed, engineering managers in industry disclosed that engineering graduates from many universities do not have the basic graphic skills required to use modern graphics effectively for design and analysis. Furthermore, technicians, although skilled in graphics, do not have the math and science background that is essential for independent design and analysis. These managers anticipate that this situation will most likely worsen. Computer-aided engineering is now a part of well capitalized companies in fields where repetitive drafting or exacting design standards are found. Because the cost of systems is dropping, smaller companies are now not benefiting from these systems more from changeover and retraining costs than from equipment costs.

Recognizing the impact of advancing technologies on engineering education, Donald D. Glower, Dean of our College, recently initiated a program to bring computer technology to the College of Engineering (10). His strategy was to introduce computer graphics first in departments where faculty-initiated projects had demonstrated support. Several key mechanical Engineering faculty members had already organized what was to become the Advanced Design Methods Laboratory for computer-aided design. In the Engineering Graphics Department there was already a nucleus of receptive faculty and an opportunity to incorporate computer graphics into the existing course structure. As a result, Dean Glower chose these two departments to introduce modern graphics.

The Mechanical Engineering Department incorporated graphics into both undergraduate required study of mechanical design principles and graduate elective study of the methodology and practice of computer-aided design. In these courses graphics enhanced the presentation of mechanical engineering principles and applications, but naturally the study of graphics itself was not the mechanical engineer's focal point.

In 1978, the Engineering Graphics Department initiated a pilot program that integrated interactive computer graphics, FORTRAN programming, and traditional graphics. Sixty students enrolled in this first series of 3 three-credit-hour courses. In 1980, 360 of the 1500 freshman engineering students participated. In 1982, 520 students elected to take this sequence, which is described in the Autumn 1982 issue of Engineering Design Graphics Journal (11). Unlike the Mechanical Engineering courses which used graphics to demonstrate mechanical principles, this new three course sequence presented the theories that underlie graphics itself.

Response to this entry level course sequence has been mixed. An evaluation of student effort showed that the average student was spending 18 to 20 hours per week on a three hour engineering graphics course as opposed to 13 to 15 hours per week devoted to a similar level five hour mathematics course. For some students, the time sped by as they become engrossed in producing interactive graphics applications programs at a level of sophistication unexpected for incoming freshman. For others the time was unwillingly extracted from a busy schedule at the expense of other important subjects such as math and physics. We were able to reduce student effort by about two hours per week by offering interactive graphics tutorial programs. However, the course still required twice the university's rcommended level of effort. To bring the course within university guidelines, we concluded that either course content should be reduced or credit hours expanded. To do either required a re-evaluation of graphics' role in the engineering curriculum.

Prior to joining the faculty at Ohio State in 1981, my eight year career in industry gave me the opportunity to participate in the development of modern engineering grahics. I recognized that the graphics that had become an integral part of the finite element method of analysis was just the unpolished beginning of a revolutionary new graphics that would take the field in a new direction. With the encouragement of Charles A. Moore, Chairman of the Graduate Committee in Civil Engineering, I developed two courses that present the analytical function of computer-based engineering graphics to advanced undergraduate and graduate students. The most immediate reason for offering advanced courses in engineering graphics was to serve the needs of graduate students whose thesis topics involved advanced development in engineering graphics or graphics support for analysis. Because engineering graphics education had become the domain of technical schools, students pursuing an engineering education through the university system were entering graduate school without the skills to use modern graphics support for research and development.

These courses have as their objectives development of the following: skill in interactive graphics programming; experience in using commercial graphics systems for engineering design, drafting and analysis; ability to evaluate graphics systems performance with respect to a specific engineering or scientific function. These objectives are achieved through a series of laboratory and field projects.

In the first course, students learn to write two dimensional interactive graphics application programs using a FORTRAN addressable graphics code. Students learn about graphics systems by interviewing those working in their field of interest and by preparing technical memos discussing project objectives and graphics software and hardware of those interviewed. Laboratory projects are assigned to give students experience in working with commercial graphics systems.

In the second course students learn advanced graphics application programming and analyze several commercial graphics applications programs and turn-key systems. For example, as a class project students use PADL-2 (12), a solids modeling language, to develop a graphics system. For this they write a graphics application program using PADL-2. FORTRAN77. and DCL (command language for Digital Equipment Corporation's VAX 11/750 operating system), and link a Lexidata 2410 high resolution color graphics terminal to a VAX 11/750. In these two courses, about half the instruction is remedial. Graduate students, for example, usually lack the basic skills in visualization and graphic communication needed to use modern graphics effectively for engineering analysis. Graduate students enter the class with graphics skills on par

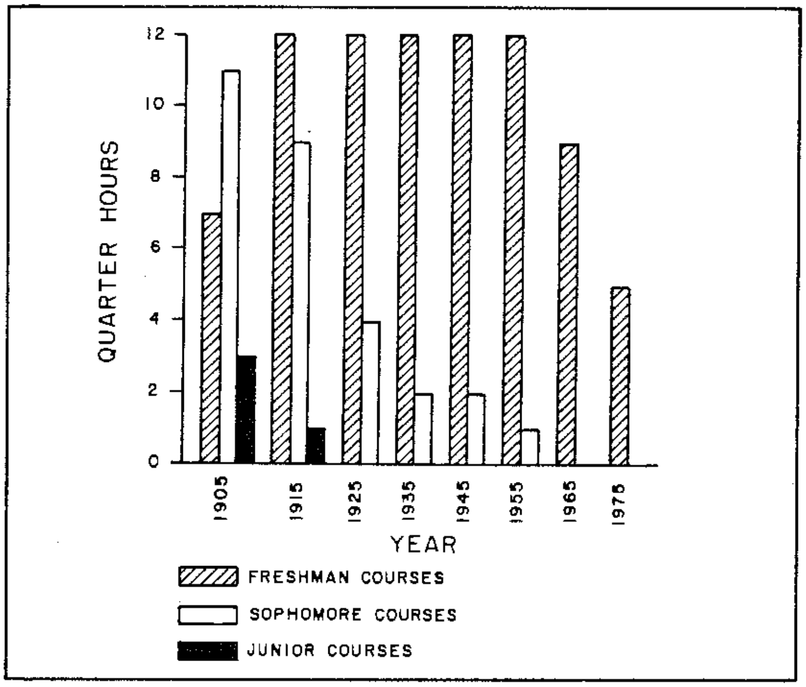


Figure 2. Course Distribution for required Engineering Graphics curriculum for Civil, Electrical, and Mechanical Engineering based on reference(4).

with freshmen, but they are able to easily assimilate interactive graphics for engineering analysis. Freshmen, on the other hand, are unable to relate graphics such as a finite element model processor to the analytical method it supports because they lack experience in numerical methods.

In the first offering, small enrollment permitted tailoring of the courses to meet individual needs. Lack of basic skills could be compensated for on an individual basis. However, as the number of students requesting enrollment in the courses increased, we realized that the time for a more cohesive approach to curriculum development had come. As we concluded from our experience with the freshman graphics sequence, here also we found it necessary to evaluate graphics' role in the engineering curriculum before proceeding with further development of advanced graphics courses.

Conclusions

The fundamental nature of engineering graphics is changing. In the past, engineering graphics was largely used for documentation. Now graphics is becoming an important part of inteactive design and analysis. We are just seeing this process beginning. Graphics work stations linked to networked or mainframe computers are giving us a glimpse of the possibilities of truly interactive design and analysis.

Engineering analysis is the domain of the engineer and scientist, not the technician. Graphics support for engineering analysis has proved to be essential in implementing the finite element method in any but the simplest geometric cases. Engineers use graphics support for finite element analysis directly. Technicians are no longer used to generate the mesh of nodes and elements. As graphics support for other numerical methods is developed and as the finite element method finds wider application, graphics will again become the engineer's rather than the technician's tool.

Although practical years ago, the bifurcation of the engineering curriculum which gave technical schools primary responsibility for graphics has now left universities without the structure to actively participate in the advances made by industry in graphics support for engineering analysis. As a result, engineering graphics in the collegiate curriculum is an abbreviated version of past courses. This reflects changes in the engineering curriculum resulting from the increased emphasis on basic science and mathematics following World War II, but is not in step with the future where the computer's impact will shape engineering.

In developing new graphics courses at Ohio State, we have met with limited success. Our many frustrations in this process result from the attitudes and curriculum which we inherited. Because of this, we found the problems encountered in developing new engineering graphics courses more complex than engineering educators generally realize. As a result, we recommend that a study addressing the following two basic questions be undertaken: what is the subject matter that comprises modern engineering graphics; and how can this body of knowledge be taught to engineers, scientists, and technicians? The answers will provide the basis for redesigning curriculum and reshaping attitudes toward engineering graphics so that modern graphics can become an integral part of the engineering education.

In answering the first question, both what engineering graphics has been and what it will likely become should be studied. Many believe that engineering graphics means that body of knowledge formalized as subject matter at its prime in the early 1900's and linked to graphics instruments in use at that time. It is characterized by line drawings, simple projections, and indelible copy. However, the form of graphics engineers now use is changing rapidly. Because much of the leadership in this area has come from industry, ties with industry through advisory groups and joint research and development projects will help us determine the new direction of engineering graphics.

The second question, which is probably the more difficult of the two, pertains to effective teaching of engineering graphics. As students proceed through the educational process they gain skill and establish departmental majors. At present, almost all of engineering graphics at universities is taught to freshmen. This may not be the most effective way to educate future engineers. Certain aspects of graphics, such as three dimensional visualization, are of general interest and require few prerequisite skills. If these were made part of the pre-college curriculum, problems such as the excessive student time demands made by our freshman courses could be diminished. Graduate instruction has demonstrated to us that other aspects of graphics, such as the use of processors for finite element analysis, may be presented better after students have better defined their career choices and have attained the skill in numerical analysis and linear algebra that allows them to better assimilate the subject matter.

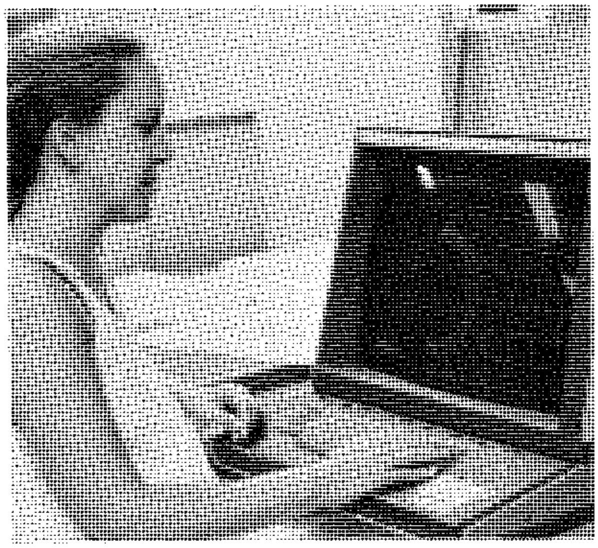


Figure 3. Graduate Instruction in Engineering Graphics

graphics is changing

Just as science and mathematics applied in engineering caused engineering to take a new course in the 1950 and 1960's, the computer's impact on engineering is causing it to change course again. Along with engineering, graphics has also taken a new direction.

Educators must address this change and bring modern graphics into the collegiate curriculum so as to graduate engineers fluent in the graphics language that is becoming an integral part of computer-aided engineering.

REFERENCES

1. C.R. Mann, A Study of Engineering Education, Bulletin No. 11, The Carnegie Foundation for the Advancement of Teaching, 1918.
2. E.A. Walker, Goals of Engineering Education, Information Document No. 2, American Society for Engineering Education, December, 1963.
3. Thomas C. Mendenhall, History of The Ohio State University, vol. 2, The Ohio State University Press, Columbus, Ohio, 1926.
4. The Ohio State University Bulletin, Published by The Ohio State Univesity, 1896-1983.
5. W.E. Wickenden, Report of the Investigation of Engineering Education, 1923-1929, Pittsburgh, Society for the Promotion of Engineering Education, vol. I, 1930, vol. II, 1934.
6. L.E. Grinter, "Report on Evaluation of Engineering Education (1952-1955)," Journal of Engineering Education, September 1955, 46, No. 1, 25-63.
7. E.A. Walker, "Goals of Engineering Education," Journal of Engineering Education, January 1968, 58, No. 5, 367-446.
8. "Is Graphics Education Keeping Pace?", personal interviews appearing in Engineering Graphics, April, 1966, 6, No. 4, 10-16.
9. Charles Fritsch, "Designing an Integrated Graphically-Driven CAE/CAM System," Position paper give at The Workshop on the Role of Computer Science in Creative Engineering Environments, The Ohio State University, Columbus, Ohio, July 18, 1983.
10. Donald D. Glower and Lindon E. Saline, A Response to Advancing Technologies, American Society for Engineering Education, 1982.
11. Michael J. Miller, Jacob J. Wolf III, and John T. Demel, "The OSU Freshman Graphics and Programming Sequence," Engineering Design Graphics Journal, Autumn 1982, 46, No. 3, 16-21.
12. Brown, Christopher M. Current Research in Computer and Information Science at the University of Rochester, Publication of the University of Rochester, 1981.

●

JOBS from page 4

SEARCH FOR ENGINEERING GRAPHICS FACULTY

The Department of Engineering Graphics at The Ohio State University is searching for nine-month tenure-track faculty at the assistant and/or associate professor level. Requirements are: degrees in fields appropriate to engineering education, of which at least one should be in engineering; competence in computer programming languages as applied to computer graphics and the solution of engineering problems; professional skills in all phases of graphical representation and communication; verbal fluency combined with talent and inclination toward classroom teaching. Duties include, but are not limited to, preparation, organization, and teaching of engineering graphics courses, supervision of teaching associates, management of multisection courses, advising students; development of instructional methodology, audio-visual materials, and programmed instruction; and performing administrative and committee functions in support of departmental activities. Faculty members will have the opportunity to participate in the development of extensive programs and facilities in computer graphics which both students and faculty will use for educational and research activities. An earned doctorate in an appropriate discipline is desirable; appropriate industrial experience will receive favorable consideration. Salary commensurate with qualifications. Resume and names of three references should be sent to John T. Demel, Department of Engineering Graphics, 2070 Neil Avenue, Columbus, Ohio 43210. Position open until filled. The Ohio State University is an equal opportunity/affirmative action employer.

PERSPECTIVE

MATHEMATICAL ANALYSIS OF AXONOMETRIC PROJECTION AND THEIR APPLICATIONS TO PERSPECTIVE PROJECTION

Ming H. Land
Department of Architecture
Miami University
Oxford, Ohio

Mathematical analysis of axonometric projection have been conducted and reported by a number of authors (See the reference list). This paper will present additional analyses of axonometric projection and their applications to three-point perspective projection.

The Ellipse Angles

The axonometric projection is a form of orthographic projection in which the object, placed in an oblique position to the picture plane, is projected perpendicularly onto the picture plane with parallel projectors. To graphically represent an axonometric projection, a Cartesian coordinate system is used as shown in Figure 1. Let the diagonal line OP represent the line of sight perpendicular to an imaginary picture plane. The projection line has been rotated about the vertical axis (OC) at $\phi°$ ($\angle AOG = \phi°$), titled about the horizontal axis (OA) at $\theta°$ ($\angle GOP = \theta°$).

Let $\angle BOP$ be w (the angle between line OP and frontal plane), then the following mathematical relationships are obtained:

$$\sin w = \frac{BP}{OP}, \quad \sin\phi = \frac{AG}{OG} = \frac{BP}{OG}, \quad \cos\theta = \frac{OG}{OP}$$

$$\frac{BP}{OP} = \frac{BP}{OG} \cdot \frac{OG}{OP}$$

Thus, the angle for ω is found as follow:

$$\sin w = \sin\phi \cos\theta \quad .....(1)$$

Let $\angle EOP$ be μ (the angle ~~between~~ line OP and side plane), then the following mathematical relationships are obtained:

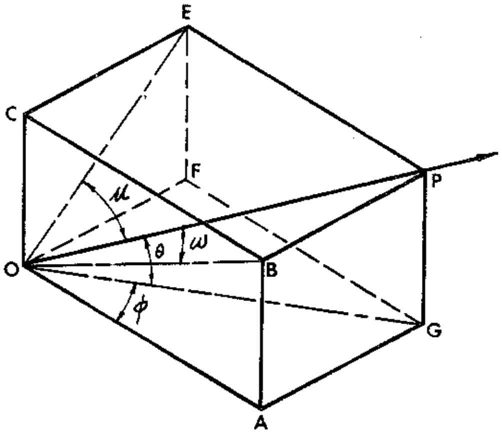


FIG. 1

$$\sin(90 - \phi) = \frac{FG}{OG} = \frac{EP}{OG}, \quad \cos\theta = \frac{OG}{OP}$$

$$\frac{EP}{OP} = \frac{EP}{OG} \cdot \frac{OG}{OP}$$

Thus, the angle for μ is found as follows:

$$\sin\mu = \sin(90 - \phi)\cos\theta \text{ or}$$
$$\sin\mu = \cos\phi \cdot \cos\theta \quad ....(2)$$

Therefore, given the two angles of rotation, ϕ and θ, we are able to obtain the angles between the line of sight and the three principal planes. These three angles, represented by w, μ, and θ, determine the ellipse angles on the three principal planes. See Figure 2.

Sample Solutions

Assuming that a cube is revolved $\phi°$ and titled at $\theta°$, the ellipse angles are found for each plane using the above two equations.

(1) Given: $\phi = 45°$, and $\theta = 35°16'$
Required: w, and μ
Solution: $\sin w = \sin\phi \cdot \cos\theta$
$= \sin 45° . \cos 35°16'$
$= 0.5773$
$w = 35°16'$
$\mu = 35°16'$
$\theta = 35°16'$ (Isometric projection)

(2) Given: $\phi = 30°$, and $\theta = 25°$
Required: w, and μ
Solution: $\sin\omega = \sin 30° . \cos 25°$
$= 0.4532$
$\omega = 26°56'$
$\sin\mu = \cos 30° . \cos 25°$
$= 0.7849$
$\mu = 51°20'$
$\theta = 25°$ (Trimetric projection, see Fig. 2)

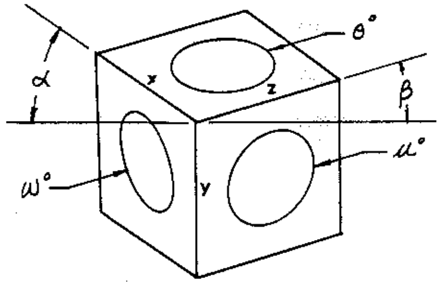


FIG. 2

The Foreshortened Scales

The ratios of the foreshortening scales of an axonometric projection are related to the ellipse angles as follows:

$x = \cos u$ ...... (3)
$y = \cos \theta$ ...... (4)
$z = \cos w$ ...... (5)

Sample solution

Given: $\phi = 30°$, $\theta = 25°$
$w = 26°56'$, $u = 51°20'$, $\theta = 25°$
Required: x, y, and z scales
Solution: $x = \cos u = \cos 51°20' = 0.62$
$y = \cos \theta = \cos 25° = 0.91$
$z = \cos w = \cos 26°56' = 0.89$
(Trimetric projection, see Fig. 2)

Axonometric Angles

An axonometric projection is not complete unless the axonometric angles, α and β (see Figure 2), are known. These two angles can be found with the following mathematical analysis. Referring to Figure 3, the plan view of a cube (represented by PQES) has been revolved $\phi°$ and tilted at $\theta°$ (represented by the $\theta°$ ellipse). PR and PT are two of the three anxonometric axes, and the third axis is a vertical one. The two axonometric angles are α and β. Then,

PN = r (radius of circle, PN = PQ = PS)
$PM = r \sin \theta$
$HR = HQ \sin \theta$

$$\frac{HR}{PH} = \frac{HQ \sin \theta}{PH}$$

$$\text{Since } \frac{HR}{PH} = \tan \beta , \quad \frac{HQ}{PH} = \tan \phi$$

Thus, $\tan \beta = \sin \theta \,.\, \tan \phi$ ....(6)
Also $\tan \alpha = \sin \theta \,.\, \tan (90 - \phi)$
$\tan \alpha = \sin \theta \cot \phi$

$$\text{or} \quad \tan \alpha = \frac{\sin \theta}{\tan \phi} \text{ ....(7)}$$

Equations (6) and (7) are two fundamental formulas for solving the axonometric angles when the revolving and tilting angles are known. These two formulas were proved in different analyses by Levens (1964, pp. 738 - 739) and Land (Winter 1980, p. 35).

Three-Point Perspective

Three-point perspective is the least used of the three types of perspective projection. This is probably because a three-point perspective requires the application of more involved theories and is more difficult to draw. However, three-point perspective is the most realistic form of pictorial drawing. It is effective for realistic illustration of tall structures and for bird's-eye views where the heights of the objects are to be emphasized for special effects.

The graphical procedures for constructing a three-point perspective diagram are often difficult to construct. The process of a three-point diagram construction by means of matrix transformation was reported by the author in a previous article (Land, Winter/Spring 1982). This paper will present additional mathematical analyses of three-point perspective diagram through applications of the above-mentioned theories and equations of axonometric projection.

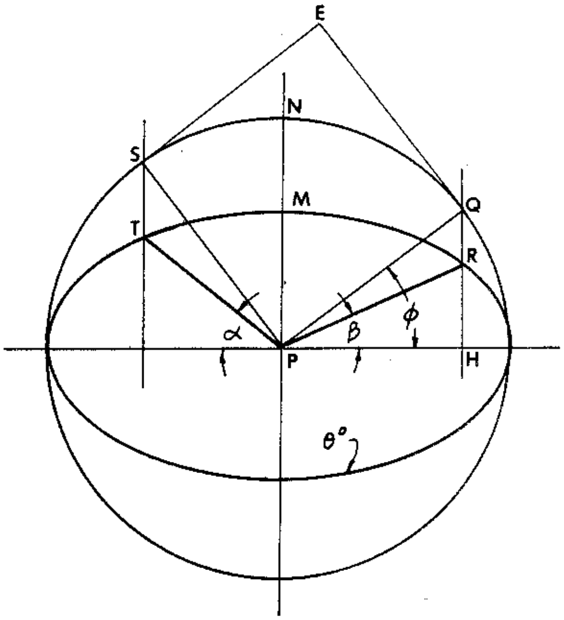


FIG. 3

Perspective Diagram Construction

The three axonometric axes, x, y, and z, of a cube, following the rotation of ϕ and tilting of θ, are shown in Figure 4. A three-point perspective is produced following the axonometric projection by a perspective transformation. In other words, a sight point is chosen and the axonometric view is then projected onto an imaginary picture plane. Thus, in Figure 4, a sight point (SP) is chosen at a distance of L from the front corner of the cube. Based on the theories of three-point perspective, the following procedures are then used to construct a perspective diagram:

1. With the front corner as center of vision and L as radius, draw a circle.

2. From point O, draw lines perpendicular to each axonometric axis. These lines intersect the circumference at sight points Sx, Sy, and Sz.

3. From Sy, draw a line to intersect OY at an angle of θ° at Vy, which is the vertical vanishing point of the three-point perspective.

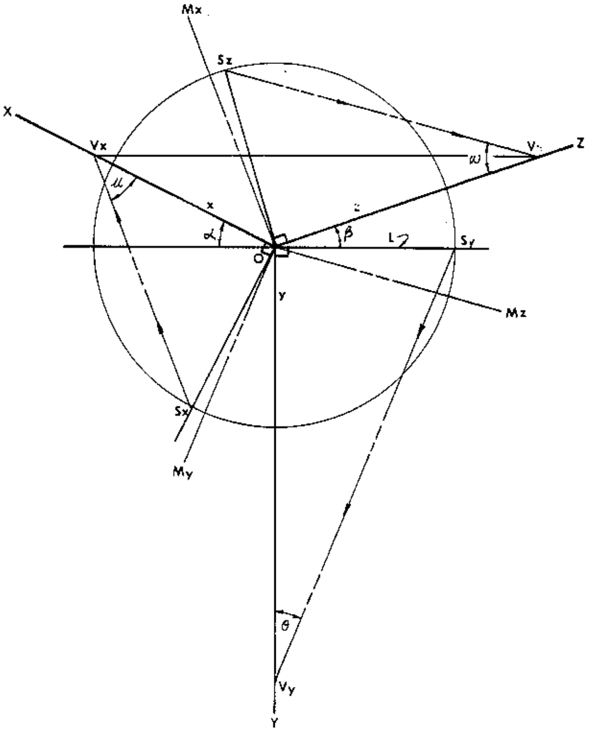


FIG. 4

4. From Sx, draw a line to intesect OX at an angle of μ° at Vx, which is the left vanishing point.

5. From Sz, draw a line to intersect OZ at an angle of w° at Vz, which is the right vanishing point.

6. Connect Sx and Vx, Sy and Vy, and Sz and Vz.

7. From O, draw line OMx parallel to SxVx, OMy parallel to SyVy, and OMz parallel to SzVz. These three lines are the measuring lines for perspective projection.

Thus far, we have located three sight points, Sx, Sy, and Sz, and three vanishing points, Vx, Vy, and Vz, and drawn three measuring lines, OMx, OMy, and OMz. This completes the diagram for a three-point perspective projection. In an example later in this paper, the drawing of a three-point perspective, using the diagram, will be explained.

The three vanishing points can be located by means of mathematical calculation and direct measurement. In Figure 4, $\Delta SxOVx$, $\Delta SyOVy$, and $\Delta SzOVz$ are right triangles. Since OSx = OSy = L, we obtain

$$OVx = L \cot\mu \ ....(8)$$
$$OVy = L \cot\theta \ ....(9)$$
$$OVz = L \cot w \ ....(10)$$

Therefore, once we obtain the axonometric angles, α and β, and the ellipse angles, μ, θ, and ω, for an axonometric projection, we can locate the three vanishing points easily by using the above three equations.

Cross-Validating Land's Diagram Construction

In a previous paper by the author (Land, Winter/Spring 1982), the perspective diagram is analyzed by matrix transformation as shown in Figure 5. (Note: the positive and negative signs are omitted here, and ϕ represents the angle of rotation and θ the angle of tilt).

Axonometric angle. From the diagram shown in Figure 5, axonometric angles, α and β, are found as follows:

$$\tan\beta = \frac{L \tan\theta}{\dfrac{L \cot\phi}{\cos\theta}} = \frac{\tan\theta \cos\theta}{\cot\phi}$$

$$= \frac{\sin\theta \sin\phi}{\cos\phi}$$

$$= \sin\theta \tan\phi$$

$\tan\beta = \sin\theta \tan\phi$ (This is Equation 6 previously provided) and:

$$\tan\alpha = \frac{L \tan\theta}{\frac{L \tan\phi}{\cos\theta}} = \frac{\sin\theta}{\tan\phi} \quad \text{(This is Equation 7)}$$

Vanishing points. Next, we will prove from this diagram that the lengths from center to the three vanishing points are as shown in Equation (8), (9) and (10).

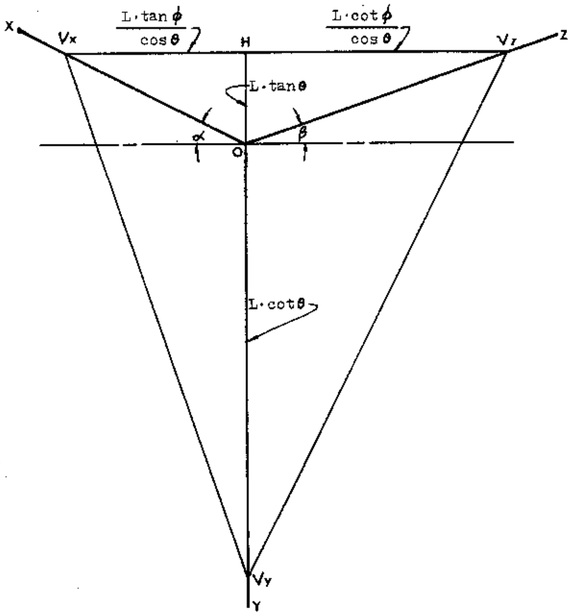


FIG. 5

Proof:

$$OVz^2 = \left(\frac{L \cot\phi}{\cos\theta}\right)^2 + (L \tan\theta)^2$$

$$= L^2 \left(\frac{\cos^2\phi}{\sin^2\phi \cos^2\theta} + \frac{\sin^2\theta}{\cos^2\theta}\right)$$

$$= L^2 \left(\frac{\cos^2\phi + \sin^2\phi \sin^2\theta}{\sin^2\phi \cos^2\theta}\right)$$

$$= L^2 \left[\frac{\cos^2\phi + \sin^2\phi \cdot (1 - \cos^2\theta)}{\sin^2\phi \cos^2\theta}\right]$$

$$= L^2 \left(\frac{1 - \sin^2\phi \cos^2\theta}{\sin^2\phi \cos^2\theta}\right)$$

From Equation (1), $\sin\omega = \sin\phi \cos\theta$

$$\overline{OVz}^2 = L^2 \left(\frac{1 - \sin^2\omega}{\sin^2\omega}\right)$$

$$= L^2 (1/\sin^2\omega - 1)$$

$$= L^2 (\csc^2\omega - 1)$$

$$= L^2 \cot^2\omega$$

Thus, $OVz = L \cot\omega$ (this is Equation 10 previously proved)

Also

$$\overline{OVx}^2 = \left(\frac{L \tan\phi}{\cos\theta}\right)^2 + (L \tan\theta)^2$$

$$= L^2 \left(\frac{\sin^2\phi}{\cos^2\phi \cos^2\theta} + \frac{\sin^2\theta}{\cos^2\theta}\right)$$

$$= L^2 \left(\frac{1 - \cos^2\phi \cos^2\theta}{\cos^2\phi \cos^2\theta}\right)$$

From Equation (2), $\sin\mu = \cos\phi \cdot \cos\theta$

$$\overline{OVx}^2 = L^2 \left(\frac{1 - \sin^2\mu}{\sin^2\mu}\right) = L^2 \cdot \cot^2\mu$$

Thus, $OVx = L \cot\mu$ (This is Equation 8)

From the diagram, we have

$OVy = L \cot\theta$ (This is Equation 9)

Sample Drawing

We will apply the above theories and equations to constructing the three-point perspective of a simple object. First, we will calculate drawing data for the axonometric projection.

Given: $\phi = 39°$, and $\theta = 25°$

Axonometric angles:

$$\tan\beta = \sin\theta \tan\phi = \sin 25° \cdot \tan 39°$$
$$= 18°35' \text{ (Use } 19°)$$

$$\tan\alpha = \frac{\sin\theta}{\tan\phi} = \frac{\sin 25°}{\tan 39°}$$
$$= 27°33' \text{ (Use } 27°)$$

Ellipse angles:

$$\sin w = \sin\phi \cdot \cos\theta = \sin 39° \cos 25°$$
$$w = 34°45' \text{ (Use } 35°)$$

$$\sin\mu = \cos\phi \cos\theta = \cos 39° \cos 25°$$
$$= 44°46' \text{ (Use } 45°)$$
$$\theta = 25°$$

With the above data, we will proceed to construct the three-point perspective of the object shown in Figure 6. Proceed as follows: (See Figure 7 and Figure 8)

1. Locate center of vision, O, and draw a vertical axis OY.

2. Draw the other two axes OX and OZ to make an angle of α and β, respectively, with the horizontal. ($\alpha = 27°$, $\beta = 19°$)

3. Assume a distance of L = 7-cm from the sight point to the center of vision. With O as center, draw a circle with a radius of 7-cm.

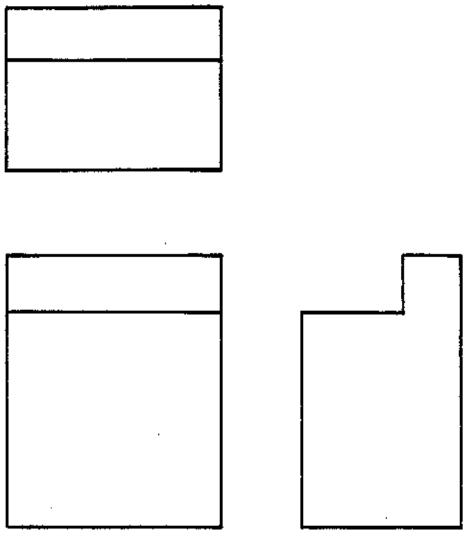


Fig. 6

4. Locate the three vanishing points, Vx, Vy, and Vz, using the following formulas:

OVx = 7·cot 45° = 7-cm
OVy = 7·cot 25° = 15-cm
OVz = 7·cot 35° = 10-cm

5. From center O, draw OSx ⊥ , OVx, OSy ⊥ OVy, and OSz ⊥ OVz. Sx, Sy, and Sz, located on the circumference, are the three sight points for the three perspective axes.

6. From center O, draw OMx//SxVx, OMy//SyVy, and OMz//SzVz. OMx, OMy, OMz are the three measuring lines. The ddiagram is completed.

7. Transfer the width measurments of the object to OMx, the height measurements to OMy, and the depth measurements to OMz.

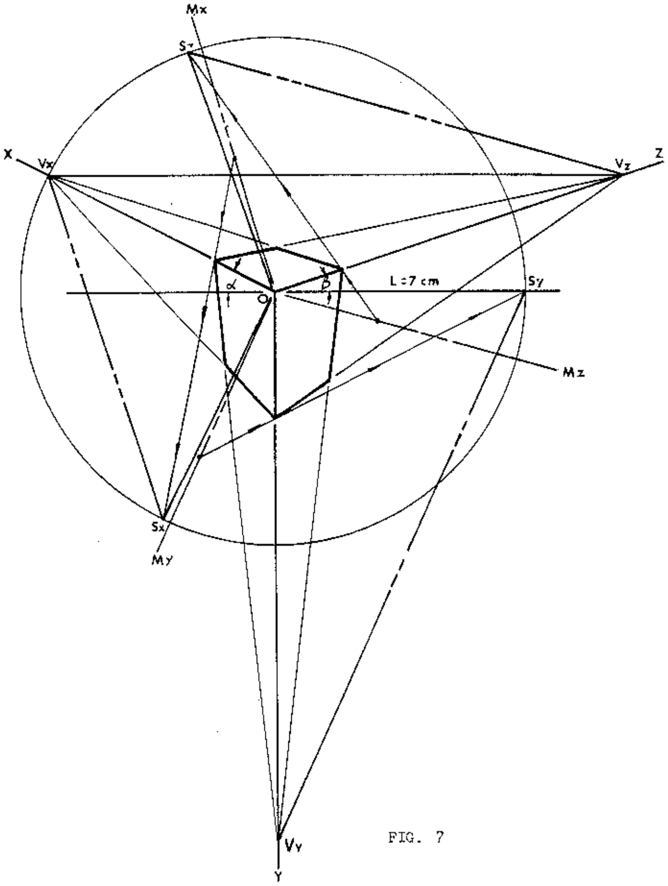


FIG. 7

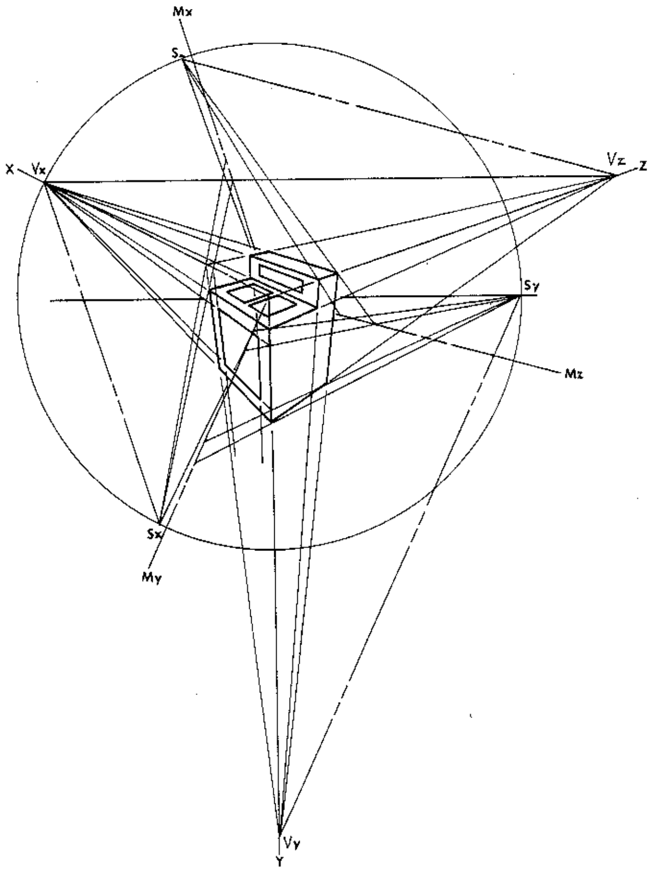


FIG. 8

8. Connect the points on each of the measuring lines to their corresponding sight point. These lines are the visual rays.

9. The visual rays intersect the three perspective axes and locate the perspective points. Connecting these points on the axes to corresponding vanishing point will complete the perspective.

10. Add any specific details to the perspective.

Summary

This paper presents the mathematical analysis of axonometric projection and their applications to the construction of the three-point perspective diagram. A three-point perspective diagram, once constructed, can be used over and over again for drawing three-point perspectives conveniently. This method eliminates the steps of drawing plan and elevation views as required in the general office method of three-point perspective drawing. It is hoped that the illustrator/designer will find that the three-point perspective can be easily constructed and make his/her illustrations of suitable subjects more interesting and more alive.

References

Blade, M.F. "A New Method for Pictorial Drawing," Proceedings--International Conference on Descriptive Geometry. 1978, pp. 149-154.

Hohenberg, F. "Several Methods of Drawing Axonometric Pictures without Auxiliary Views," Proceedings -- International Conference on Descriptive Geometry, 1978, pp. 155-159.

Land, M.H. "Applications of Odaka's Equations of Perspective Projection to the Determination of Scales and Ellipse Guides in Axonometric Drawing," Engineering Design Graphics Journal, Spring 1979, pp. 55-59.

Land, M.H. "The Sine Double-Angle Equations of Axonometric Projection for Solving Angles and Scale Ratios," Engineering Design Graphics Journal, Spring 1980, pp. 25-28.

Land, M.H. "Three-Point Perspective Transformation and Diagram Construction," Engineering Design Graphics Journal, Winter/Spring 1982.

Levens, A.S. Graphics, New York: John Wiley, 1964, pp. 738-739.

Niayesh, H. "Critical Review of Pictorial Drawing in U.S. Graphical Literature," Engineering Design Graphics Journal, Winter 1977, pp. 25-29.

Odaka, S. "Fundamental Equation of Perspective Projection and its Applications in Axonometric Projection," Proceedings -- International Conference on Descriptive Geometry, 1978, pp. 95-97.

Sauvageau, M. "A New System for Exact Axonometric Projection," Engineering Graphics, December 1970, pp. 32-35.

Sauvageau, M. "A New System for Exact Axonometric Projection," Engineering Graphics, January 1971, pp. 12-14.

●

Editor's Note: Professor Land is currently in the Industrial Education and Technology Department at Appalachian State University, Boone, North Carolina.

EARLY PLANNING

DEVELOPMENT OF INTERACTIVE COMPUTER AIDED DRAWING INSTRUCTION: A LONG RANGE PLAN FOR ENGINEERING GRAPHICS AT NORTH CAROLINA STATE UNIVERSITY

William A. Ross
Visiting Instructor
Graphic Communication
North Carolina State University

The Graphic Communications Program at North Carolina State University is a service program housed in the School of Education and furnishing instruction in Engineering Graphics to over 2,000 students annually. At least one course in Engineering Graphics is currently required for every engineering student, thus creating a heavy, but welcome, teaching load. The rapid evolution of microprocessors and expanding computer graphics capabilities have created a myriad of perceptions for those concerned with Engineering Graphics education. Enhancing the limitless visual-analytical powers of the human mind with an extremely fast and powerful problem solving tool is an exciting prospect. No one should be more concerned with insuring the congruous development of computer aided drawing within Engineering Graphics instruction than those who teach and love the subject. The computer presents a highly complex, controversial and perhaps unavoidable challenge for Engineering Graphics educators. The purpose of this paper is to describe how we are addressing this issue.

Faculty members in Graphic Communications have developed a systematic, articulated long range plan for developing, establishing and maintaining computer aided drawing instruction focusing on Engineering Graphics fundamentals. The various factors influencing or directly affecting the accomplishment of this plan have been identified. From these factors, specific goals, activities, objectives and time frames have been set for developing and maintaining instructional and professional expertise.

Although our ongoing activities in developing and conducting this plan began only a year ago, and are still evolving, positive and tangible benefits are beginning to show. We at North Caroline State University hope that by sharing our experiences with the Design Graphics Division, dialogue will be fostered and development enhanced.

OUTLINE OF LONG RANGE PLAN

Problem Statement

To develop and conduct a long range plan for integrating interactive computer aided drawing instruction with engineering graphics fundamentals.

Factors Influencing Development

1. Facilities
2. Existing equipment
3. Faculty development and training
4. Existing courses and curriculum structure
5. Integration with other campus agencies, schools and departments
6. Changing state-of-the-art in microprocessing technology
7. Application to needs of industry and business
8. Activities at other universities and schools
9. Equipment costs and upgrading
10. Financial support

Major Phases With Goals and Activities

PHASE I: PREPARATION

1. Establish communications with affected campus agencies, schools and departments
2. Seek committee involvement
3. Establish contacts with industry and business
4. Formally involve faculty in developmental activities (field trips, equipment shows, industrial tours, seminars, courses, etc.)
5. Survey other university engineering graphics programs
6. Review available texts and literature
7. Examine existing equipment and facilities for C.A.D. support capabilities
8. Develop preliminary instructional goals and objectives for interactive computer aided drawing instruction (Figure 1)
9. Evaluate existing educational microprocessor C.A.D. system (Figure 2)
10. Begin instructional innovations and experimentation with existing equipment (learning activity packages, software library, instructional mini-grants, etc.)
11. Secure equipment for faculty development and training
12. Gain funding and financial support base for equipping to teach

PHASE II: IMPLEMENTATION

1. Develop and offer pilot course
2. Evaluate and refine instruction
3. Establish formal course(s)

PHASE III: EXPANSION

1. Establish industrial-educational advisory group for C.A.D. instruction
2. Seek developmental grants and additional funding
3. Develop workshops and courses for industry, secondary and post-secondary schools

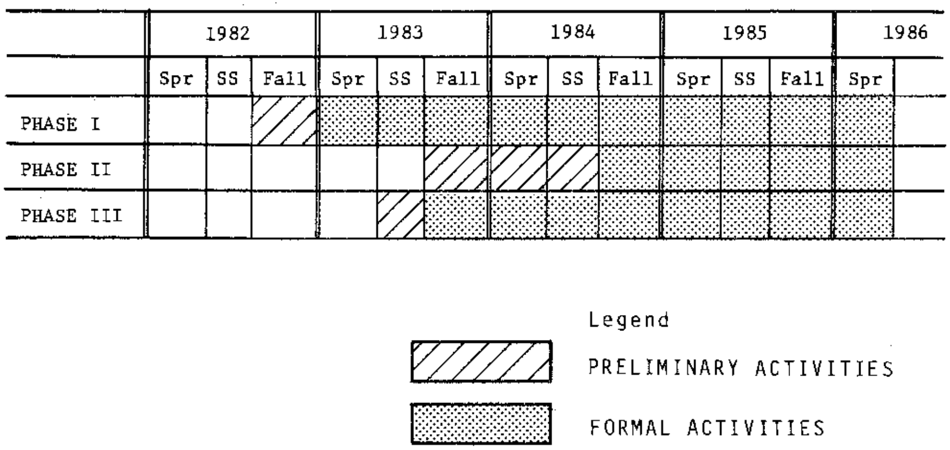
Model of Long Range Plan

Summary of Phases

PHASE I: PREPARATION - Developmental activities, goals and initial assessment

PHASE II: IMPLEMENTATION - Initial formal coursework and evaluation

PHASE III: EXPANSION - Service, research and extension work and other upgrading activities



	1982			1983			1984			1985			1986
	Spr	SS	Fall	Spr	SS	Fall	Spr	SS	Fall	Spr	SS	Fall	Spr
PHASE I			▨	░	░	░	░	░	░	░	░	░	░
PHASE II						▨	▨	▨	░	░	░	░	░
PHASE III					▨	░	░	░	░	░	░	░	░

Legend

▨ PRELIMINARY ACTIVITIES

░ FORMAL ACTIVITIES

"Time Frame Model"

highly complex and controversial challenge

PRELIMINARY INSTRUCTION GOALS:
AN INTRODUCTORY COURSE IN COMPUTER AIDED DRAWING
ENGINEERING GRAPHICS

1. Develop basic knowledge of the types and functions of hardware and peripheral components common to all computer aided drafting and design systems.

2. Develop a basic terminology for and knowledge of how data representing graphical information is input, stored, manipulated and output in the form of engineering drawings, graphs and charts.

3. Provide structured learning experiences for students to interact with the computer in producing lines, geometric constructions, symbols, dimensions, notes, multiview and pictorial drawings simulating the principles used on large industrial computer aided drawing and design systems.

4. Develop only those elementary programming and system operating skills required to acquaint students with the basic functions of a computer aided drafting and design system. Prior knowledge of a structured programming language would be useful, but should not be a prerequisite.

5. Expose students to developing accurate and conventionally correct multiview and pictorial drawings with the computer. In order to do this in the span of one course, freshmen and sophomore students must already be competent in the fundamentals of engineering drawing. Students electing this course will need GC 101, or an equivalent course, as a prerequisite.

6. Focus on principles common to all computer aided drafting and design systems, not just the operational abilities of one specific sytem.

7. Use microcomputer technology to the fullest extent possible to accomplish these goals for practical reasons of economy and availability.

Figure 1

EVALUATION GUIDELINE-CHECKLIST FOR SMALL CAD SYSTEMS
CONSIDERED FOR ENGINEERING GRAPHICS INSTRUCTION

Software Characteristics:

- Method of data input
- Method of 3-D display
- Multiple windows
- Scale capabilities
- Creation of angles
- Creation of polygons
- Creation of arcs and circles
- Hidden line methods
- Zoom features
- Method of cursor alignment
- Line types and menu
- Method of dimensioning
- Mirroring repetitive features
- Ability to define subshapes
- Method of editing
- Text on drawing screen
- Graphic and text dump to plotter
- Graphic and text dump to printer
- File storage and retrieval
- Overlay capabilities
- Logic of menu layout
- Clarity of documentation
- Shading and fill routines
- Linkage to other software
- Ease in modifying and upgrading

Hardware and Peripheral Device Characteristics:

- Type of processor(s)
- Type of operating system(s)
- Monitor (CRT) resolution
- Storage capabilities
- Ergonomic considerations
- Flexibility to add peripheral devices

Overall Considerations:

- Cost
- Networking capabilities for multiple stations
- Language support and availability
- Multipurpose uses
- Manufacturers support and assistance
- Initial installation and training
- Maintenance contracts

Figure 2

FRESHMAN GRAPHICS

ENGINEERING GRAPHICS/COMPUTER GRAPHICS
AN IOWA STATE INTERIM REPORT

Ronald D. Jenison
Freshman Engineering
Iowa State University

Introduction

Exactly two years ago, a freshman engineering classroom accommodating 48 students was equipped as an instructional computer graphics facility. Twenty-five terminals, including one for the instructor station, were available for computer lectures and interactive exercises. The terminals were Digital GIGI with BARCO monitors. A VAX 11/780 served as the host machine. The facility could handle 350 - 400 students per semester operating on an 8 a.m. - 5 p.m. class schedule. About 25 open laboratory hours were scheduled per week.

The Freshman Engineering Department immediately scheduled one class of the graphics/design course into the facility to experiment with new teaching techniques which would take advantage of computer graphics. At the 1981-82 Midyear Meeting of the EDGD (just prior to the first offering of the experimental graphics/design course), I proposed that engineering graphics instruction and computer graphics be merged for the benefit of engineering education. Utilization of computer graphics was expected to provide the following enhancements to graphics instruction:

1. Increased use of repetitive learning exercises which cannot be accomplished with time consuming instrument and freehand drawing techniques.

2. Use of drawing packages to improve the visualization and communication of 3-d geometries.

3. Increased coverage of graphics fundamentals.

4. Increased study of more complex objects including the function of an object in an overall assembly.

5. Integrating graphics instruction with modern design techniques incorporated in the CAD/CAM processes.

At the 1982-83 Midyear Meeting, I described a design component within our graphics course which took advantage of computer graphics to introduce the beginning engineering student to CAD. This design component involved establishing a correct geometry within defined constraints, visualizing the effect of control variables on potential solutions and the determination of a "best" solution according to a predetermined performance factor.

This interim report will focus on the results of the implementation of the experimental graphics/design course which makes extensive use of computer graphics. The coverage will be compared to that in the standard course. Changes in approach to certain graphical topics will be discussed. A more structured design component has been implemented and will be described. All of these experimental changes will be evaluated in light of course goals, student reactions and faculty impressions.

The Computer As a Tool

Approximately 10 of the 90 class hours in the experimental course, hereafter called Fr.E. 166X, are devoted to instruction and practice on the tools of graphics. Three and one-half (3.5) of these hours are used for instruction on the computer grapics hardware and software. The 10 hours compares to 11.5 hours spent on instruction in the use of the tools of graphics in the traditional course, called Fr.E. 165. Of the 11.5 hours, 1.5 hr. are spent on a computer graphics demonstration using the Tektronix 4051 and an oscillating linkage program. Since we have only one 4051, the hour and a half is used for a class of 24 students meaning that the hands-on exposure to computer graphics equipment is minimal for individual students.

The breakdown of time spent on instruction in the use of graphics is shown in Table 1.

	CLASS TIME* (HR)	
	165 (Trad.)	166X (Exp.)
Lettering	1.0	1.0
Sketching	4.5	3.0
Instruments	1.5	1.0
Scales	3.0	1.5
Computer Graphics	1.5 (Demo)	3.5

*Time includes instruction plus one or more supervised laboratory exercises.

TABLE 1. Instruction time for use of graphics tools

The 3.5 hours of instruction on the use of the computer is divided up as shown in Table 2. The GIGI is not a good stand-alone drawing system and we do not have a 2-d drawing package available for VAX. Thus we limit the experience to the basic drawing commands of vectors (lines), curves and text. One problem is assigned where the students create a "program" of graphics commands which draw a particular figure such as an isometric pictorial. The students must calculate the nodes and then write the commands which connect the nodes. Curves are normally included as shown in the example in Figure 1 (see next page).

COMPUTER INSTRUCTION	TIME (HR)
Introduction to VAX	0.5
Graphics commands: stand-alone graphics	1.5
2-d drawings	1.5

TABLE 2. Computer Instruction Time

Graphics Software

Three categories of software are available for student use. Nearly all of the software has been developed by Freshman Engineering faculty with programming assistance from undergraduate computer engineering students. At this time there are 23 graphics lessons, 7 interactive programs and 2 presentation graphics packages in our software library. The graphics lessons are made as slide showns with each slide appearing much like an overhead transparency made with colored pens. The lessons include graphics topics such as multiviews, sections, dimensioning as well as lessons that describe how to use interactive software packages. The instructor may control all of the student terminals in what is called the "slave" mode or may send the signals from the instructor terminal to overhead monitors while the students are working in pairs on the classroom terminals.

The seven interactive programs consist of 2 rotation programs, 2 problem exercises on multiview problems, a fastener selection problem, a bicubic patch program for surface generation and a design problem. There are also several small FORTRAN analysis programs used interactively in the design component of the course but as yet only tabular results and not graphical output are directly available from the program.

The two rotation programs permit the generation of wire frame diagrams from nodal input. The object generated can be rotated to simulate viewing from any spatial viewpoint. One of the programs operates with a split screen to allow simultaneous study from two viewing positions. A typical problem begins with a handout of the necessary orthographic views of an object from which the students construct the data base and then determine certain viewpoints and geometric properties of the lines and planes that outline the solid.

The desire to work from the computer data base in determining such geometric properties as true length of a line and true shape of a plane led to the use of vector methods in such computations. To accomplish these basic computations the vector cross product and dot product are introduced. Given two free vectors defined as A and B, then

$$|A \times B| = |A|\ |B|\ \sin\theta$$
$$A \cdot B = |A|\ |B|\ \cos\theta$$

where is the angle between the vectors assuming the lines of action of the vectors are made to intersect. A x B yields a vector normal to both A and B. This becomes the basis for viewing certain geometric properties on the screen. The expressions for the magnitude of the cross product and dot product provide quantitative measures of many geometric properties.

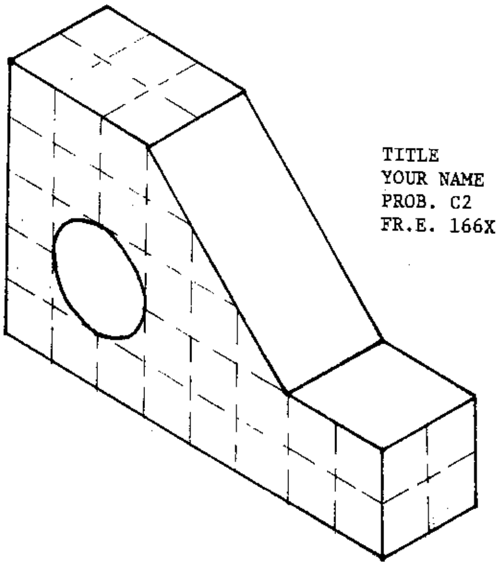


FIGURE 1. A 2-d drawing exercise

As a brief illustration of the use of vector methods, consider the object in Figure 2. The vectors are written in standard form using the unit vectors i,j,k. Some of the properties of the plane ABC are as follows:

1) True shape of ABC

viewpoint - The space coordinate obtained from the scalar components of the vector AC x BC.

area ABC - 0.5 $|AC \times BC|$

2) Angle θ

viewpoint - same as for true shape of ABC

magnitude - $\sin\theta$
$= |AC \times BC| \; / \; |AC||BC|$

3) Dihedral α , between ABC and horizontal plane containing BC.

viewpoint - The space coordinate obtained from the scalar components of the vector BC (line of intersection viewed as a point).

magnitude - Determine normal vectors to the two planes as

AC x BC and J.
$\sin\alpha = |(AC \times BC) \times j| \; / \; |AC \times BC|$

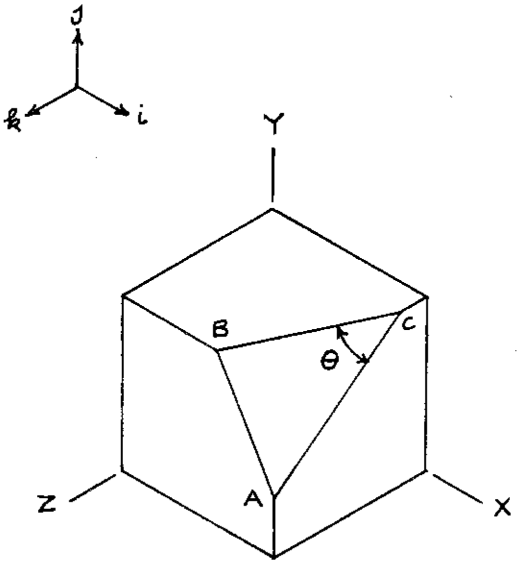


FIGURE 2. Representation of a 3-d object

The vectors AC and BC are determined from the end points of the respective lines.

Note that the true length of any of the lines AB, AC, BC is seen from the same viewpoint as the true shape of ABC. However, there are an infinite number of viewpoints for the true length of any line since the cross product of the line vector and any other vector will produce a line of sight perpendicular to the given line.

We were somewhat reluctant to try the vector approach. Most students had not yet been exposed to this in mathematics at the time they were taking the graphics course. However, the students took to the procedures easily. We now feel that this is an excellent example of mathematics in practical use and will actually serve as a motivator for the vector theory encountered in mathematics. The teaching staff for the experimental graphics course feels that understanding of 3-d geometries is actually improved by the combination of vector computation of geometric properties and simultaneous visualization of the object using one of the rotation programs as compared to traditional pencil and paper development of the solutions.

We are just beginning to develop interactive graphics lessons. A graduate student in Industrial Education, as part of his Masters Degree requirements, prepared two lessons for the GIGI which assist the student in interpreting drawings. The first, shown in Figure 3 is one of a set of 20 problems in which the student must choose the correct right profile for the given horizontal and front views. The student must choose until the right answer is obtained. Scores are tabulated within the computer program. The second, shown in Figure 4, requires the student to interactively construct a correct front view from the given horizontal and profile views. If the correct answer is not obtained, the problem is repainted on the screen with some hints. Continued incorrect answers will bring the correct solution to the screen for the student to study before going on to the next of the 20 problems.

One principal advantage of this type of exercise is that it provides the important repetitive drill in a reasonable amount of time. Another principal advantage is the instant feedback. Another might be that learning may take place without the frequently heard comment about the drudgery of drawing.

The bicubic patch program is used in the course as a capstone to the study of solids. Typical examples used are automobile fenders and outside mirror mountings, aircraft engine nacelles and approximations to mathematically defined shapes.

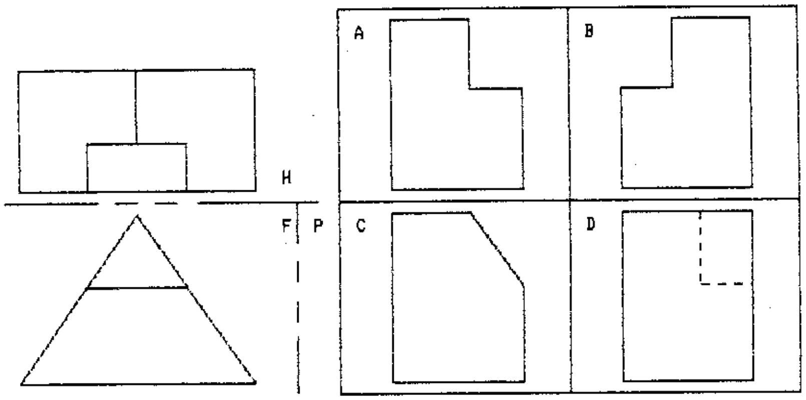


FIGURE 3. Interactive exercise on multiview representation

The two items of software referred to as presentation graphics packages are used to produce plots to illustrate relationships among design variables. EZGIGI is the Tektronix EZGRAPH programmed to run on the DEC GIGI terminal. RS/1 (Research System/1) is a package that has just been made available to us through the VAX system. It has capabilities for both 2-d and 3-d plots from data or mathematical functions as well as statistical capabilities. We are looking forward to developing the potential of this software package for future classes.

Design and Computer Graphics

In the design component of the experimental course we have deviated from the open-end team problem concept and have developed several types of problems which 1) introduce the design process with team problems and individual problems which require creative solutions and appropriate presentation ofd results, and 2) lend themselves to computer analysis and design techniques (CAD) for optimal solutions. The design component is one third (1 semester credit) of both Fr.E.165 and 166X but in the experimental sections we attempt to maximize the use of graphics in the design component by controlling the problems the students are assigned. Thus the two segments of the course, graphics and design, are clearly related and the dependence of design on graphics is emphasized. In addition, the students have the opportunity to gain additional practice in the graphics areas they have studied.

During the fall semester, 1983, the experimental course required four design problems. The first was an individual effort which required the students to begin with a general problem definition, establish reasonable criteria and constraints and develop one alternative solution to the problem. For the second

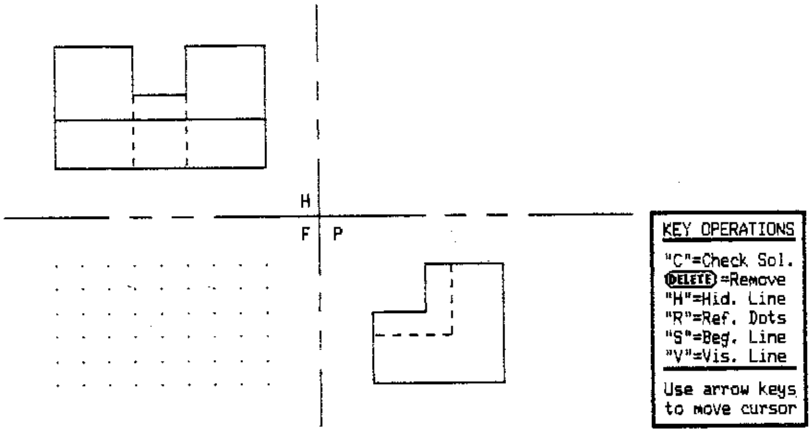
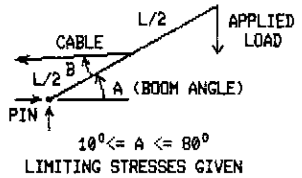


FIGURE 4. Missing views to be generated by user

DESIGN BY ANALYSIS - CRANE PROBLEM



1. MINIMUM CABLE DIAMETER REQUIRED
2. MINIMUM PIN DIAMETER REQUIRED

FIGURE 5. Problem conditions for the crane problem

design problem, the students were placed in teams of four. They pooled their efforts from the first problem, redefined the problem, criteria and constraints if they desired, generated several potential solutions, analyzed these solutions in light of the criteria and constraints, and selected the best solution. An oral presentation of the efforts on problem two was required. These two problems were intended to develop in each student an appreciation of a design process. No computer work was involved.

Problem three, called the crane problem, involved design by analysis. A configuration for a crane boom was given, the equations of equilibrium were established and the students determined the minimum pin and cable diameters required. Appropriate factors of safety and stresses were given. Figure 5 shows the problem condition and Figure 6 gives the results for one set of conditions. Note the use of a plotting package, in this case RS/1, to produce the graphical result.

The students are required to solve the equations for one set of conditions using a calculator. Then they are allowed to use an analyzer program which prompts the user for the initial conditions and then prints out values of the loads for the range of boom angle required. This is where the computer has a tremendous impact on design education. In a very short time period, the student, using the analyzer program and plotting package can generate a host of load profiles for different conditions which "stretch" the solution space for the original problem. For example, what if the cable is attached at a different point along the boom? What if boom mass is not neglected? What if the boom angle = 0? Without the assistance of an analyzer program and computer graphics, this entire series of problems would never be investigated. The student/computer pair can function as a productive design team very early in the engineering education program.

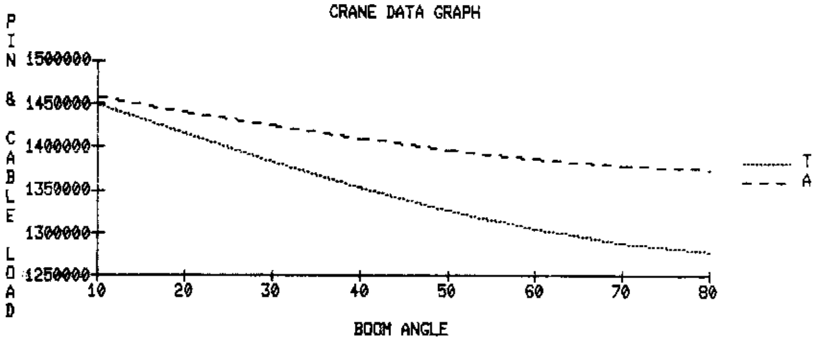


FIGURE 6. Results from crane analysis

The fourth problem is the three-point tractor hitch that has been previously documented.

Summary

I will refer back to the "expected" enhancements and relate these to the "realized" enhancements during the past two years.

1. We have only begun to develop the computer aided learning exercises. The software effort needed is tremendous. We will continue to develop small segments of the course into interactive lessons and then verify in the classroom before expanding the effort in a particular segment.

2. We will continue to use the 3-d rotation packages and the surface routine. We will not use a 2-d drawing package of the size found on the market today. There is not enough time in the course to make use of such a package.

3. As of now, we have not increased coverage of graphics fundamentals. We feel that the coverage is more thorough now in the areas we do cover. With more experience in the course, we feel we will eventually add additional material such as clearances and connectors and perhaps intersections as the software packages are developed.

4. We are able to work with reasonably complex wire frame representations of objects. As our 3-d software is expanded we can continue to work with more realistic models.

5. We have been very successful in integrating the instruction with the design techniques employed by CAD/CAM processes. The students leave the course with a definite appreciation of how and where graphics fits into the engineering world. The required use of graphics in the design problems reinforces the appreciation.

The Future

The Freshman Engineering Department is aggressively seeking funds for expansion of its computer graphics facilities. We have secured one grant for about $250,000 which will be used to purchase a central processor in the VAX 11/780 class. We are also writing proposals to industry and funding agencies for equipment to upgrade a total of six classrooms so that all freshmen will have the same exposure to computer graphics. The estimated cost of the total project is about $1.5 million. This would include networking and terminals in all faculty and staff offices as well as terminals for advisers. We are looking at a 3-5 year time frame to accomplish this expansion.

Recommendations

If you are struggling with the impact of computer graphics instruction on your graphics courses as we are, here are some recommendations that we have formulated from our experience.

1. Do not hesitate to challenge students. Most of them have some kind of computer experience coming in and the remainder are eager to learn. There is a difference between assigning work which requires hours of drawing time and little thinking to a well designed problem which requires appropriate graphics but uses other tools of engineering, such as the computer, to generate the best solution (and maximize student learning) in the time available.

2. Experiment with non-traditional approaches. One of our first areas of concern when we started was that the computer lectures and proposed interactive problems looked just like the existing lectures and problems except that they were depicted on a computer screen. For example, one of our programming hangups was how to have the student create a hinge line on the screen, line up the projection and complete the view. What we were doing was to simply transfer the pencil and paper procedures to the screen. Once we understood this, the vector approach in conjunction with our rotation programs was the logical solution.

3. Have a strong faculty development program. Unless all faculty get the opportunity to experience the new approach there will be some resistance simply because of the unknown factors. At this time 25 percent of our permanent faculty has taught the course. Because of the team teaching potential plus the doubling of the number of experimental sections next fall, all permanent faculty will be offered the opportunity to teach the course by the spring of 1985. The final content of the course for the next catalog will then be a decision by informed faculty.

4. Be responsive to the engineering departments you serve. We constantly remind ourselves that we are a service department and must listen to departmental needs. We feel we are responding to the graphics needs expressed in the departments with the content of the experimental course. We are watching the development of CAD in many programs and the increased use of computer graphic in instruction. Some of this development is based on the success Freshman Engineering has had with its computer graphics facility.

Bibliography

1. Jenison, R.D. and Bernhard, R.J. "The First Step Toward CAD - A Freshman Design Component," Engineering Design Graphics Journal, Vol 47, Number 1, 1983.

2. Jenison, R.D. and Vogel, J.M. "Engineering Graphics Instruction and Computer Graphics - A Necessary Merger," Engineering Design Graphics Journal, Vol. 46, Number 1, 1982.

3. Dahl, Ronald. Unpublished research on interactive software for engineering graphics, 1983.

COMPUTER DRAWING

THE ARC SUBROUTINE EXERCISE

William J. Kolomyjec, Ph.D., M.F.A.
Department of Engineering Graphics
The Ohio State University

Introduction

One exercise that seems to work particularly well with freshman engineering students in an introductory computer graphics course involves producing "single view" drawings of objects with curvilinear shape. This task requires the student to understand a fairly versatile graphic algorithm, encode it (in FORTRAN, BASIC or whatever) and use it to generate a drawing or display consisting of circular curves and straight lines. This article will present: a generalized arc drawing algorithm, a corresponding logic diagram, and an example. The material would be presented to the student in much the same way. However, we will go one step further and present a complete listing of the program in Applesoft(TM) BASIC at the article's conclusion.

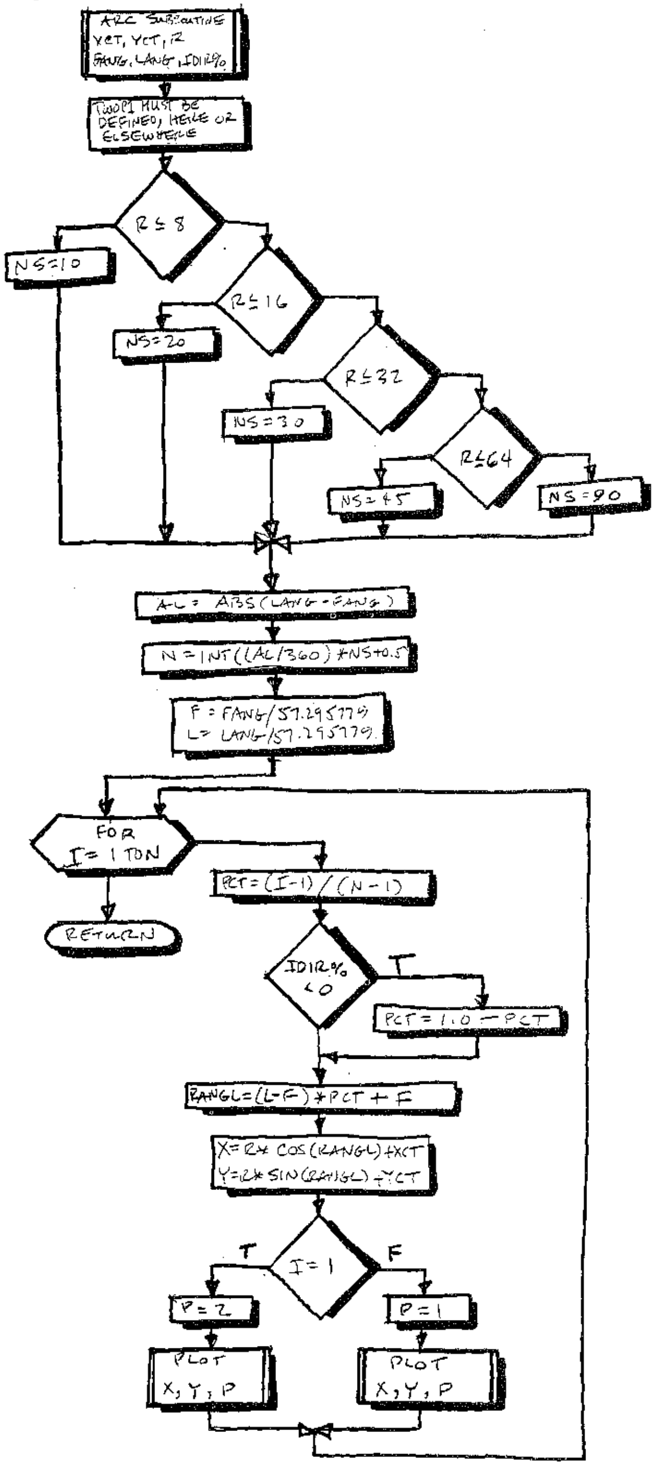
Arc Subroutine

If one comprehensive subroutine was required relative to drawing regular curves (circles and arcs), then it would be the general arc subroutine, entitled the ARCSUB. Not only will the arc subroutine draw any arc, it will draw any circle. ARCSUB can do variable sampling based on a given radius size and allows the direction in which it is to be drawn (clockwise or counter-clockwise) to be specified. This latter feature is significant in that it allows continuous path drawing similar to "tool path" applications in industry.

The given general routine for drawing arcs and circles uses the following parameters:

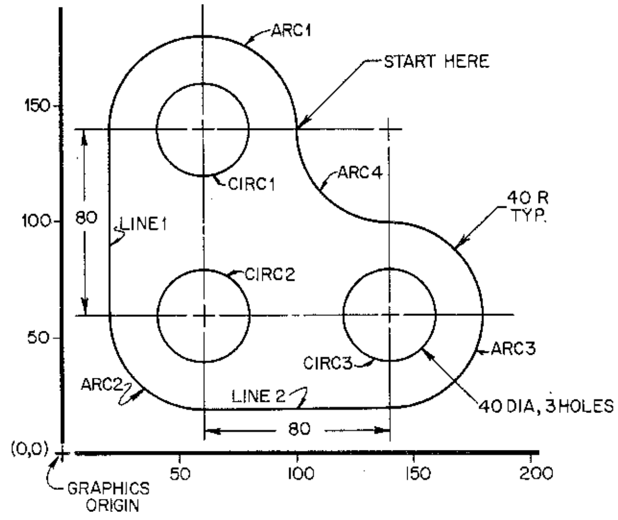
XCT,	X-coord. of center
YCT,	Y-coord. of center
R,	radius (screen units)
FANG,	first or beginning angle (degrees)
LANG,	last or final angle (degrees)
IDIR%,	direction flag (integer variable)

To begin, a few assumptions need to be made. First, the initial or starting point of the arc is always MOVE'd to, and a DRAW is used for subsequent points (the pen could be controlled by an additional parameter if so desired). Second, FANG must ALWAYS be less than LANG. This is a critical requirement for the correct operation of the algorithm. Lastly, the direction flag parameter IDIR%, will be greater than or equal to zero: +1 (positive) for counter-clockwise movement, and -1 (negative) for clockwise movement. Carefully inspect the flowchart presented below which illustrates the logic of generalized arc drawing subroutine.



Pivot Link Example

An example employing ARCSUB is the drawing of a "mechanical" component, a metal stamping called a Pivot Link. See the layout sketch in Figure 1. The task at hand is to generate the drawing of this object on the display screen. (Note: to completely describe a stamping, only a single view is required.) In the sketch, axes are included as well as significant dimensions (in screen units) and appropriate annotation. Annotation includes: the starting location, numerical data for drawing arcs, lines, and holes (circles); also, an initial drawing (connectivity) sequence is indicated by numbering the arcs as they are encountered.



NOTE: DIMENSIONS ARE IN SCREEN UNITS

FIGURE 1

The Need for Planning

Experience has repeatedly shown that before programming a curvilinear shape, such as the Pivot Link, it is a good idea that the student do some preliminary thinking. Construction of a layout sketch similar to Figure 1 is a necessary prerequisite for formulating a sequence of operations or a database. Making a rough sketch organizes thinking and saves hours of terminal time. This is particularly important when several students are sharing a microcomputer system or timesharing graphics terminal. A student should never begin a terminal session that involves drawing a specific image with graphics algorithms without previously organizing their databases.

a generalized arc algorithm

A preliminary database for the Pivot Link is presented below in tabular form:

SHAPE	XCT	YCT	R	FANG	LANG	IDIR%
ARC1	60	140	40	0	180	1
LINE 1						
ARC2	60	60	40	180	270	1
LINE 2						
ARC3	140	60	40	270	450	1
ARC4	140	140	40	180	270	-1
CIRC1	60	140	20	0	360	1
CIRC2	60	60	20	0	360	1
CIRC3	140	60	-20	0	360	1

Table 1: Preliminary database for Pivot Link.

The Pivot Link database is almost complete. There are two line segments which must be drawn, one between ARC1 and ARC2, and one between ARC2 and ARC3. Basically, the pen is dragged from the end of one arc to the beginning of the next arc. Look to the listing to see how this is done. Notice ARC3 has a FANG angle greater than 360, i.e., 450. This must be done to satisfy one of the algorithm requirements (assumptions), namely, FANG > LANG. Also, notice that all arc directions are counterclockwise except for ARC4 which must be drawn clockwise to complete the outline. The computer generated output of this program is given as Figure 2.

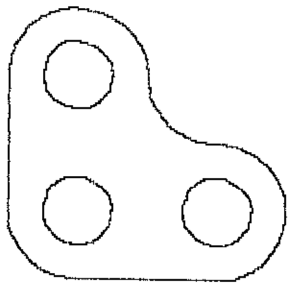


FIGURE 2

Conclusion and Challenge

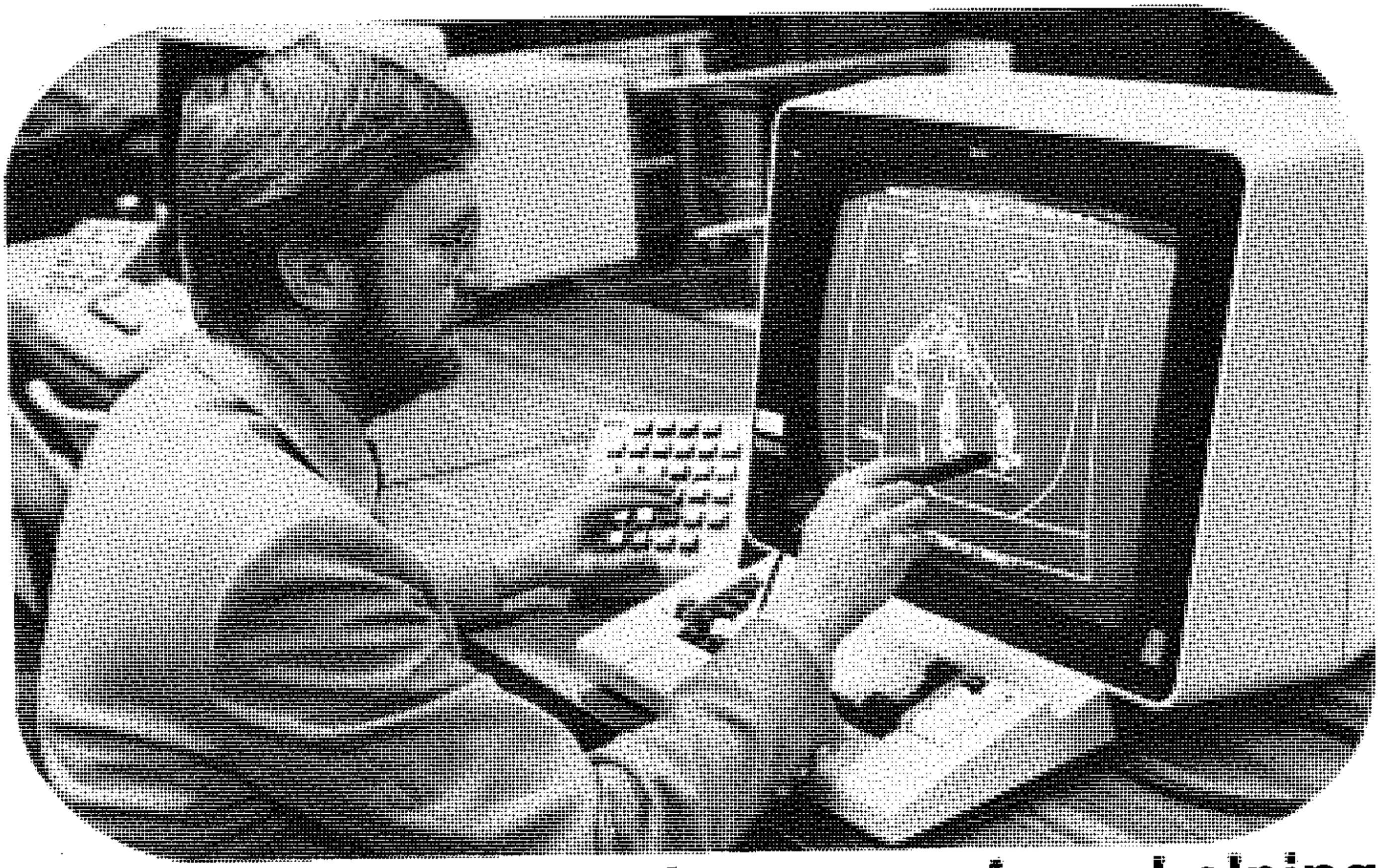
We have found this to be an interesting assignment that motivates students. But why should they have all the fun? We wish to share the experience with our readers. We're willing to bet that most of you have access to a computer system with computer graphic capabilities. To make this more of a challenge you will find several problems to be drawn on your favorite computer graphics sytem, be it Apple, IBM PC or VAX, adorning the cover of this issue of the Engineering Design Graphics Journal. We invite you to implement the arc subroutine and produce the curvilinear drawing of your choice from the selection provided. Experience first hand the virtue of this exercise.

```
100  REM  <<<<< PROGRAM PIVOT LINK >>>>>
105  REM
110  REM  COPYRIGHT 1984 W.J.KOLOMYJEC
120  REM
130  HGR2 : HCOLOR= 3: REM  ENTER GRAPHICS
MODE
140  REM  ARC1
150 XCT = 60:YCT = 140:R = 40:FANG = 0:LANG
 = 180:IDIR% = 1: GOSUB 1500
160  REM  LINE1
170 X = 20:Y = 60:P = 1: GOSUB 1000
180  REM  ARC2
190 YCT = 60:FANG = 180:LANG = 270: GOSUB 1
500
200  REM  LINE2
210 X = 140:Y = 20:P = 1: GOSUB 1000
220  REM  ARC3
230 XCT = 140:FANG = 270:LANG = 450: GOSUB
1500
240  REM  ARC4
250 YCT = 140:FANG = 180:LANG = 270:IDIR% =
  - 1: GOSUB 1500
260  REM  HOLE1
270 XCT = 60:YCT = 140:R = 20:FANG = 0:LANG
 = 360:IDIR% = 1: GOSUB 1500
280  REM  HOLE2
290 YCT = 60: GOSUB 1500
300  REM  HOLE3
310 XCT = 140: GOSUB 1500
900  INPUT A$: TEXT : REM   TERMINATE GRAPH
ICS MODE
999  END


1000  REM  <<<<< PLOTTING SUBROUTINE >>>>>
1010  REM  PARAMETERS: X,Y AND P
1020  REM  P VALUE IS BEAM CONTROL: 1=DRAW,
 2=MOVE
1030  REM  FLIP Y COORD. AND CORRECT ASPECT
 RATIO (0.881)
1040  REM  PLOT AREA: 0<=X<=279,0<=Y<=217
1050 Y9 = 192 - (Y * 0.881 + 0.5)
1060  IF P = 1 THEN  GOTO 1100
1070  IF P <  > 2 THEN  PRINT "PEN ERROR":
STOP
1080  HPLOT X,Y9
1090  RETURN
1100  HPLOT  TO X,Y9
1110  RETURN
1500  REM  <<<<< ARCSUB >>>>>
1510  REM
1520  REM  PARAMETERS:
1530  REM       XCT- X-COORD OF CENTER
1540  REM       YCT- Y-COORD OF CENTER
1550  REM       R  - RADIUS
1560  REM       FANG - FIRST OR BEGINNING AN
GLE
1570  REM       LANG - LAST OR ENDING ANGLE
1580  REM       IDIR% - PLOT DIRECTION: 1=CC
W, -1=CW
1590  REM
1600  REM  USE RADIUS DEPENDANT SAMPLING
1610  IF R <  = 8 THEN NS = 10: GOTO 1660
1620  IF R <  = 16 THEN NS = 20: GOTO 1660
1630  IF R <  = 32 THEN NS = 30: GOTO 1660
1640  IF R <  = 64 THEN NS = 45: GOTO 1660
1650 NS = 90
1660  REM  FIND ARC LENGTH
1670 AL =  ABS (LANG - FANG)
1680  REM  DETERMINE SAMPLING RATE BASED ON
 AL AND NS
```

```
1690 N =  INT ((AL / 360) * NS + 0.5)
1700 F = FANG / 57.295779
1710 L = LANG / 57.295779
1720  FOR I = 1 TO N
1730 PCT = (I - 1) / (N - 1)
1740  REM   PLOT ARC IN DIRECTON IDIR%
1750  IF IDIR% < 0 THEN PCT = 1.0 - PCT
1760 RANGL = (L - F) * PCT + F
1770  REM  CALCULATE X & Y ADD IN CENTER
1780 X = R *  COS (RANGL) + XCT
1790 Y = R *  SIN (RANGL) + YCT
1800  IF I = 1 THEN 1830
1810 P = 1: GOSUB 1000
1820  GOTO 1840
1830 P = 2: GOSUB 1000
1840  NEXT I
1850  RETURN
```

Share Your Expertise ... Expand Your Horizons



Enjoy the rewards that come from helping to shape a new generation of experts.

If you have had experience in either **engineering graphics** or **computer-aided design**, the career opportunity you've been waiting for may be at Michigan Technological University.

We are one of the largest engineering universities in the nation. And our computer-aided design/computer-aided manufacturing facilities are among the best.

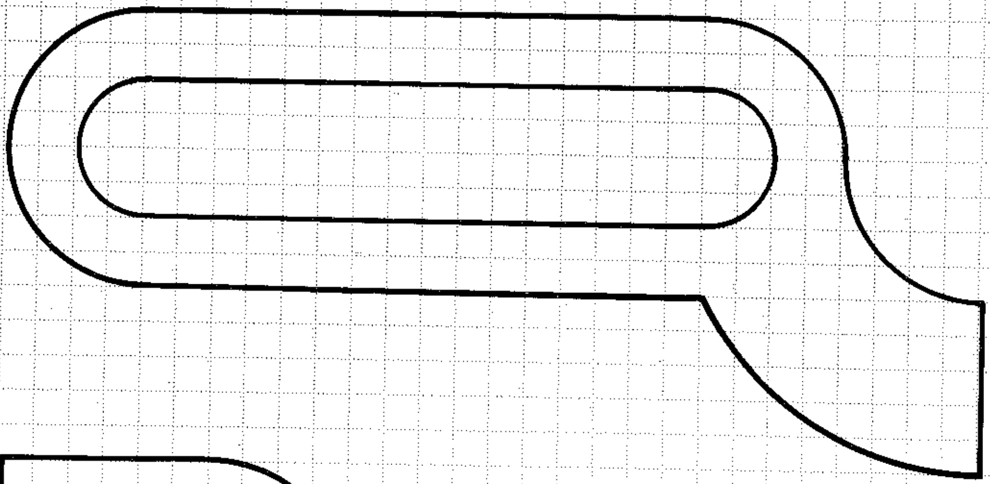
A master's degree is required, but your years of experience are most important. Send a resume.

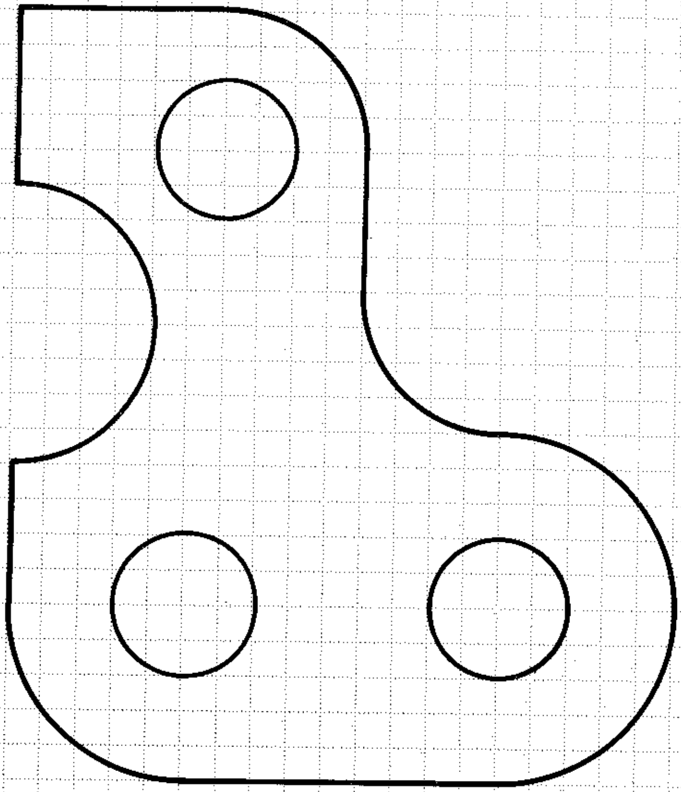
Write to:

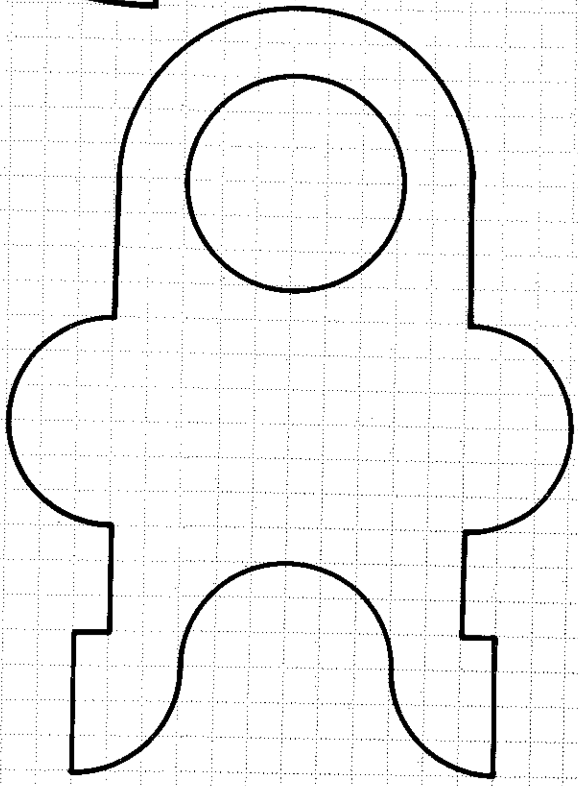
Dr. Harold W. Lord, Chairman
Department of Mechanical Engineering-Engineering Mechanics
Michigan Technological University
Houghton, Michigan 49931

Michigan Technological University is an equal opportunity educational institution/equal opportunity employer.

ENGINEERING DESIGN GRAPHICS JOURNAL
CIRCULATION MANAGER
DEPARTMENT OF ENGINEERING GRAPHICS
THE OHIO STATE UNIVERSITY
2070 NEIL AVENUE COLUMBUS,OH 43210
(address correction requested)







C&R ☐

SCALE

NAME

INSTR

TABLE

HOUR

DWG

AMERICAN ASSOCIATION FOR ENGINEERING EDUCATION