# THE ENGINEERING DESIGN GRAPHICS Journal

Autumn 1987 Volume 51 Number 3

ENGINEERING DESIGN GRAPHICS DIVISION

AMERICAN SOCIETY FOR ENGINEERING EDUCATION


- The Past, Present, and Future of Graphics
- Visual Propositions for Integrating CADD and TRAD
- Displaying a Cylinder
- 3-D Strategies
- A CADD Lab at Wisconsin-Milwaukee
- Industrial Strength CADD in Canada

ISSN 0046-2012

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EDGD MIDYEAR MEETINGS

1987 LOUISVILLE hosted by The University of Louisville

1988 EVANSVILLE hosted by The University of Southern Indiana

1989 TUSCALOOSA hosted by The University of Alabama

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## OBJECTIVES OF THE JOURNAL

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 the fundamentals of engineering graphics education and graphic technology.

2. To stimulate the preparation of articles and papers on topics of interest to its membership.

3. To encourage teachers of graphics to experiment with and test appropriate teaching techniques and topics to further improve the quality and modernization of instruction and courses.

4. To encourage research, development, and refinement of theory and application of engineering graphics for understanding and practice.

## DEADLINES

The following are deadlines for submission of articles, announcements, and advertising: FALL-September 15; WINTER-December 1; SPRING-February 1.

## STYLE GUIDE FOR JOURNAL AUTHORS

1. All copy is to be typed, double spaced, on one side only using white paper with black ribbon in standard English. Dot matrix copy is acceptable if high quality.

2. All pages of the manuscript are to be numbered consecutively.

3. THREE copies of each manuscript are required.

4. Refer to all graphics, diagrams, photographs, or illustrations in your text as Figure 1, Table 1, etc. Be sure to identify all material. Illustrations cannot be redrawn. Accordingly, be sure that all linework is black and sharply drawn and that text is large enough to be legible when reduced to 4.25" in width. Good quality photocopies of sharply drawn illustrations are acceptable.

5. Submit a recent, glossy black and white photograph (head to chest). Make sure that your name and address are on the back. Photographs, illustrations or other submitted materials cannot be returned without postage prepaid.

6. The editorial staff will edit manuscripts for publication after return from the board of review. Galley proofs cannot be returned for author approval. Authors are encouraged to seek editorial comment from their colleagues before submission.

7. Enclose all material, unfolded, in a large envelope. Use heavy cardboard to prevent bending.

Continued inside back cover.

THE ENGINEERING DESIGN GRAPHICS

# Journal

Volume 51 Number 3

ENGINEERING DESIGN GRAPHICS DIVISION

AMERICAN SOCIETY FOR ENGINEERING EDUCATION



## DEPARTMENTS



## FEATURES

## FROM THE DESK OF THE EDITOR

### We Goofed!

To the readership of the EDGJ, I apologize for the cover of the Spring issue. A month or so after it appeared with the Winter issue's cover mistakenly used, the editor received a copy of the correct cover and an apology from the printer. To correct this, we have published the correct cover on page 7 of this issue, blank on the back side. This allows you remove the page from this issue and affix it to spring's issue and have the correct cover. The EDGJ has never been afforded the luxury of reviewing proof pages before publication. It is just one of those things that may happen when one does not have complete control over the publishing process.

### Hats Off

For those of you who went to Reno and attended the ASEE Annual Conference, a word. Many didn't realize that the conference almost didn't come off, and that only by the super efforts of Cal Poly faculty and students did the thing go on. It should discourage ASEE from awarding the conference to schools who simply don't have the logistical support to organize and run the show—no matter how attractive the location.

### Not a Slight

Two letters to the editor in this issue deal with the notification in Volume 51 Number 1 of the passing of Steven A. Coons. It*was* unfortunate that the EDGJ did not note his death in a more timely fashion, and for that, our deepest regrets.. It is also true that Steve was a pioneer in what has developed into the greatest change in the tools with which engineers do their jobs. Yet it is not suprising that the computer graphics field recognized his contributions to a greater extent than have we. There is no history of computer graphics before, say, 1968. By that time, Engineering Graphics (nay Engineering Drawing) had seen the passing of hundreds of leaders in engineering graphics education, some who were giants, who by their sheer will carved out an entire discipline. Can any of us cite the pioneers of drafting machines, or technical pens, or polyester film?

### A Call for Curriculum

Possibly the time is ripe for considering a national curriculum project in Engineering Graphics. Surely between Arizona State, Iowa State, Illinois, Purdue, Ohio State, and Penn State (to name a few) the institutional support can be found for such a project. And what about industrial sponsors? Don't the major equipment manufacturers have a vested interest in what we do? Other disciplines have solved this long ago. Why can't we?

### Reader's Survey

To those who returned the reader's survey printed in the past issue, I thank you. The response, however, was such that the opportunity to respond will again be presented to the readership at the ASEE/EDGD Mid-Year Meeting in Louisville. By the time you read this, the EDGJ should have your response.

# chairman

## A MESSAGE FROM THE DIVISION CHAIRMAN

While I was recently updating my Curriculum Vitae for the annual departmental review process, I found my ASEE activities were tucked away at the end under the University prescribed heading of SERVICE. Indeed, this activity does frequently seem to be at the tail-end of the triumvirate of academic responsibilities: teaching, research, and SERVICE. Yet, this heading of SERVICE is an excellent description of the way I view the Engineering Design Graphics Division. During my past eight years as a member of the EDGD, I have witnessed the dedicated SERVICE of many colleagues who have contributed to our central goal of advancing engineering graphics and computer graphics education. The SERVICE of these individuals, whom to me bear semblance of a family, has led to a Division that is vibrant and that continues to display a leadership role in ASEE. I am privileged to now SERVE this "family" as the 1987/88 chairman.

The division SERVES the membership in many ways to enrich the professional status of engineering graphics education.

1. Our Division in one of only a few in ASEE that holds its own annual Mid-year meeting. The paper sessions present a concise forum for hearing on the latest developments in engineering graphics and computer graphics. Also, the collegial spirit of the meeting cannot be matched, as you meet new friends and discuss common professional concerns.

2. The Division is taking steps to expand its visibility within ASEE. More active recruiting at the Annual Conference has been initiated to reflect our current strength in the area of computer graphics. We are taking steps to enhance the ABET position on engineering graphics, and perhaps to ultimately obtain a more positive clause in the accreditation guidelines.

3. The EDG Journal continues to SERVE as the main communication network amongst the membership. A formal technical review process, initiated in 1986, is emerging from its infancy. We have a commitment to make the Journal a high-quality archival publication, and to this end, we have initiated a reader survey and established an ad hoc committee to study the Journal.

4. The Creative Engineering Design and Display competition is one of our major contributions to the Annual Conference. The Division continues to foster this event, and we are working on ways to encourage and reward participation at all class levels.

5. The Division continues to support the International Conferences on Engineering Graphics and Descriptive Geometry, with the third of these being held in Vienna next Summer 1988.

These are just some of the ways the EDG is SERVING the engineering graphics profession this coming year. Remember, though, that a strong society can only exist if it has strong support from the individual membership. Do you wish to participate in this SERVICE?

Please feel free to write me about any questions, concerns or offers to SERVE the Division.

Ronald E. Barr
Mechanical Engineering
University of Texas at Austin
Austin, Texas 78712

Comment

# Oddities in Graphics

W.G.G. Blakney
Associate Professor
Industrial Engineering
Auburn University

A latecomer to graphics could be very curious about things recommended in graphics that have no apparent necessity. If reasons exist, they must be (1) too obvious to state or (2) done so long ago that no one bothers to mention them any more. One need not be a latecomer to be curious about the recommendations and practices coming from the computer version of graphics.

**1. Orthographic Multiviews**

Is it necessary to have what is called an alternate view in multiview othographics? The theory of an imaginary glass box, every side of which hinges on the frontal plane (except the rear which might hinge elsewhere) is perfectly reasonable and quite understandable. While front, top, and right side views are preferred, front, top, and left are accepted if visibility is helped. Why then should anyone resist front, right, and bottom? Why change the theory (and the object) around only so as to refer to the front, top, and right side views?

The only answer that seems likely is that people can't visualize bottoms as well as tops. Not so. It is just as easy to visualize from the bottom as to think of a contorted box that places the object in an unexpected position.

**2. Alphabet of Lines**

Classical graphics has line types known by names adopted by "all" literature on graphics. The fact that someone might prefer and wonder why *visible* lines were not called object lines would not set them on a mission to change a rather reasonable term. Then in recent years, computers have been applied in ways that have been deemed "user friendly" —as we are reminded. Surely any user friendly system would adopt the language of the discipline to which it is trying to be friendly.

Unfortunately, the system I work on (ACAD) has a new type of line called a *continuous* line. It is not hard to understand the temptation the efficient world of computers feels for straightening out the inefficiencies of the old world. But there need not be a proliferation of new terms when there exists words which already conveys its sense of *use*.

**3. Plotting**

The equivalent operation with computers to drawing is plotting. In drawing, one of the paramount requirements is to draw at some workable scale. In plotting, a newcomer likely gets the impression that scale is of little importance. Certainly in a world of dimensioned drawings, that position is easily defended. But if plotting is to be friendly to old graphics people, scale should be as easily achieved as are dimensions.

Like everything else, its easy if you know how! But what a surprise awaits if one chooses units, size of paper, and scale and then plots, only to find that the drawing is not to scale! The non-computer oriented user is amazed to find a border drawn on the *very edge* of the paper, not where the borders are normally drawn. How odd that the computer would not set the border a reasonable distance from the edge. Stranger still is the fact that if one wishes to plot (with ACAD) at a scale of 1:2, one chooses a scale of *2 Times*, not *half*, when setting up the plot.

**4. Random**

Why would a textbook offer this drawing as the proper way to dimension an item if accuracy is needed? It appears to be a marvelous example of the

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AMERICAN SOCIETY FOR ENGINEERING EDUCATION

# DISTINGUISHED SERVICE AWARD TO CLARENCE HALL

## LSU Professor active in education

The 1987 Engineering Design Graphics Division Distinguished Service award was awarded to **Clarence Hall** at the awards banquet June 25, 1987, in Reno, Nevada. Clarence was unfortunately unable to attend but sent his acceptance by way of Amogene DeVaney. The entire membership of the Division congratulates Clarence on this, the most prestigious recognition of the Engineering Design Graphics Division.

Professor Hall began his career teaching in Texas in 1941 where he continues to hold Principal and Superintendent credentials. He taught in the Knoxville evening program from 1947-1951. A long career in Engineering Graphics at Louisiana State University followed including service for 13 years as chairman of the department. Professor Hall retired in 1985, yet has remained active with gifted and talented students through the Continuing Education Division at LSU, and in religious education with a seat on the Board of Regents of the Alabama Christian School of Religion in Montgomery, Alabama.

Clarence Hall served the Engineering Design Graphics Division in several capacities throughout his career: Advertising Manager of The Journal, Vice Chairman of the Division, and Chairman of the Division in 1977.

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# COMMENT

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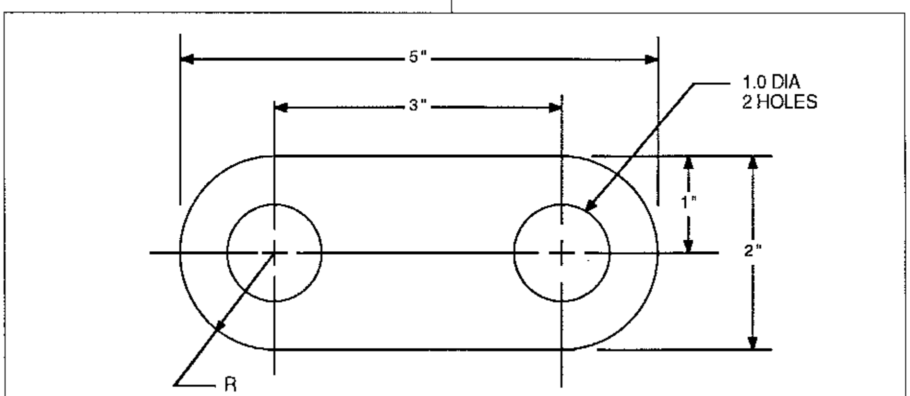


redundancy we are to avoid. Why would a textbook cite orthographic conventions in a chapter on sectioning? Students are then led to believe that conventions are peculiar to sections. Why talk at all about the contour principle of dimensioning if cylinders are dimensioned differently than are holes? What are supervisors in industry doing with computer plots that so easily disregard recommendations for the proper application of hidden lines? How much time do they think their computer drafter should take in controlling line weights?

**5. Conclusion**

The questions raised here could easily be taken to be criticisms of the computer approach to graphics. Rather, they should be taken in the spirit of a *wish list* that the computer world might solicit from the graphics world. The computer world is to be congratulated on having such confidence that they would invest the resources to provide a way of removing some of the tedium of manual drawing, and to have done it so thoroughly.

## IN MEMORIUM

From Rollie Jenison:

"The Engineering Design Graphics Division is saddened at the passing of our distinguished colleague, Dr. Ralph T. Northrup. We extend Sympathy to members of his family.

Although I did not know Ralph personally, I have learned that he served the Division for many years and was the recipient of our highest honor, the Distinguished Service Award, in 1965. He had significant impact on the development and advancement of graphics in engineering education."

# EDGD Marks Contributions of Alexander Levens

Alexander S. Levens, a faculty member at Berkeley for 26 years and Assistant Dean of Students from 1961-62, was an authority on engineering graphics. He was professor emeritus of mechanical engineering at Berkeley from 1967 until his death (December 10, 1986).

He was the author of five textbooks on engineering graphics and descriptive geometry, all widely used internationally and regarded as classics in their field.

In addition to his textbooks, Professor Levens wrote a number of workbooks for engineering drawing classes and was the author of more than 100 technical papers.

Professor Levens was noted as an outstanding teacher and a friend to his students. As one colleague noted, *"His painstaking preparation for class, his masterful presentation of spatial relationships, and the relevance of his classroom work to the engineering world were always sources of inspiration and guidance to his students and to staff members who worked with him."*

Noting that several industrial firms invited Professor Levens to conduct classes for their engineers, another colleague said, *"In the nearly 24 years that I have known him, I have never ceased to marvel at his superb skill as a teacher, his imaginative approach to making graphics an exciting course for students, and his ingenuity in constantly revising course material to make it relevant to the times."*

Professor Levens received the Western Electric Fund Award for engineering instruction presented by the American Society for Engineering Education. He was a director of the society for five years, was active on several of its committees, and was instrumental in organizing many ASEE workshops on teaching engineering graphics. Born in Minneapolis, he graduated from the University of Minnesota in 1922 and earned the master's degree in civil engineering there in 1924. He also received a professional degree in civil engineering from that university.

See Levens, Page 11

# Distinguished

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He also was instrumental in initiating the first International Conference on Engineering Graphics in 1978—held in Vancouver, British Columbia. He continued his international activity when he contributed to the 1984 International Conference Proceedings with a paper validating Wellman's skew line connector theorum. An early interest of his, namely the establishment of engineering curricula in high school, has seen a return to popularity. His 1963 proposal, brought before the world engineering education community at Illinois Institute of Technology in 1965, has seen a recent resurgence with summer engineering courses for talented high school juniors. Clarence Hall continues his life-long interest in graphics and descriptive geometry.

# Levens

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Professor Levens taught at the University of Minnesota's College of Engineering from 1922 to 1941. He joined the mechanical engineering faculty at UC Berkeley in 1941 and retired in 1967.

At Berkeley he developed research programs that used graphics to help solve human movement problems (including the development of prosthetic devices), pioneered computer-aided design of nomograms (charts of scaled lines or curves to aid in design calculations), and applied projective geometry to convert rectangular cartesian coordinate charts to alignment charts. Graphical mathematics and methods developed by Professor Levens are used extensively by engineers in many disciplines.

After his retirement, he served as a consultant to industry and government, including advising on computer graphics.

He was also a visiting professor at Imperial College in London and the Technion Institute in Haifa, Israel.

Professor Levens and his wife, Ethel, had a son, David Levens of Santa Clara, and a daughter, Naomi Steinhardt, of Los Angeles.

In the spring of 1986, after his wife's death, Professor Levens established an endowment fund in her memory to reward promising mechanical engineering students at the University of California at Berkeley. Following his death at the age of 86, a trust he had established renamed the fund the Alexander and Ethel Levens Memorial Mechanical Engineering Awards Endowment.

The fund grants an award to a lower division student who has excelled in engineering graphics and to an upper division student who has done outstanding work in mechanical design.

division

## Klaus Kroner to Represent EDGD

### Distinguished Service Recipient in Austria

Klaus Kroner, Professor of Engineering at the University of Massachusetts and the 1986 Distinguished Service recipient of the EDGD, has been appointed the official Engineering Design Graphics Division reporter for the upcoming International Conference on Descriptive Geometry and Engineering Graphics to be held in Vienna, Austria. With the appointment, Professor Kroner's impressions and analysis will appear in the EDGJ. We all look forward to a personal report from this important conference.

## Graphics Teachers Strut Their Stuff

Graphics teachers from around the country presented their solutions to a common geometric problem at the 94th Annual ASEE Meeting held June 21-26 in Reno, Nevada. This was a unique opportunity to compare first-hand the "teachability" of different systems as well as to analyze different approaches to solving the problem. AutoCAD, CADKEY, EZ Draft, Computervision, MATCCAD, Holguin, Hewlett Packard and others were featured. Many in the audience were amazed with the different approaches—from modeling the geometry to electronic etch-a-sketch. Many of the same presenters got an encore at North Carolina State University where an east cost audience got their chance to compare the products. Ed Galbraith is planning a twist on the problem for the ASEE

See Teachers on Page 12

# Letters

I read with great sadness of the death of Al Levens. As a former editor of this journal of the scholarship of our division, I have been aware of the memorable articles that appear. The very first article that was published in the (then named) Journal of Engineering Drawing was Vol. 1, No. 1, Page 1, 1936. The title of the piece was "Quinine." It was written by Alexander S. Levens.

Irwin Wladaver
Miami Beach, Florida

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I was astonished to find out that *only* after almost eight years, the death of Steven A. Coons has been acknowledged by your journal! Such an awesome Engineering Graphics/Computer Graphics figure and *the true* originator of CAD should not have been treated like that. But better late than never. Coons proved that true genius is far above earthly things like college degrees. It is sad that the engineering graphics field is not paying the respect that *the* major personality coming out of its own ranks deserves. As you are certainly aware of, just the opposite happens in the Computer Graphics world: SIGGRAPH has instituted the Steven Anson Coons award for "outstanding creative contributions to computer graphics." The first recipient in 1983 was Ivan E. Sutherland, a former student of his.

Harold Santo
Lisbon, Portugal

## EDGD Midyear in Louisville

The 1987 EDGD Midyear meeting will be held November 22-24 at the Galt House in Louisville, Kentucky. Hosting this year's meeting, which emphasizes Expert Systems in Graphics Instruction and Design, is the Engineering Graphics Department at The Speed Scientific School, University of Louisville. Over 25 technical papers are planned for the meeting.-ed

## TEACHERS

From Page 9

Annual Meeting in Portland next summer. Possibly now is the time to concentrate on *how* we solve the problems, rather than on *what* the problem is solved.-ed

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# jobs

### Purdue University Seeks Assistant Graphics Professors

The Department of Technical Graphics at Purdue University West Lafayette Campus seeks applications from qualified individuals for appointment at the assistant professor rank.

The TG department is one of eight departments in Purdue's School of Technology and offers an Associate in Applied Science degree in Technical Graphics as well as providing service instruction to over a dozen university academic areas.

The successful candidate should have a Master's degree in an appropriate discipline and an established interest in teaching modern graphics. Areas of specialization might include CADD, electronic publishing, architectural, mechanical, or electronics drafting. The School

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# Engineering Graphics and Computer Graphics about their past, present, and future

Davor Juricic and Ronald E. Barr
Mechanical Engineering Department
University of Texas at Austin

**"...Shall I invite you to consider a possibility that photography combined with electronic science may be developed to a point where entirely new methods of recording and conveying ideas may be devised?"**

Frederic G. Higbee
Professor of Drawing
June, 1946

## INTRODUCTION

Since ancient times the process of engineering design has required some methods and tools that would help a designer in his activities. This is equally true for a detail designer, whose main concerns are about the shape and size of the design product. The first and maybe the most important need of a detail designer is a procedure that helps in visualizing, composing and spatially solving the design problem. Another important need of a detail designer is a method of recording and communicating his design solutions.

To satisfy these needs, some methods and procedures were developed over the years. Having had only two-dimensional media available for recording ideas, the methods developed were based on projective transformations and descriptive geometry. These methods have been with us for a long time as a main part of the discipline of Engineering Design Graphics. Over the years these methods have used different tools: from the clay styli, T-squares, and drafting machines, to recent computer-graphics based CADD systems. The approach used, however, was always the same, based on projective transformations and descriptive geometry.

New developments in Computer Graphics and in Computer-Aided Design, specifically the present work on Solid Modeling, and stereoscopic display techniques, as well as new advances in the field of integrated CAD/CAM systems, indicate that some substantial changes in the approach to satisfy both needs of a detail designer should be expected. It is possible that in the very near future the complete process of designing a detailed part will not need any sketch or drawing produced, neither on a manual nor on an electronic drawing board. That may have far-reaching implications on Engineering Design Graphics, to the point that a new name may be needed for a discipline that will cover new methods to satisfy those designer's needs: the need for a procedure to help visualize, compose, and spatially solve a design problem, and the need to communicate the size and shape of the solution.

## FROM THE CLAY STYLI TO 2D CADD

It is not our intention here to review the history of engineering graphics. We want, however, to compare the time periods between cornerstone events in the development of engineering graphics to rightly dramatize the changes that we are now witnessing.

The first record of what appears to be an engineering drawing is a temple map from 2600 B.C. (the tablet on the Guldea's statue from Chaldea). More or less, the same methods — plan views or unrelated multiview drawings produced on a drawing surface with a pointed device — were used for more than four thousand years, all the way up to about 1500 A.D. At that point, the first record of what could be called related multiview projections appeared in Renaissance Italy (Pierro della Francesca). The appearance of these related multiview drawings based on principles of orthographic projection could be considered a cornerstone in the attempts to precisely describe a design object.

Following these events, other elements of descriptive geometry started appearing in unrelated solutions to specific problems, but it took another three hundred years until Gustav Monge systematized all practical solutions in use and unified them under his well known treatise *Geometrie Descriptive*. His contribution set a foundation for engineering graphics as we know it today.

After this second fundamental cornerstone, one that was based on a qualitative step in the methodology of engineering graphics, the advances that followed were made mostly by improving the tools that speeded up the application of this existing methodology. After more than two hundred years of T-squares, protractors and triangles, a "universal drafting machine" was patented at the beginning of this century, claiming to substitute for all of those instruments and to speed up the production of drawings by up to 50%. Its reign lasted for slightly more than half a century. It was replaced together with all other instruments by a truly universal, computer based drafting machine: our present 2D CADD system. Although digital in character and thus using analytical methods, these CADD systems are still emulating the approach laid down by Monge's descriptive geometry. They claim to further improve the production time of drawings, up to 1000% compared to the productivity achieved with the mechanical drafting machines.

## PRESENT TRENDS

Reaching now to our present time, it would be of interest to compare the periods between

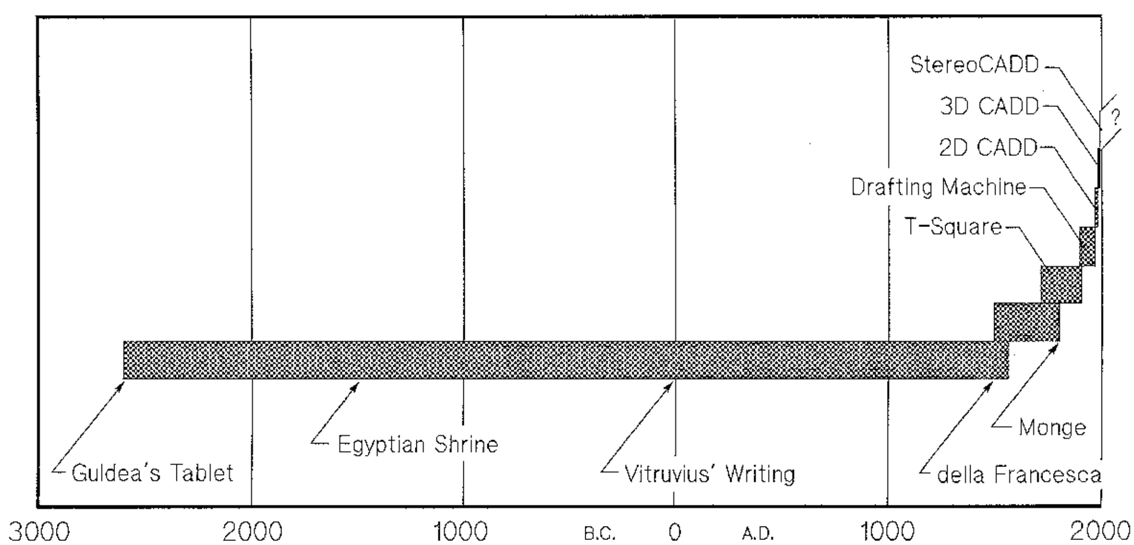


Figure 1

those main improvements in the tools and methods used by designers through the past centuries and our present. A linear time scale is used in Figure 1 for proper comparison. While a few millennia were needed to arrive at somewhat organized multiview drawings, only three hundred years were necessary to set a firm foundation of the methodology. Similarly, the life span of T-squares and similar drafting instruments stretched over several centuries, but the life span of the drafting machine lasted only about half a century.

What will be the life span of our present 2D CADD technology? It seems that its decline is in sight and a superior substitute is emerging. Present market research in this field estimates that 70% of all detail and layout design activities at this time are being made on 2D CADD systems. It also predicts that by the year 1990 about 70% of the same activities will be done on 3D CADD systems, i.e. the systems with solid modeling capabilities. We can thus deduce that the life span of our 2D CADD systems will be roughly one decade.

Basic 3D CADD systems with solid modeling capabilities already exist, but it will take several more years to produce industry acceptable systems that will automatically produce hardcopy outputs in the form of engineering drawings. These drawings will be needed because an integrated CAD/CAM solution will not be available by that time for a majority of applications. The screens of these solid modeling systems will still be two-dimensional, relying on an understanding of the concepts of projections, although not necessarily orthographic. However, when used to visualize, compose, and spatially solve the design problem, the approach will be thoroughly three-dimensional, quite different from the present approach through orthographic multiview projections. With drawings still needed for communicating size and shape, and having 2D projections on the screen to visualize the design object, the needs to master Engineering Design Graphics will still be unchanged for several years.

## SPECULATIONS ABOUT THE FUTURE

How long will the reign of this 3D CADD last? If history keeps repeating it should not last more than five years. By the year 1995 we could expect a new cornerstone in the development of the procedures available to the designer. The changes in the procedures may be so fundamental that the concepts taught in our traditional Engineering Design Graphics may not be relevant any more. Basing our predictions on present research in the field of stereoscopic and holographic computer graphics, and on the advances in the integration of CAD and CAM systems, we will try to describe the system of the

*"If history keeps repeating itself, 3-D CADD should not last more than five years."*

future. For the sake of brevity and the lack of a better name we will call that system StereoCAD.

StereoCAD will be based on a Solid Modeler in the same way as 3D CADD, but its screen will not show a projection. The design object will be perceived as being in three-dimensional space at all times. A designer will be able to inspect the object being designed during all stages of the design process as if it were a model in his hands. The designer will wield a *space-mouse* to remotely control a three-dimensional cursor. The size of any feature of the object will be displayed at request. Would extension and dimension lines be used? Not necessarily, as some other solutions using color may be better in this case. We recognize that this new tool for visualizing, composing, and spatially solving design problems will not require that a designer master our traditional Engineering Design Graphics based on 2D orthographic projections.

How about recording and communicating size and shape? Computer records describing size and shape of the designed part will be downloaded to the computers controlling production machinery. Anybody else interested in the designed part will have its computer data available to show and inspect the part on his own StereoCAD screen, just like the designer did during the design process.

Will we need the tools of descriptive geometry for our freehand sketching which we use today? It is difficult to say when freehand sketching will disappear and to what extent. But it is possible that our future engineers will think in terms of "computer space" and will always have their hand-held computers nearby. We have heard recently about designers in a multi-national chemical company who are not able to design anything on the drawing board, but are perfectly comfortable with a computer-aided design system.

## CONCLUSION

Does this sound a little bit far-fetched? For those skeptical may we recall the case of the slide-rule. Many of us remember how important the slide-rule was to engineering, how long it was with us, and how suddenly it disappeared from our engineering lives. Engineering drawings, the designer's tools based on descriptive geometry, are needed when only two-dimensional media are available to a designer to record and communicate design ideas. *As soon as the three-dimensional media become available, those two-dimensional tools will not be needed any more.*

Does it mean that ten years from now there will be no Engineering Design Graphics? Not necessarily. We may keep the name but the topics taught will not be the same. The name was fortunately chosen: Engineering and Design will still be relevant while Graphics may be referenced to Computer Graphics, one of the foundations of CAD. To describe roughly the course content one could say that it will be a course on three-dimensional detail design and StereoCAD literacy. That is what Engineering Design Graphics will be as we approach the twenty-first century.

# Jobs

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of Technology values industrial experience. Potential candidates with industrial experience in engineering design and graphics are encouraged to apply. Faculty in the TG department teach lower and upper division undergraduate courses, engage in research appropriate to the discipline, actively write and lecture, may serve on the graduate faculty, and are in demand as consultants in their areas of specialties. For further information contact:

**Chair, Search Committee**
**Dept. of Technical Graphics**
**363 Knoy Hall**
**Purdue University**
**West Lafayette, IN 47907**

# Visual Propositions for the Integration of CADD and TRAD

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## INTRODUCTION

The engineering graphics field is currently being revolutionized by the rapid development of electronic communication devices, artificial intelligence (AI), Computer-Aided Design Drafting (CADD) and computer graphics. Some of these advancements have prompted a series of scholarly efforts delineated in previous issues of this Journal (1,3). Engineering Graphics university programs are responding by incorporating innovative graphical techniques into their curricula, while keeping the essential traditional (TRAD) engineering graphics concepts (2,4,6).

The transformation of engineering graphics from a quasi-empirical field, where certain knowledge-based rules have evolved, into a challenging scientific/artistic field seems unavoidable. This emerging field, has yet to be named. Some suggestions have been made, namely: Engineering Computer Graphics, Integrated Engineering Graphics, etc. For the purpose of this discussion, this field will be coined: INTERactive Engineering GRAphics (INTEGRA). The acronym INTEGRA (i.e., from the latin integrare, "to make complete") is used here to convey a sense of integration, rather than elimination, of the important subject matters within the Engineering Graphics field.

"It is vital to ensure that the new tidal wave does not erode centuries of engineering design graphics developments."

Several studies (3,4) indicate that the graphics field should preserve the valuable aspects of traditional engineering graphics and at the same time incorporate new technological and graphical modeling tools like CADD and AI. It is vital to ensure that the new tidal wave does not erode centuries of engineering design graphics developments by pioneers like: Gudea (plans), Vitruvius (geometric construction), Gutenberg (printing), Alberti (views), da Vinci (creative design/sketching), Monge (descriptive geometry), and Sutherland (computer graphics). Nor should it dilute the modern engineering graphics concepts presented by contemporary writers and educators. However, the task of preserving the old while merging it with the new is immense.

## PROPOSITIONS

In order to provide a direction for new generations of engineering graphics professionals, some basic principles are required. Without them, both present and new generations will be forced to use clairvoyance, educated guesses, and intuition. There seems to be a consensus on the need not only to preserve traditional graphics topics, but also to incorporate the new graphics techniques (3,6). Based on this presumed consensus, four propositions are advanced here to foster a dialogue and provide for the articulation of ideas.

The *axiomatic technique* assists in making resolutions in synthesis and in analyzing the existing engineering graphics approaches. *Axioms* are, of course, undemonstrated postulates and propositions. They are concerned with an undefined set of relationships but are generally acknowledged to be true. *Propositions* are statements to be offered for discussion.

The suggested propositions are described as follows:

**Proposition A1: Maintain the essential aspects of engineering graphics** (i.e., spatial visualization, sketching, orthographic projections, descriptive geometry theory, dimension and tolerancing).

**Proposition A2: Incorporate the use of new production tools** (i.e., CADD, AI, etc.), without losing perspective and understanding of the basic engineering graphics principles.

**Proposition A3: Minimize the need to learn cumbersome computer programming skills**, at the engineering graphics introductory level.

**Proposition A4: Maximize design graphics problem solving educational opportunities.**

The propositions state that we should preserve the traditional aspects essential to the understanding of graphical communication while taking advantage of the new technological tools available. However, engineering curriculum designs that satisfy these axioms are not easily attainable.

One problem is the limited time available to teach and learn all these concepts in the present engineering curriculum. The second problem is the shortage of trained professionals in the area. The constraints are governed by the demands of an overcrowded engineering curriculum, the refusal to expand the engineering program one additional year and the scarcity of advanced and graduate level programs in engineering graphics. One alternative and possible solution to the first problem is presented in this paper. It consists of integrating the new with the old using an integrated engineering graphical (4) approach.

Solutions to the second problem are not elaborated in this paper, but as evidence there are efforts to initiate new graduate programs in interactive engineering graphics and computational graphics at the master's and doctorate levels at Georgia Tech and other institutions.

## INTEGRATED GRAPHICS

The proposed integrated graphics approach for visual communication is not new. It draws on existing concepts and ideas; however, it has the objective of providing some articulation and perspective to the new variations of the visual communication field. The previous propositions are the basis for the INTEGRA or integrated approach.

In the integrated approach, the traditional aspects of engineering design and graphics language are covered in conjunction with interactive graphics and CADD applications. For example, some aspects of descriptive geometry theory (points, lines and planes) are discussed concurrently with geometric entity construction. ANSI standards, dimensioning and tolerancing are presented in conjunction with the computer system drafting functions and menu operations. Solid Modeling and hidden line removal are taught in conjunction with intersection concepts.

In this approach, the student utilizes the graphics language to analyze, communicate and reproduce information about design projects using the most productive technological tools available. Traditional aspects are integrated with more recent developments like: interactive graphics, computer document composition and electronic transmittal of information.

One effort to integrate traditional graphics with computer graphics is currently being conducted at Georgia Tech where the freshman course, Visual Communication and Introduction to Engineering Design, provides an introduction to the verbal and graphical languages of engineering. The course contains an overview of the resources and techniques available for the effective communication of design ideas and research findings. Upon successful completion of the course the student is prepared to communicate design ideas by means of the interactive engineering graphics language. Students are able to generate and plot graphic models with the use of several application programs. Graphical modeling (5) and interfacing topics are discussed at the end of the quarter. Some of the initial course objectives are outlined below.

- To understand how engineers and designers are able to develop devices, systems and processes using Interactive Engineering Graphics systems.

- To discern the design information required by those who will be manufacturing devices, constructing structures or supervising processes.

- To understand traditional engineering graphics concepts: sketching, descriptive geometry, orthographic projections, spatial visualization, dimensioning and tolerancing.

- To utilize the most productive engineering graphics tools available.

Students discover, early in their career, the benefits of learning about and utilizing the latest technological instruments for the communication of design ideas. For instance, microcomputers and terminals connected to supermini and mainframe computers allow the transmission of information from student to student (and faculty) located elsewhere on campus. The results have been an increase in productivity and improvement in sharing of information activities. Students learn how they can utilize the information systems by integrating the basic forms of communication to their daily activities. Presently, students review class lessons on several of the software packages available (e.g., ICEMDDN, CADKEY, AutoCAD, CATIA, CADAM, etc.) using Computer-Aided Instruction (CAI) tutorials like PLATO. The PLATO (Programmed Logic for Automatic Teaching Operations) author language has been a valuable interactive educational tool in attaining the class objectives.

## INTEGRATED GRAPHICAL SOLUTIONS

This section contains illustrative examples of the application of INTEGRA to solve familiar problems. The first problem is a minimum path problem with a unique graphical solution. The second is a simple design problem.

### Example 1: Minimum Path Problem

Engineering students are required to solve analytical and design problems. They apply knowledge-based concepts, experience, intelligent deductions and even a little bit of intuition to reach a solution. In many cases, mathematical and graphical procedures are implemented to solve the problem. Since engineering is a problem oriented profession, most academic training consists of solving technical puzzles and quandaries. Engineering students discover, very early in their career, that in addition to the technical knowledge it is necessary to graphically record the problem solutions and design alternatives. The following problem will demonstrate the utilization of INTEGRA to graphically obtain the minimum path traveled by an ant, so as to reach a grain of sugar.

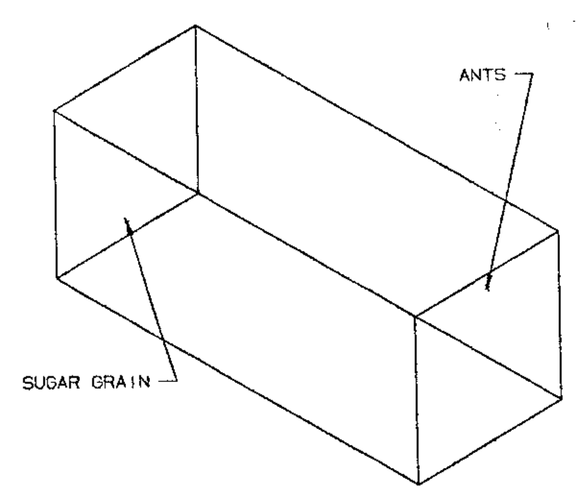


Figure 1

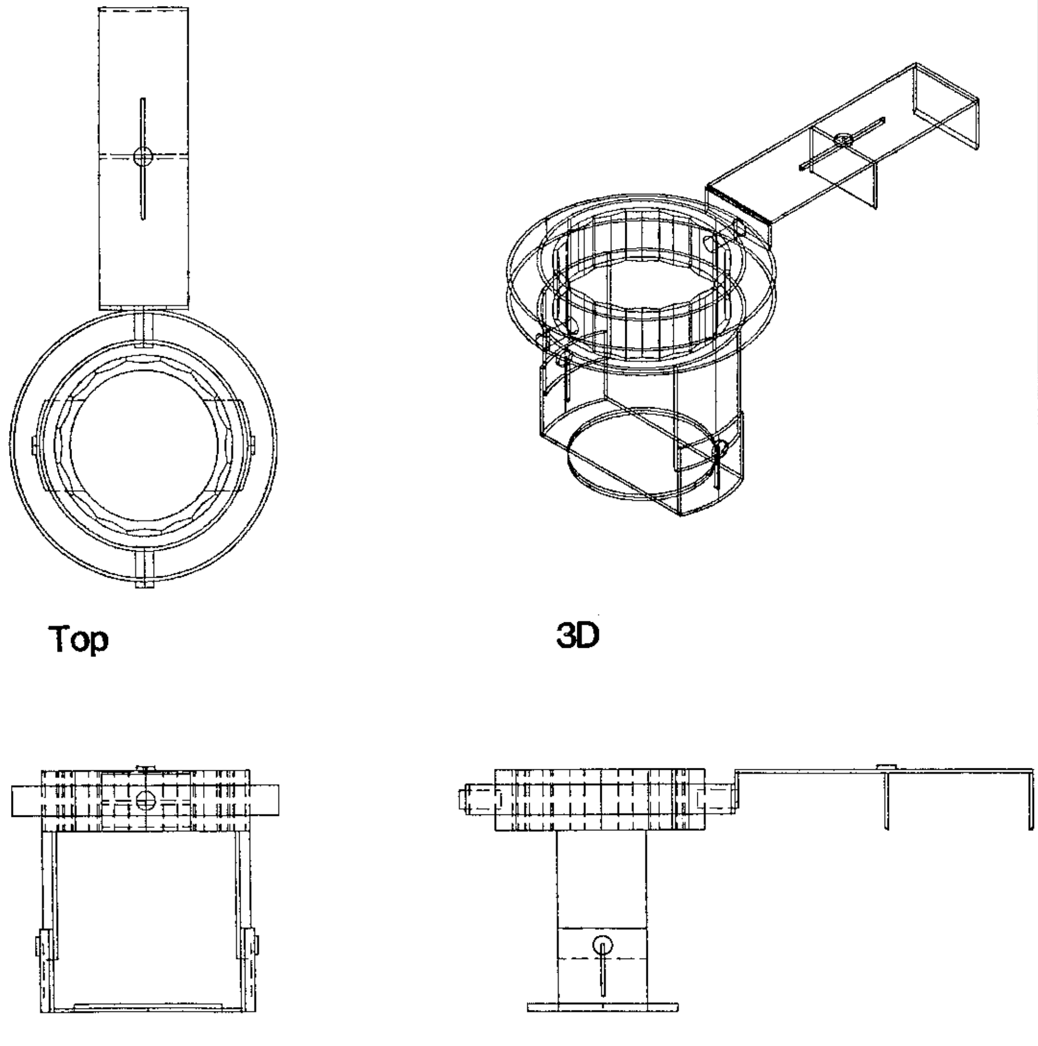


Figure 5

Interactive graphics systems, CADD, CAE (Computer-Aided Engineering), CAM (Computer-Aided Manufacturing), and AI are new tools available to the engineer. However, spatial visualization and manual sketching of ideas remain in the domain of unique human abilities. It is helpful to develop traditional engineering graphics and interactive graphics skills, very early in the professional engineer's career. These abilities can be developed by solving spatial visualization and design practice problems. One educational strategy consists of manually sketching and then generating the final drawings using CADD systems. The use of CAI programs like PLATO along with microcomputer and supermini computer graphics packages provides the engineering student with an experience that simulates his or her future professional environment.

Integrating both CADD and TRAD might prove to be instrumental in improving the effectiveness of engineering graphics education. Four propositions have been advanced in an effort to provide a frame of reference for a new generation of interactive engineering graphics scholars.

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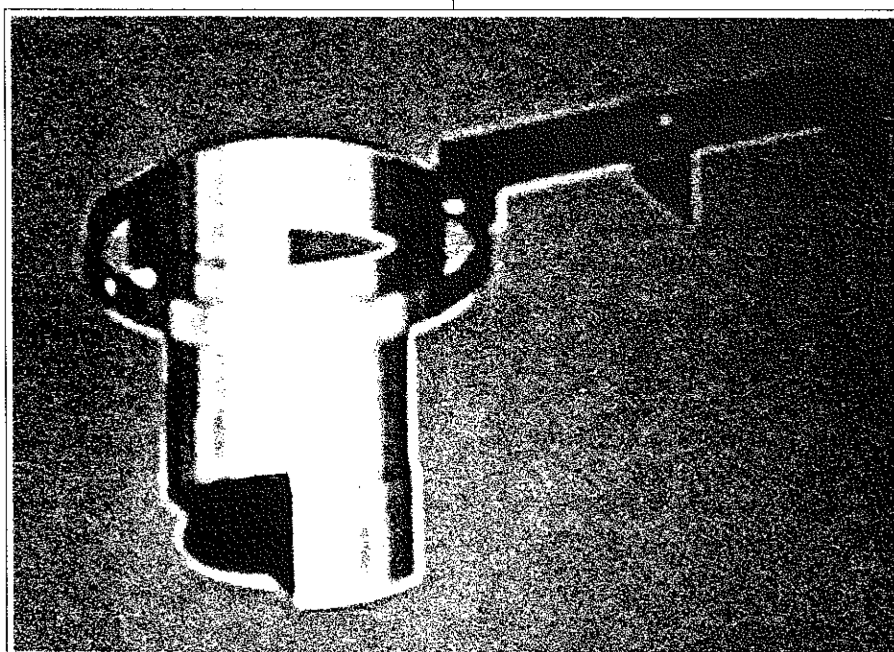

# THREE-DIMENSIONAL REPRESENTATION OF A CYLINDER ON A GRAPHICS DISPLAY DEVICE

Alan Lynch and Roland Jenison
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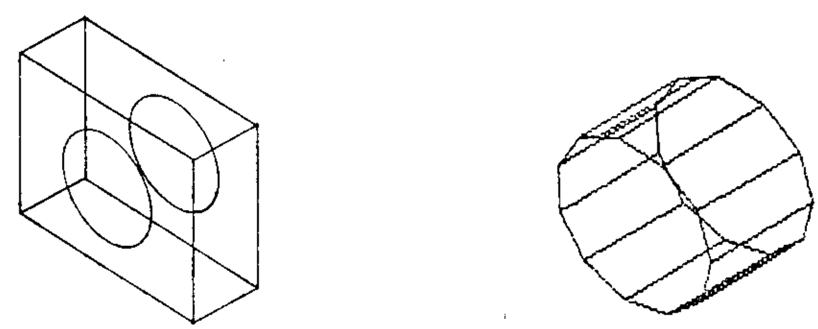


a. b.

Figure 1

## INTRODUCTION

Representation of three-dimensional geometries with a wireframe scheme creates some visualization problems particularly for those who are receiving their first exposure to engineering graphics and geometric modeling. Pure wireframe models (no removal or special designation of hidden lines) may lack contour or profile information necessary for quick identification of the geometry (Figure 1(a)). On the other hand, excessive use of lines to represent the geometric profile may create visualization problems (Figure 1 (b)).

The cylinders represented in Figure 1 are examples of the limitation of wireframe models. When a drafter is confronted with drawing a cylinder in axonometric, an ellipse is constructed for both the front and back surfaces. To complete the drawing, parallel lines tangent to the ellipses and perpendicular to the major axes are drawn to show the limits of the cylindrical surface. This representation is shown in Figure 2. This concept of parallel tangent representation is intuitive and can be readily extended for computer graphics applications.

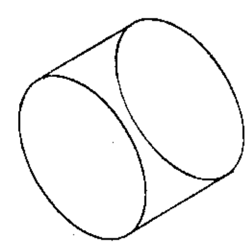
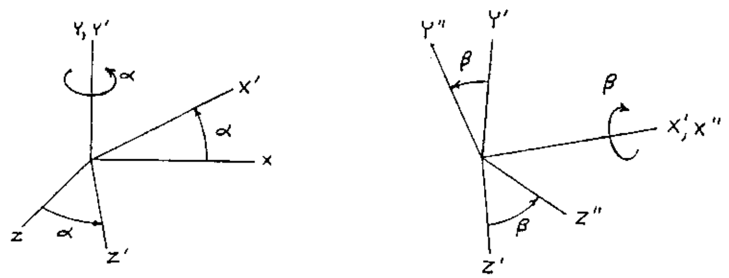


Figure 2

The purpose of this paper is to demonstrate one method for finding the parallel tangents to a cylinder using a graphics display device. The method is based upon geometric properties of the three-dimensional representations of the cylinders. The basis of the three-dimensional representation is a rotation transformation.

## ROTATION TRANSFORMATIONS

In order to obtain a three-dimensional view of an object, two rotation transformations are performed relative to an xyz coordinate system. The object is defined in the base xyz system which shall be referred to as the object coordinate system. The first rotation is an angle $\alpha$ about the y axis in the *object coordinate system* (Figure 3(a)). The second rotation is about the rotated x axis (x') through an angle β (Figure 3(b)) to the x"y"z" system which shall be called the *viewing system.*




a. b.

Figure 3

The rotations are described mathematically by rotation transformation matrices. Thus, the relationship between the viewing coordinate system and the object coordinate system is described as

$$\begin{bmatrix} x'' \\ y'' \\ z'' \end{bmatrix} = [A] \begin{bmatrix} x \\ y \\ z \end{bmatrix} \quad (1)$$

where [A] is the rotation transformation matrix defined as

$$[A] = \begin{bmatrix} C\alpha & 0\alpha & -S\alpha \\ -S\beta\ S\alpha & C\beta & -S\beta\ C\alpha \\ C\beta\ S\alpha & S\beta & C\beta\ C\alpha \end{bmatrix} \quad (2)$$

$(C = \cos\alpha,\ S = \sin\beta, \text{etc})$

Equation 1 may be applied directly if the rotation angles α and β are known. However, it is more likely that a viewpoint coordinate $(x_v,y_v,z_v)$ is known in the object coordinate system. The viewpoint is defined as the point through which the z" axis must pass in order to view a desired geometric property of an object. The viewpoint, which may be selected for viewing advantage or calculated for viewing a specific geometric property, is used to calculate the angular rotations.

$$\alpha = \tan^{-1}(x_v/z_v) \quad (3)$$

$$\beta = 360 - \tan^{-1}\left(y_v/(x_v^2 + z_v^2)^{0.5}\right) \quad (4)$$

Now Equations 3 and 4 can be used in conjunction with Equation 1 to transform any point, line, or object from the object system to the viewing system.

## METHOD FOR DETERMINING PARALLEL TANGENTS

Conceptually a cylinder may be described by specifying the center of each circular face, the radius and an orientation. The height can then be computed from the coordinates of the centers of the faces. The representation of the cylinder on a graphics display device is a collection of straight line segments produced from a discrete database. How are the parallel tangent lines to be determined to show the limits of the cylinder surface when displayed from a specified view point?

One method involves application of the vector dot product and magnitudes of vectors which can be defined from the database. Consider the cylinder in Figure 4. For convenience the circular faces are assumed to be parallel to the xy plane in the object system. A viewpoint of (0, 0, 1) would then display the circular (normal) view of the cylinder. The problem is to determine the parallel lines $L_1$ and $L_2$ at a specified viewpoint $(x_v,y_v,z_v)$ from which the circles would appear as ellipses.

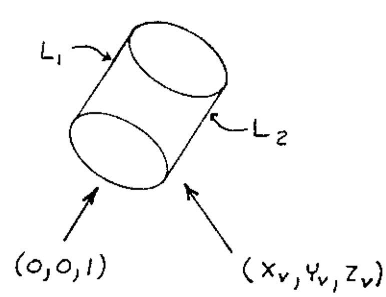



Figure 4

In order to draw the parallel lines, $L_1$ and $L_2$, a common tangent to each transformed circle (ellipse) must be found which is perpendicular to the major axis of the ellipse. An algorithm was set up to determine these tangents which would produce the proper display at any desired viewpoint. The steps in the algorithm are outlined below.

1. Specify the center (x,y,z) of each face of the cylinder, the radius and the desired viewpoint $(x_v,y_v,z_v)$.

2. Compute $\alpha$ and $\beta$ from Equations 3 and 4.

3. Compute N discrete points along the circle and transform these points using Equation 1.

4. Compute, for two successive points on the transformed circle, the dot product of the radius vector defined to be from the center of the ellipse to the transformed point and the vector defined by connecting the transformed point to the next point of the ellipse. In Figure 5 the dot products for the successive points 1 and 2 would be

$$\overline{01} \cdot \overline{12} \quad \text{and} \quad \overline{02} \cdot \overline{23}$$

5. Compute, for the same two successive points, the magnitudes of the radius vectors. The magnitudes for points 1 and 2 on Figure 5 are denoted as

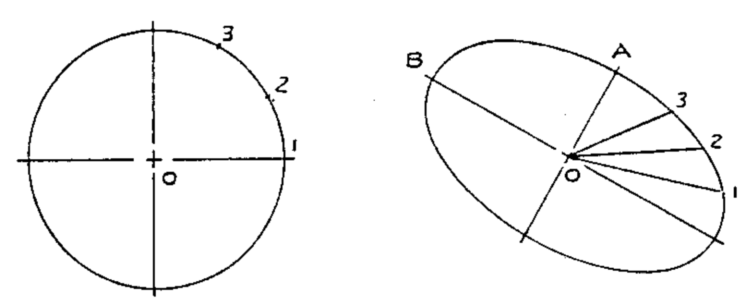



Figure 5

$|\overline{01}|$ and $|\overline{02}|$

6. Compare the dot products and magnitudes for two successive points in light of the geometric properties of the transformed circle. In Fig. 5, assume a starting point at 1 and continue in the direction of 2,3, … N around the ellipse. The dot product will approach zero when the semi-minor axis OA or the semi-major axis OB is approached since the vectors in the dot product become perpendicular. However, the magnitude of the radius vector becomes smaller as the semi-minor axis is neared and larger as the semi-major axis is neared. This geometric distinction enables the tangent point to be located in a discrete sense.

Thus the comparison can be made in the following manner. Is the new dot product less than the last dot product and is the new vector magnitude greater than the last? If yes, store the midpoint between the two discrete points as a possible candidate for the end point of a parallel tangent. If no, consider the next point.

7. Repeat steps 5 and 6 until there are no more points.

Notice in the algorithm that the two faces of the cylinder may be drawn first and then a search conducted to find candidate points that meet the criteria. Also, no mention was made of the value of N, the number of discrete points required. In the limiting case, when N approaches infinity, a smooth cylindrical representation will be obtained. However, the computational resources required to produce parallel tangents will increase. Conversely, the algorithm is applicable for N = 3,4 or any M number of discrete points which produce a triangular prism, rectangular prism or an M-sided prism respectively.

**Results**

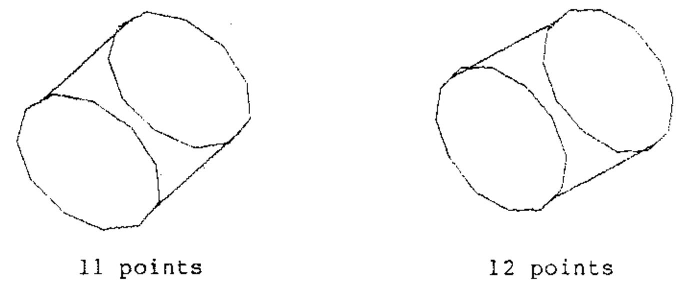
Some results of the performance of the algorithm are described here. Figure 6(a) shows the representation of a cylinder with 11 discrete points displayed in isometric (viewpoint (1,1,1)). Figure 6 (b) reflects the same viewpoint with the model having 12 points. Both cylinder models are too coarse so parallel tangents are not physically possible. However, Figure 6 does illustrate the midpoint aspect of the algorithm. Also, Figure 6 illustrates that an odd number of discrete points produces a nonsymmetric result for the tangent locations.

Figure 7 shows an 18-point and 36-point representation. For 18 points, the discrete representation is still discernible but the 36-point model (1 per 10 degrees of arc) shows the algorithm was successful in representing a smooth cylinder within the resolution of the display device.

## CLASSROOM APPLICATIONS

The algorithm has been used in experimental classes of a first course in engineering graphics. The intent is to have students experience different approaches to modeling a cylinder on a graphics device. They begin with a prismatic representation as illustrated in Figure 1(b). The limitations of this approach as the number of sides of the prism is increased as studied. At this point a software package using the parallel tangent algorithm is introduced. The students are asked to vary N and the viewpoint as well as the cylinder parameters of radius and center locations. This approach improves the students' ability to read three-dimensional wireframe diagrams on a display device and provides an opportunity to relate display device resolution to desired graphics quality.

A more in-depth study of the algorithm will take place in a sophomore course being offered for the first time during spring semester 1987. Students will be assigned the task of developing the parallel tangent algorithm. It is an excellent exercise for relating desired graphics display to the computational geometry methods required for computer representation of objects. The inherent geometric meaning of vectors and the applications of vectors to problems involving perpendicularity and parallelism is fundamental to computer-aided-design (CAD).




a. b.

Figure 6

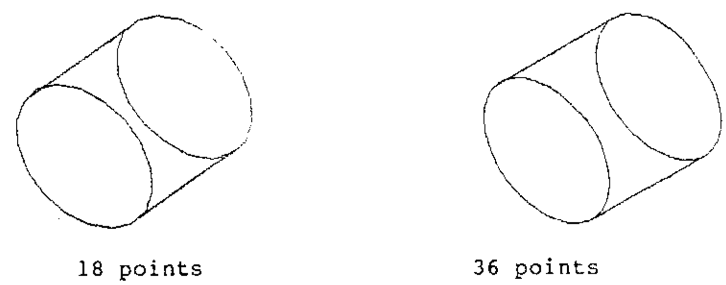



Figure 7

## CONCLUSIONS

One method for finding the parallel tangents to represent the limiting surface of a cylinder on a graphics display device has been presented. The method is intuitive from a graphical standpoint but there are limitations on the quality of the display required by a user. For example, a 20-point model would appear to suffice on a low resolution terminal. However, a 30-or 40-point model may be required for high resolution terminals. The trade off for the quality of the cylinder is in the execution time for finding the parallel tangents.

The nature of the method makes it an ideal educations tool for students just beginning to study engineering graphics and the use of graphics display devices. It also provides a good starting point for those studying computational geometry methods as a lead in to CAD.

# TECHNIQUES FOR GENERATING OBJECTS IN A THREE-DIMENSIONAL CAD SYSTEM

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*So that we understand each other, let me start with a definition of terms. CAD in the context of this paper is the database generated by a computer defining the points of each primitive geometric element in terms of a spatial rather than planer location.*

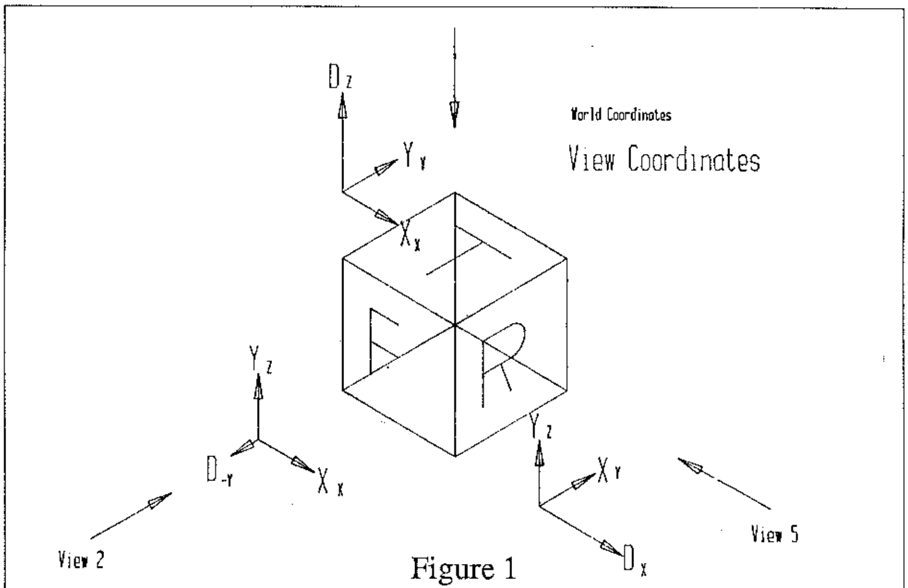

Figure 1

## COORDINATE SYSTEMS

The means we have for quantifying the location of CAD geometry are based on one of two systems. In 2-dimensional terms we call those systems *cartesian coordinates*, in which all objects are located via a horizontal and a vertical offset from a single point called the origin; and *polar coordinates*, in which the objects are located by a straight line (a vector) distance from the origin and the vector is in turn oriented at a specific angle to a reference line which passes through the origin. These same systems can be expanded for the generation of a 3-D database. Two-dimensional cartesian coordinates become a set of three axes which all pass through a common point (the origin) and which are mutually perpendicular to each other. Polar coordinates translate the definition of geometric primitives in three dimensions as vectors of specific lengths at a given tilt and spin from the reference. Simply establishing the three mutually perpendicular axes is not sufficient for determining standard notation for locating geometry in space. With space coordinates, the problem of "handedness" rears its head. Specifically, which is to be considered as the positive direction for the third axis? If the thumb of a person's hand is used to indicate the direction of the positive X-axis, the index finger for the Y-axis, and the middle finger for the Z-axis, then the two different polarities will describe either a left-hand or right-hand coordinate system. Most disciplines now prefer the right-hand system. It works very well for CAD geometry, but the orientation of the axes to the real world also needs to be considered. Specifically, which pair of axes describes a horizontal plane? Or conversely, which axis is vertical? For conformity between CAD and standard NC languages, the X-Y plane should represent a horizontal surface and the Z-axis should be vertical. Either 3-D system (cartesian or polar) can be used to describe primitives in CAD. In practice, I have found that I use both interchangeably as the occasion demands.

## UNITS OF MEASURE

Obviously, it is important to the point of being essential that data may be entered into a CAD system in any units. Many CAD systems do not provide selectable unit switching and very few allow a user to arbitrarily intermix units for input. Metric units are not a serious problem in this regard, but conventional units of feet, inches, yards, miles, and common fractions are. Many CAD systems require input to be solely in decimal form regardless of the base unit — i.e. decimal feet instead of feet and inches, decimal inches instead of common fractions, etc.

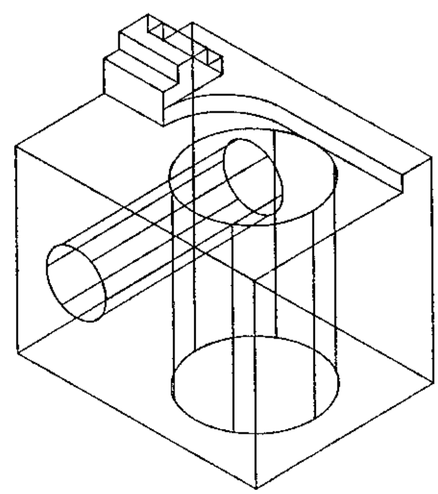

Figure 2

## SCALING

*Scaling* takes on new meaning with CAD. Design work on a CAD system is done at life size. Otherwise, dimensioning procedures become tedious. Scaling occurs only as a procedure used to make more or less of the design visible on the computer display, or to size output for a specific plotter or other hardcopy device.

*Clipping* is the process of disregarding data elements which lie beyond limits on a display device. The limits may be user determined or automatically set by the software. The importance of clipping occurs with windowing for selection of data elements and with the editing of data for display purposes.

*Windowing* allows the user to determine which portion of a database is to be mapped to the viewport or active display area of the screen or other output device. Depending on the application, windowing may or may not imply an active change of display scale. It should not imply an actual change of design scale. In well-integrated CAD systems, attributes such as grid, snap, and lettering size are set in world coordinates rather than device coordinates. This means that these attributes remain constant with respect to the geometry being described regardless of the display scale.

## LEVELS

Fundamental to efficient utilization of a CAD system is a good understanding and use of levels for designing the part geometry. Levels in CAD should be thought of as representing the overlays that architects and engineers have historically used to develop drawings. Individual levels may be used for construction geometry and grids. Additional levels may be added for wireframe geometry, notes, dimensions, mesh geometry, patterns, groups, and specific design primitives. Not all CAD systems allow the use of levels in this manner. Some popular software has limited level definitions and always correlates level number with plotter pen or display color. Such a use of levels makes writing the application program easier, but is not conducive to the long-range use of levels as a real aid in the design process. Display colors, pen colors, line types, and line widths *are* appropriate discriminators for the use of levels, but not at the exclusion of other determining factors. For instance, in designing a three layer printed circuit board, I need the capability of defining a level for the modular grid, circuit path on each layer, drilling pattern on each substrate, component layout, registration bullets, and annotation; plus the ability to display the levels individually or in combination and to create mirror images of each or any combination of them. In practice, CAD systems currently on the market contain the provisions for from 10 to several thousand levels. My personal preference is for a system which allocates particular functions to specific levels but which also allows open user

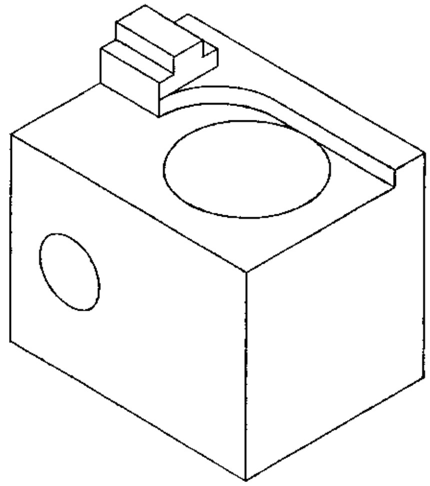
Figure 3

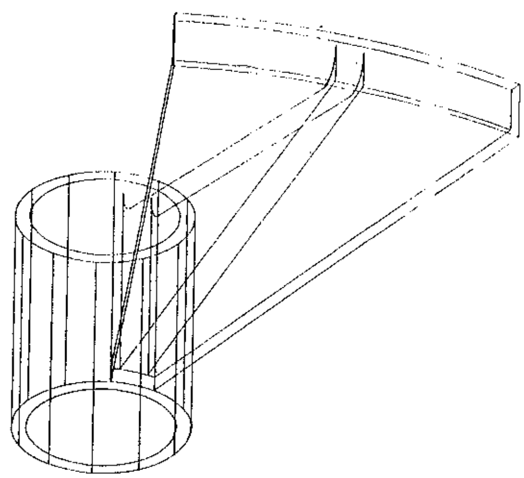
Figure 4

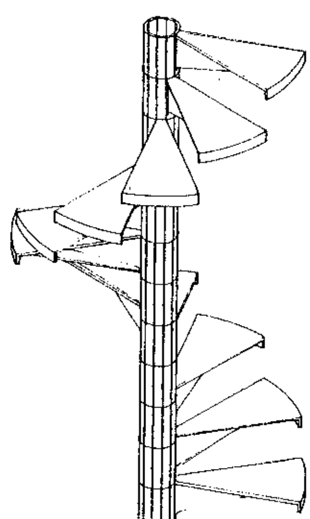
Figure 5

definition of 200 to 300 levels for any purpose I so desire.

## INPUT MODES

### Geometric Oriented Input

Data input can be in two general forms. It is either geometry based or it is in the form of direct coordinates. Historically, geometric orientation for data input is the more recent mode. With proper attention in generating the application program, this can be a very powerful way to communicate with the computer. The fundamental power of geometry related input lies in the complexity of relationships allowed in the form of tangencies, parallel and perpendicular relationships, and trimming and extension functions. As a criterion for judging the capabilities of any CAD software to perform these functions, test the ability of the software to handle the problem of describing a circle which is tangent in any combinations of relationships to three given circles of different diameters, or in 3-D terms, describe a sphere tangent to four other given spheres of different diameters. Very few 2-D packages can handle the plain geometry version of this problem, and I have yet to find a 3-D package which will solve the solid geometry version without conditions or restrictions on the type of tangencies, or on the geometry of the given spheres. But regardless of this benchmark test, all CAD packages contain the capability to generate primitive geometric elements such as lines, circles and arcs. Many also allow for or automatically generate ellipses and other second order curves as well.

One of the major powers of a CAD system is the ease with which it can be used to generate patterns (also called templates or symbols) and its ability to consider such patterns as a single entity or not (grouping). The truly powerful packages allow maximum ease and flexibility for user definition of patterns which can be stored in either 2 or 3 dimensional form, can be called up, scaled, and placed in the database at will, and can be edited after placement.

### Direct Coordinates

We dare not forget the history of computer aided design. It is the current state of development which started with numerically controlled machine tool operation. NC programming is still one of the outcomes from CAD and good CAD packages will allow for the input and output modes associated with this important production tool. A normal output of the CAD package should be a numerical file which can be read as the part geometry for a numerical control language. Conversely, the program should be capable of using a numerical file as input. This is not only essential for machine part processing, but also allows field note data such as stadia notes to be used as direct input to the CAD package for contour and surface plot routines.

### Transformations

At the heart of the technique for generating 3-D geometry is the ready capability of performing transformations. Transformations exist in 3 types — scale, which changes the display size of a group of entities with respect to the world coordinates (this is not the same function as zooming, which I discussed earlier); translation, which allows for movement, copying, or extrusion in any direction; and rotation, which allows geometric entities to be revolved about any linear axis. With these functions used singly or in combination, it is possible to generate the geometry of a 3-dimensional part very quickly. A cube, for instance can be generated by invoking the rectangle function for one face and then extruding it in the direction normal to that face. Other prismatic shapes can be generated by changing the shape of the original polygon or by translating in multiple directions simultaneously.

Rotation allows geometry to be transformed by revolving entities about any axis. Usually, rotation is applied to entities which have already been placed in the database, but an equally powerful technique is to position the 2-dimensional geometry generation reference surface (current drawing plane) in the proper orientation and then to generate additional 3-dimensional entities from this new point of view. The method for doing this latter transformation is not standardized, but generally involves the database as a means of defining a new view for generating additional geometry or defining a line of sight which is perpendicular to a user definable plane selected from the existing geometry. Possibly the most advanced transformation is helical — the combination of simultaneous rotation and translation. Using such a transformation, the design of a spiral staircase becomes an easy exercise.

These 3-dimensional transformations are what makes generating objects in space an easy and natural method for working. It takes a very small amount of time, working in this mode, to become spoiled — to not wish for a return to orthographic projection with its problems, limitations, and vagaries of interpretation.

> "Hand drafting emulation is a short-sighted approach to computer-aided design."

### Annotation

As with hand drafting, annotation is an important aspect of CAD. On machine elements, the placement of notes and dimensions still must be done in a manner similar to that which has been

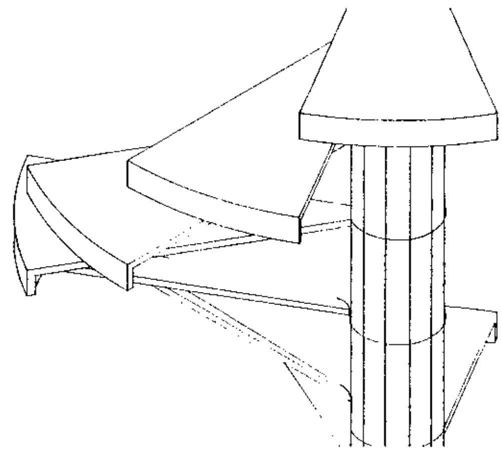

Figure 6

used in drafting rooms all over the world. Dimension placement is still a very open-ended process which requires human decision and interaction. Distances themselves do not need to be kept track of, the values in the database are sufficient for this, but this location of dimensions cannot be easily programmed. In two-dimensional CAD, where the only viable end product of the design process is a hardcopy plot of the screen, the technique for dimension placement is very similar to the hand drafting methods to which we have become accustomed. Entities are selected in the "view" you wish the dimension to be seen and a dimension number location is indicated. Unfortunately, a 3-dimensional dimensioning process does not exist. No one has ever devised one because we have never had solid models to work with before. The best we can do is to modify the existing 2-D dimensioning standards to the solid model we see before us.

The technique is to select the view in which a particular dimension should appear and place it according to conventional dimensioning standards. A distressing thing occurs the first time you do this on a 3-D CAD system; that is, when you change views, the dimension disappears! This phenomenon points out very vividly the limited nature of all dimensioning practice. Dimensions are linear, requiring a single dimension for definition, and require an additional dimension only for purposes of conventional annotation.

In addition, lettering height in 3-D CAD may be tied to the scale of the database rather than to the drawing sheet size. Working with this condition means having to scale lettering height in proportion to the longest dimension on the object (a process heretofore unheard of) if the lettering is to adhere to conventional standards. Before we become too concerned about this situation, we really need to assess whether it is necessary to generate the hardcopy in the first place. The answer in most disciplines is "No." The construction industry and its related fields, architecture, architectural engineering, structural engineering, and civil engineering, will very likely continue to require hardcopy output for new designs. For other disciplines, hardcopy will soon disappear from the documentation sequence. As a matter of fact, the most sophisticated micro-computer based graphics system available today has at best a shaky interface for hardcopy output. The best available for this computer is direct video output which can be recorded. The reason is that there is no currently available technology for reproducing the wide range of colors and fine resolution directly to a hardcopy device. Line drawings routed to a plotter have a practical limit of 15 different pen sizes and color combinations. Ink jet and color laser printers have a limit of 7 color combinations. None of these devices can cope with the 1.6 million colors available on the latest video displays.

### Editing

One type of image which results from a 3-D database is a wireframe model. After the geometry is complete, the next step usually undertaken is the process of editing the wireframe. This usually is for the purpose of removing hidden lines to give the also using in-house. Marquette University was using a variety of hardware and software. The University of Missouri-Rolla installed a version of AD-2000 on IBM mainframe equipment. While faculty at the University of Minnesota had developed MINNDRAFT for technical institute graphics programs, we were surprised to find that they were using a small 3-D modeling program in their freshmen graphic course. MINNDRAFT is a 2-D program, operating on a DEC based micro computer.

When the University of Wisconsin-Madison entered the field using Apple computers and using the Basic language to teach a course in descriptive geometry the pressure increased to do something. Yet, we were not ready on any level. First, the college budget did not allow us to maintain existing levels of undergraduate labs, let alone establish expensive new ones. In addition, with years of discussion behind us, we were not prepared to get involved in CAD for public relations sake. This meant that we had to be prepared to justify our position to a Dean's office that was feeling pressure as well.

Indeed, our experience had created the belief that we should carefully follow a basic systems natural law:

*"If you don't know where you are going, you won't know when you get there."*

Corollaries to the law are:

*"It won't matter in which direction you go, because Murphy will be your travelling companion."*

We had also learned the following truisms by this time: "You know when a computer salesperson is lying when his/her lips move," and "The only difference between a computer salesperson and a used car salesperson is that the used car salesperson knows when he/she is lying."

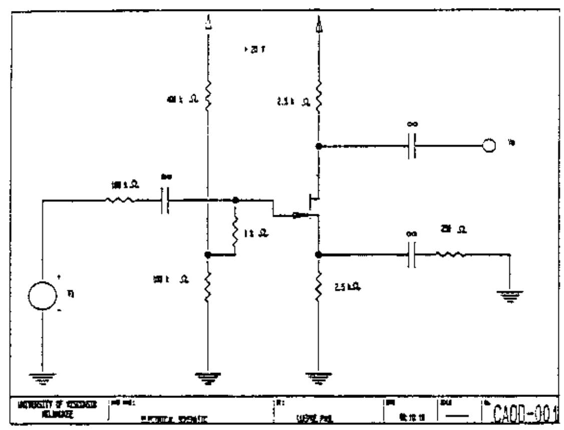


Figure 3

Unfortunately, academics have also been known to tell good stories about "new" developments.

The following refined set of design criteria had been developed by the end of 1982:

I. Limit negative impact on existing course content.
   A. Short learning curve.
      1. Interactive.
      2. Menu driven.
   B. Extended graphics functions.
      1. 3-D modeling.
      2. ANSI drafting standards.
      3. IGES data transfer module.
      4. Calculation features.
      5. Layers and color are desirable.

II. Low cost:
   A. System - maximum of $7,000 per work-station.
      1. Hardware
      2. Software
      3. Furniture
   B. Annual Operation: Added TA staff ?
   C. Annual Maintenance: 10-12% of capital investment.

III. Avoid Copyright problems.

IV. IBM PC/MS-DOS compatibility.

V. Human Factor Consideration.
   A. Work space.
   B. Lighting.
   C. Display Resolution.

## TESTING A BASIC WORK-STATION

Early in 1982 we sensed that some monies would be available in the 1983-84 academic year, and that is was time to put the conceptual design in a more concrete form. Knowing that any computer purchase would go through a standard bidding process, we needed to establish a specific set of product standards that would be compatible. When the amount of money available was known it became obvious that we would be able to experiment with a small set of components, but not install the minimum number of workstations necessary to install a set of units in the course. Since we were still probing the definitions of CAD, opportunities to expand our thinking were a high priority. This meant that more than one graphics program was selected and we would indulge ourselves with the purchase of a 3-D digitizer when a good deal presented itself.

We were able to purchase the following items and began to explore the real world of computer aided graphics:

I. Hardware
   A. Columbia Data PC.
      1. 2- 360K Drives
      2. 512 K RAM
      3. 8087 Co-processor
      4. IBM color graphics card.
      5. Amdek color monitors
   B. GTCO Digitizer Tablet w/stylist.
   C. Micro Control 3-D Digitizer
   D. Hewlett-Packard 6-pen, B-size plotter.

II. Software
   A. Advanced Space Graphics by Micro Control Systems.
   B. Fast Graphs.
   C. First Draw.
   D. Vector Sketch by GTCO.

The 1982-83 year provided us with some very valuable learning experiences. First, we relearned that the term compatibility is one of the most misused terms in the business. It makes no difference who made the assurances that items were compatible, until one learns to ask very detailed and specific questions, problems of interface will occur at every level. In spite of compatibility problems, we know that we would always need to build a system from components. The premium cost of turnkey systems would always be out of reach of our budget.

Second, we learned what had already been suspected: that great care would be needed in the selection of teaching assistants or project assistants. Computer science students abound with basic knowledge and desire to get involved, but they most often wish to play with the system rather than tune the system for useful work. When they view the lab as a computer graphics playground, rather than a place for novices to do graphics work, more problems are created than solved. Thus, we looked for knowledgeable engineering students that have a good technical work experience for these positions.

It was at this time that we deliberately selected the term CADD (Computer Aided Design/Drafting) for the lab. We found it important and necessary to educate students, faculty, and administration alike that computer graphics is in the domain of the computer scientist/engineer, and that drafting/drawing is still the main engineering function of the system. We understand that the goal is to develop a component of a CIM (Computer Integrated Manufacturing) system and a paperless environment. Yet, we believe that for many years to come "the paperless factory is as real as the paperless bathroom."

At the end of this trial year, we were pleased that the design criteria seemed to be sound. We also were assured that funds would become available over the next several years to build a complete CADD facility.

## INSTALLATION OF PHASE ONE OF THE CADD LAB: 1984-85

Funding for 1984-85 allowed us to think in terms of 8 workstations. It was our judgement that a 16-station lab would meet our goal of including at least 3 assignments per student per semester.

When Micro Control Systems announced the introduction of CADKEY in the fall of 1984 a trip to the company was arranged in order to check the program. The timing was perfect; this was the software that we have been looking for the past several years. In addition to the 3-D capability, the menu was less cryptic than AutoCad and other programs reviewed. After talking to the Micro Control people we were convinced that the program would grow in the directions that our design criteria had pointed us. This was the first program that we reviewed that showed a clear understanding of the need of the product designer/drafter. Not only was the price right for educational institutions ($495 per copy), but the hardware protection scheme used by CADKEY eliminated our concern of copyright problems.

Two additional concerns were identified at this time. One was the need to be able to provide demonstrations to class size groups. The second was to realize that any lab developed would have to be a multiple purpose facility. Video equipment was added to the purchase order. Flexibility was to be maintained by committing to stand alone computers, rather than terminals networked to a hard disk. Our preference for stand alone workstations was also influenced by earlier observations of crisis at some installations when the main system went down.

As a result, the following purchases were made:

I. Hardware,
- A. 9- Columbia Data PC's, configured as previously purchased w/ GTCO digitizers [One w/10MB harddisk & video board for experi mentation and backup]
- B. 1- HP 6-pen plotter
- C. 2- IBM Color Printer.
- D. 1- video tape recorder.
- E. 2 - 25" TV monitors

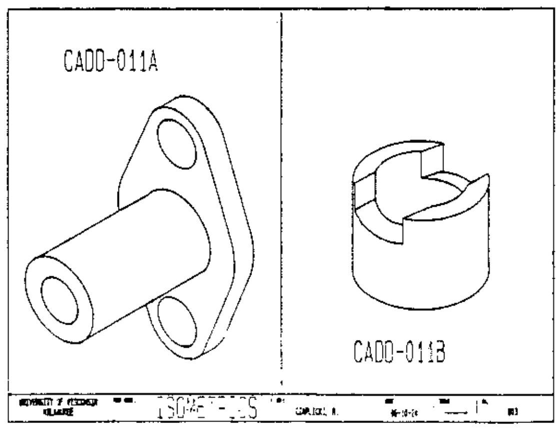


Figure 4

II.Software,
- A. 10- copies of CADKEY, version 1.1

With this equipment, an 8-station lab was established, and 2 stations were assigned for faculty development. The video equipment was an immediate hit, but is used much more often for other A/V needs in the department than for graphics. However, remember earlier comments about compatibility and computer salespeople. Even when you have learned to ask the right questions, correct answers are not assured. A basic problem is that the IBM Color Printer is not supported by CADKEY, even though we were assured by three IBM salespeople that its protocol was the same as that of the EPSON printer.

Since the new facility was not completed until late in the school year, it was made available to a variety of students on the personal request basis. This provided us with the opportunity of observing students under a wide range of conditions. We gained some understanding of how students would use the system under conditions of specific assignments, and when left to their own devices.

A major shortcoming of the lab was the furniture. While furniture was included as a human factor condition early in our planning, it was one item that was deferred due to limited funding. Four inexpensive computer tables were purchased, but proved to be inadequate.

## COMPLETING THE CADD LABORATORY: 1985-86

As the 1985-86 academic year approached, it appeared that sufficient funding would be available to complete the lab. Although it was not clear that a high resolution color capability could be installed, funding was to be sufficient for improving the furniture situation.

A new consideration was the desire to be able to provide a limited resource for people to examine and compare different software. It appeared feasible to add copies of several other micro computer CAD software.

Several new problems also appeared on the horizon. While the Columbia Data computers were operating well, it appeared that the manufacturer would not survive. This later proved to be true.

Second, CADKEY software was in the process of growing in size because of the addition of many new functions, and new versions would no longer work on a floppy disk system. In order to purchase machines with hard disks, something would have to be given up.

Standard operating policies for the lab had received some thought, but still needed detailed discussion and definition.

Another development within the College appeared to be in our favor. The Dean and University Administration had agreed to develop a college CAD facility based upon recommendations of a faculty committee. The specifications of this new lab seemed to offer the opportunity to utilize it as a backup, or supplementary facility for our needs. In addition, telephone conversations with CADKEY personnel hinted that an updated floppy disk version might be available at a future date. Thus we held to our original equipment specifications.

We immediately began to design a workstation after failing to find a suitable commercial table or desk. After several cardboard models were evaluated a final design sketch was prepared for vendor bidding (Figure 1).

The selected vendor's bid used a leg on the desk that was adjustable from a height of 25-32." Since this leg was of the same make as other tables to be used in conjunction with this and other labs, it would also provide desired flexibility. The only bid that integrated the divider panel into the desk design was too expensive. Separate semi-acoustical divider panels were purchased. When the table components arrived it was determined that we had assumed too much. While the vendor specified 4 legs when only 3 were needed, appropriate leg bracing was not provided. Rather that enter into protracted negotiations with the vendor when we were already behind schedule, it was decided to provide braces separately using department supplies, expense funds, and our labor. The extra legs are being used by other department faculty in a CAM lab being developed this year.

Attention was also given to chair selection. The plan called for a chair with casters, and a back. Previous experience with drafting chairs had indicated that adjustable backs and seats created too many maintenance problems. A standard 4-legged, upholstered desk chair with casters was selected. It was reasoned that the adjustable table height would allow the table and chair to be matched in an acceptable manner. This has proved to be a correct judgement.

The following equipment was purchased to complete the lab:

I. Hardware.
   - A. 10 - Leading Edge, Model D PCs w/2-360K drives, 640K RAM, 8087 Coproces sor, Hercules graphics card, and Monochrome/ orange monitor.
   - B. 10 - SummaSketch digitizers, w/puck.
   - C. 2 - HP A-size, 2-pen plotters.
   - D. Houston 14-pen, D-size plotter.
   - E. 2-JDL Dot Matrix Printers (emulates 4 other printers)
   - F. Limelite Computer Projector.

II. Workstation Furniture.
  A. 16- 'L'-shaped table w/shelf for CPU.
  B. 20- Chairs, 4-legs w/casters.
  C. 20- Partitions, 42" high x 48" wide.
  D. 4-Adjustable, Printer/plotter stands.

III. Software
  A. 10- copies of CADKEY, Ver sion 2.0
  B. AutoCAD
  C. MegaCAD
  D. Prodesign II
  E. Generic CADD
  F. Draphix II

The Leading Edge computers were selected because experience had indicated that the higher resolution of the monochromatic monitor was to be preferred to the resolution of the standard color cards. A review of human factors literature indicates that the orange monochromatic monitor was to be preferred choice. The budget did not permit an upgrade to the higher resolution color graphics boards and monitors.

The Summa Sketch digitizers resulted from a special opportunity that bundled them to the purchase of the additional CADKEY units at a considerable savings. By this time the GTCO Digi-Pad 5 digitizers were old technology and were found to require different switch settings to configure them to each different graphics software program. This was a significant inconvenience. Now with nine months experience, we find that the pucks used with the new tablets are much preferred to the stylist on the GTCO tablets. We will replace the stylists with pucks at the first opportunity. A single Houston D-Size plotter gives us the added capability of producing larger drawings.

The video monitors worked adequately for small groups, but were not adequate for groups of 50 or more. Thus, a portable monochrome computer projector (LimeLite) was purchased to increase our ability to give demonstrations to large classes. This projector received heavy use this summer and fall. As soon as the computer science faculty knew of its existence it really became mobile.

The new equipment was completely installed by March 15, 1986, and the CADD lab has been used since that time. Figure 2 shows the final lab layout. One detail that we don't talk about is how sufficient electrical power was jerry-rigged for the lab.

During the summer of 1965, Autodesk, Inc., made an offer to distribute copies of AutoCAD to selected schools. A short proposal was quickly written and was successful in obtaining 8 copies of this software. One copy is available in our lab for examination purposes. The other copies are distributed throughout the College. AutoCAD is the program of choice in the School of Architecture on our campus.

Many of the added purchases were made possible by the dropping prices of basic equipment produced slack in a budget created a year earlier.

By the Fall of 1985, planning for the College CAD facility was completed. We were able to have significant input during the final stages of this project due to the fact that the faculty committee involved had not spent time on detail specifications for the IBM AT's and a number of ambiguities resulted. In addition, no provision for furniture was made for this lab. By providing services to this project we were able to insure that the PC/AT's would be compatible with our graphics needs, and also obtain better prices on our lab furniture when the order size increased by 20 complete workstations for this second lab. As a result of these efforts we decided to contribute an additional 10 copies of CADKEY, Version 2.0 to this second lab from our budget. The payoff of this contribution will begin next semester.

## CADD LABORATORY ACCESS AND UTILIZATION

The lab has operated at near capacity often during the past semester. Students in three different courses used the lab for at least one assignment. Students in the freshman engineering graphics course completed 3 assignments as part of normal weekly assignments, and an extended semester project. About 1/3 of the sophomore design project teams used the lab for drawing related to their semester design projects. About 1/3 of the graphics section populated by pre-architect students decided to do their final course project on CADD. Other students were allowed to use the lab on a fill-in basis. This group of students were required to give up their seats as soon as demand for space by an authorized student existed.

The lab is only scheduled for class sections during the first three weeks during initial demonstrations when students also format and make copies of CADKEY on the disks they have purchased. At all other times the lab access is controlled by a computer card system. Each student purchases a card for a nominal cost. The card is registered with each course enrollment related to the CADD lab and access is programmed. Currently the card allows access 8:00 a.m. to 10:00 p.m., 7-days per week. Each use of the card in the system is recorded by the controlling computer.

The lab is unsupervised for the better part of each day. Since the drafting labs are within a short distance from the CADD lab, the graphics staff divide their normal scheduled supervision time between the manual drafting and CADD labs. In addition, teaching assistant's offices are located directly across the hall from the CADD lab and are easily consulted during office hours. One ten-hour per week TA position was added to cover general hardware and software maintenance needs.

Except for a problem of securing a large enough inventory of cards to begin the program, the system has worked with surprising effectiveness. Card loss was much less frequent than predicted. Once a student has purchased a card, it may be used every semester that the student is enrolled in a course related to this or a number of other labs.

## CURRENT CADD ASSIGNMENTS

We believe that it is unlikely that the graphics course will contain more than 30% CADD assignments in the near future. In fact, we do not believe that a higher percentage will be justifiable for many years. Recent changes in the undergraduate Electrical Engineering program reduced the graphics course enrollment by at least 40% this year. This allowed us to add CADD content to the graphics course beyond that originally planned.

## ASSIGNMENTS

Assignment #1 is a 2-D drawing. The purpose of the drawing is to introduce the student:

1. To the computer system, including elements of the MS-DOS operating system.
2. To basic CADKEY drawing, editing, and data management functions.
3. To different types (part, pattern, plot) of CADKEY files and how to use them.

Figure 3 shows a typical completed 2-D assignment. Students select a problem from a number of areas: electrical diagrams, room layouts, etc..

Assignment #2 is part that utilized 2 1/2-D modeling techniques. The purpose of this assignment is to provide the student with knowledge of:

1. the differences between 2-D and 3-D models.
2. the difference between using the computer for modeling and/or drafting.
3. additional CADKEY functions that relate to the use of levels (layers), and transformations.
4. strategies for creating multi-view drawings.

Figure 4 shows a typical drawing from this assignment. The selection of views and the format of the final drawing (treatment of hidden feature, etc.) is the student's decision.

Assignment #3 is a dimensioned 2-D multiview drawing. The main purpose of this assignment is to introduce the students to the DETAIL (dimensioning and labelling) functions of CADKEY. This is a relatively short project. Since the students are given the multi-view drawing in a pattern file, and they work from a freehand sketch that they have previously completed (Figure 5).

The fourth and final assignment begins with a layout of a small assembly, followed by the creation of detailed drawings of each part, and an assembly drawing. Students may elect to work as individuals, or in teams of two, after an initial design sketch has been submitted by each person. The project is designed to introduce the students to :

1. decisions required in detail design work.
2. data management requirements of related component parts.

This assignment this semester was the design and documentation of a Vice-Grip pliers. The designs most often followed existing products very closely, containing 8 to 11 parts. Some students created complicated geometry that they later found to be very difficult to dimension. Of course, some students only learned to save and back-up their files after a disaster had occurred. The staff also learned much, probably much more than the students.

## FUTURE NEEDS AND DIRECTIONS

Funding this year is limited to upgrading the computers with hard disks. Of course, a new (compatibility) problem was discovered with the Columbia Data machines. It was just discovered that the ROM in this machine is actually a set of three EPROM chips. The EPROMS in each model of this machine were programmed for a specific configuration. Thus, a floppy disk machine is not programmed to read an additional hard disk drive. It has not yet been determined if a feasible solution to the problem exists. We may end up using the existing funds to purchase additional Leading Edge machines and begin phasing out the Columbia Data PCs to lower priority uses.

The CADKEY people solved two problems with the recent release of Educational Version 1.4. This unprotected version of CADKEY can be used in PCs with 2 floppy disks and the file structure is the same as the Version 2.1. We believe that Version 1.4 provides all the functions necessary for a first course in graphics, However, compatibility with current full Version 2.1 will allow us to move 10 additional CADKEY protection modules (SIMs) to the PC/AT in the 2nd College laboratory and provide the graphics students with a backup facility. At this point in time, CADKEY has become the de facto standard in the 2nd lab and many upperclass students have already requested that CADKEY be made available on all PCs. The installation of Version 1.4 will take place between semesters.

During the coming year we hope to make progress in the following software related areas by:

1. Expanding the existing pattern file library.

2. Expanding the existing problem assignment file.

3. Securing a site license for SuperSap, a finite element analysis program that is compatible with CADKEY.

4. Beginning to explore potential relationships between the CADD lab and a new CAM lab being developed in our department.

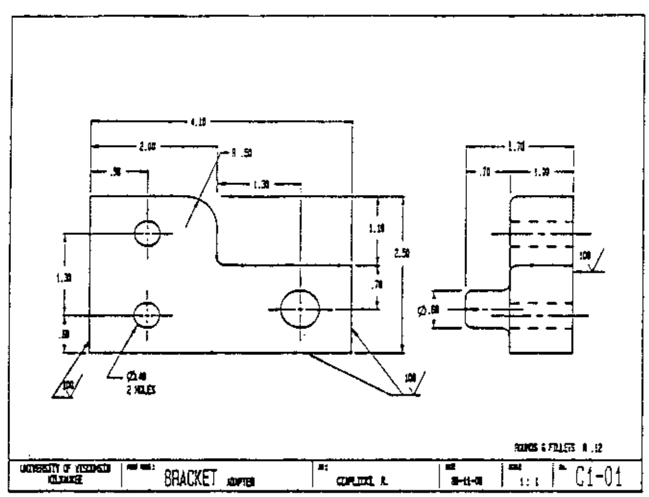


Figure 5

5. Exploring the use of CADKEY's recently announced Learning SoftwareModules.

6. Continuing to explore and develop reference material for 3-D CADD methods for application to typical descriptive geometry problems.

Additional work will be directed at:

1. Improving the coordination of the lab and different courses as student loading increases during the coming year.

2. Developing local standards for 3-D modeling. National standards appear to be many years away.

3. Keeping the CADD software library updated.

4. Continue to explore how CAE (Computer-aided-engineering) developments will change the nature of engineering work and education needs. Example: What is the future impact of expert system programs?

Concerns for the future:
1. Funding for maintenance needs as the hardware ages.

2. Funding to upgrade the performance capabilities of the lab equipment as current micro computer performance standards and student expectations rise.

## SUMMARY

While getting a late start in introducing the elements of CAD into the UWM engineering graphic course, reasonable planning provided for a relatively smooth development of a CADD laboratory over the last 3-years. Unlike the history of pre-CAD graphics since 1900, change will be a constant need as CADD software and hardware continues rapid development over next several decades. It will require much diligence on our part in order to keep track of this moving target and keep the basic graphics course content and facilities within reach of the state of the art. Given reasonable resources, it would be a lot of work, if it wasn't so much fun.

# Using 3-D Industrial CADD Software in a Teaching Environment

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## INTRODUCTION

There is a firm commitment at the Royal Military College of Canada to introduce computer aided drafting and design (CADD) to all engineering students. It was decided to teach CADD by including it in the engineering graphics course, which is given to all second year engineering students. The goals are to teach the students the basics of CADD in general, and to make them aware of its possibilities and its power as a tool in engineering design and communication. On a longer term basis, we want to integrate CADD into the conventional graphics course and to use it to reinforce the students' understanding of pictorials, orthogonal views and descriptive geometry.

## CHOICE OF THE CADD PACKAGE

Generally speaking, a CADD package should be rich in low level entities such as points, lines and arcs, and manipulation of these entities should be easy. However 2-D CADD packages which usually meet these conditions can only be used to teach automated drafting and cannot easily assist in teaching 3-D visualization. On the other hand, a full 3-D CADD package can be used to teach these principles but its complexity may mean that more time is required to teach each particular engineering graphics topic.

In an attempt to resolve this issue, and to gain some insight into the problems involved in teaching CADD to undergraduates, experimental courses were run in 1984-85. We began with a fourth-year elective course on computer-aided design and computer-aided manufacturing (CAD/CAM). The software used was ANVIL-4000 installed on a Honeywell DPS-8 mainframe running the CP-6 operating system. At the time, the choice of a CADD package was easy; ANVIL-4000 was the only one available running on our computer.

When the time came to introduce CADD in the second year Engineering Graphics course, it was decided to use the available ANVIL-4000 on an experimental basis before committing ourselves to purchases of additional hardware and perhaps different CADD software. The aims of this experiment were to test the usability of industrial-grade software in a first course of engineering graphics and to gain some hands-on experience with CADD teaching at that level. The decision to use ANVIL-4000 was made despite our fears of overwhelming the students with the numerous features available in a 3-D industrial package. If proven successful, it would allow the use of the same CAD/CAM package to teach at all levels of the engineering curriculum.

## IMPLEMENTATION OF CADD IN THE ENGINEERING GRAPHICS COURSE

Ten percent of the engineering graphics course was devoted to CADD for the first time in the fall of 1985 and the experiment was repeated in the fall of 1986 with minor adjustments. Some provisions were made to ensure that the knowledge acquired by the students was not too heavily related to the particular software used.

CADD was introduced after nine hours spent on conventional techniques such as multiple views and isometric projections. It consisted of:

- a two-hour lecture on CADD in general and on the menu layout of ANVIL-4000.
- One hour of familiarization on the graphic workstation.

In the summer of 1986 a manual was prepared containing the information needed to use the CADD software on the mainframe. It includes information on accessing the system, plotting the drawings, management of the database, brief description of frequently used menu items and some introductory exercises on points, lines arcs and circles. The students were asked to do these exercises and then the first real challenge came when they had to reproduce the front view of a part as illustrated in their reference text (see Figure 1).

Other exercises followed on dimensioning, cross-hatching of sectional views and one 3-D model. A total of five tutorial hours with instructors were used for these exercises. They had to spend some extra hours on their own to complete the work.

The timetable was prepared to allow one terminal for each student (an arrangement we consider essential). From 7 to 10 terminals for each instructor was maintained during tutorial sessions. The scheduling was complicated because we possess only 14 graphic workstations and almost 100 students were enrolled in the course.

## RESULTS

The results obtained during these two years of CADD instruction in the engineering graphics course were very encouraging. Emphasis was put on 2-D drafting because of a lack of time and hardware to teach 3-D modelling systematically but one test showed that nothing would prevent us from doing this.

Student enthusiasm started high and increased. Fears of problems associated with complexities related to industrial strength software proved to be groundless. Even if only a few items of the multi-layered menus were presented in class, students took the others as a challenge and often "explored" them on their own. When students were asked to produce their first drawing (Figure 1), some of them dimensioned it, even if nothing had been said in class about dimensioning or its menu items in ANVIL-4000. We are now convinced that a full-featured 3-D CADD package can be used effectively in a 2nd year engineering graphics class.

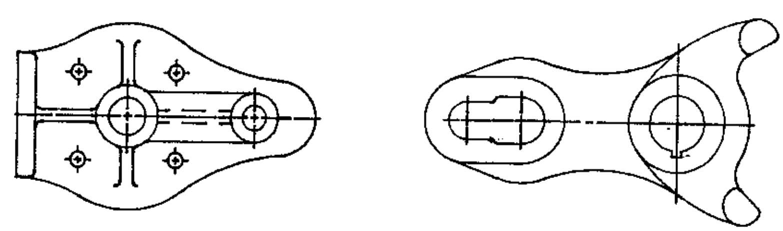

Figure 1

## OBSERVATIONS AND REMAINING QUESTIONS TO BE ADDRESSED

Some important questions remain to be addressed. It is comforting to discover that students do not seem to be bothered by the many features of a 3-D industrial package. But we still do not know what is the real effect of the use of CADD on the learning of engineering graphics.

There are two main goals in an engineering graphics course:

1. to teach the technical graphics language,
2. to develop students' ability to visualize and solve problems in three dimensions.

These two goals are strongly interconnected because 3-D visualization is needed to make good drawings. But the importance of the second goal is also due to its applications in many other aspects of engineering. An example is the design process, where sketches are generated from an abstract concept. From these sketches, technical drawings are produced. Although improvements are being made in this area, CADD is still weak in helping the user to produce sketches and lay-outs. These activities are generally thought intensive and require the user to visualize the part currently designed.

CADD can easily be used to learn

the technical graphics language but it is much harder to implement it so as to reinforce three-dimensional visualization. In the pre-CADD era, 3-D visualization was taught with various exercises on orthogonal views and descriptive geometry. We intend to continue in the same way. CADD must not replace descriptive geometry per se but must reinforce the principles emulated by these techniques. A new way of solving problems may be applied but the original goal must not be forgotten. The computer relieves the user from most of the manual work, but it cannot do the thinking.

## FUTURE PLANS

In the future, we want students to become fluent users of CADD so that CADD can be used as a tool for teaching graphics and not a subject by itself. As an example, understanding of relation between the views can be improved by watching a modification on a part presented in windows on the screen with the three principal views and an isometric view. Beginning this autumn, we intend to increase the time spent on graphic workstations to 40% of tutorial time. We also intend to teach more of the design capabilities of modern packages.

In the proposed curriculum, each regular engineering graphics subject will be covered in the following fashion:

1. Brief lecture on the subject in class.
2. Easy exercise solved on paper to immediately reinforce knowledge gained during the lecture. These exercises are solved on paper to ensure minimal interference between the student and the subject to learn.
3. More sophisticated exercises solved on paper and on graphic workstations.

The full integration of CADD in the 2nd year Engineering Graphics course will require much pedagogical effort to ensure that CADD is used to improve understanding of the usual topics of the course and re-enforce knowledge gained with conventional means. The students must not be distracted by this toy with flashing lights and must not lose contact with the real subject they are learning. An example would be the student who thinks he understands dimensioning on the screen. The first exercise on a particular subject may be done on the workstation only if the students are fluent enough on the system to make it quite transparent so it does not interfere with their view of the subject.

Since it is impossible to convert 40% of the course to CADD with only 14 graphics terminals, it has been decided to acquire twenty-five stand-alone graphics workstations linked in a network. The final choice of the CADD package has not been made yet and the bidding process is still in progress. It will definitely be a state-of-the-art 3-D industrial package which will also be used for the fourth year CAD/CAM course and will be linked to the numerically controlled machine in the machine shop. Using the same industrial CAD/CAM package in second year and in fourth year class is welcomed by both students and professors for an obvious reason; they only have to learn one user interface.

## CONCLUSION

Our experience has shown that it is possible to introduce sophisticated CADD software and hardware to students with little or no technical drafting experience and have them to respond effectively and enthusiastically. Many students told instructors that they prefer to produce drawings on graphic workstations rather than by using pencil and eraser. They like the feeling of being able to make mistakes and correct them without leaving a mess on the paper.

The response was convincing enough to lead to a full integration of CADD in the Engineering Graphics course starting next year. We are confident that 40% of the tutorial time can be spent on the workstations without altering the regular curriculum of the course too much. A full-featured industrial CAD/CAM industrial package will serve our needs well.

8. All articles shall be written using Metric-SI units. Common measurements will be accepted at the descretion of the editorial staff.

9. Send all material in one mailing to:

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