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CONTRIBUTED PAPERS

ENGINEERING DESIGN GRAPHICS DIVISION
AMERICAN SOCIETY FOR ENGINEERING EDUCATION

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"SilverScreen is very easy to use and learn. The graphics capabilities are fantastic! The product makes it very easy to manipulate solids, change variables, and understand file structure. This package exceeds the capabilities of any PC-based systems I have worked with."

Richard Fleming, Industrial Technology Institute
Ann Arbor, Michigan

This is just one of many responses to SilverScreen, a revolutionary new software product from Schroff Development Corporation, which was featured at a recent seminar for educators. The seminar was held in the Kansas City area August 2-3, 1989.

What is SilverScreen?

SilverScreen handles 3D drawing, solids modeling (using Boolean operations), shading and presentation graphics in a DOS-based software.

Of special interest to educators is SilverScreen's site licensing offer. The cost of a site license covering all computers used at a school is $500. This is quite a substantial savings over the retail price of $3,000.

Other comments heard during the seminar include:

"SilverScreen makes the transition from 'real world' 3D to CAD 3D easy. The software executes rapidly and outperforms the shading and surfacing of other CAD software systems."

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"SilverScreen is an extremely powerful and interesting product. I think that we are looking at the next generation of graphics software today!"

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Johnson County Community College
Overland Park, Kansas

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Ed Lovitt, Johnson County Community College
Overland Park, Kansas

"I like the 'real world' approach to creating solid geometric objects quickly. Modifying is like machining or drilling on a solid if you like."

G. Richard Thomas, Oklahoma State University
Stillwater, Oklahoma

"Of the 3D CAD packages available for education, SilverScreen is the most logical and comprehensive. A real joy to use and teach!"

Mary A. Jasper, Mississippi State University
Mississippi State, Mississippi

"I am impressed with the power and the potential of SilverScreen. Great Product!"

Bruce Taylor, University of Arkansas
Fayetteville, Arkansas

"I found SilverScreen a very fast and powerful PC-based solid modeler."

Ali Manesh, University of Arkansas
Fayetteville, Arkansas

"This 3D modeling system is very friendly, full of meaningful helps when needed and is tailored for the users."

R.E. Pollock, St. Louis University
St. Louis, Missouri

"SilverScreen is much more friendly to use and my students will find it much easier to learn, control and be successful with."

Steve Gillespie, TAD Technical School
Kansas City, Missouri

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Stephen J. Schroff
Schroff Development Corporation
P.O. Box 1334
Mission, Kansas 66205
(913) 262-2664

SilverScreen TM

Some Geometric Operations for Solid Modeling

Ronald E. Barr and Davor Juricic

Mechanical Engineering Department
University of Texas at Austin
Austin, Texas

Solid modeling is inherently reliant on the use of three-dimensional primitives to build the solid model. This building process uses the Boolean operations of union, difference, and intersection on solid primitives to build higher-order geometry. However, most commercial solid-modeling systems accommodate an expanded list of geometric operations beyond Boolean operators. These capabilities include unary operations on solid primitives, designing custom primitives using revolution and extrusion, and the addition of geometric details, such as chamfers and fillets. Various types of geometric operations available in the typical solid modeling system are described. An example of building a solid model using operations available on the IBM CATIA system is given as an illustration.

Introduction

Geometric modeling is the process of constructing a precise mathematical description of the size and shape of a real object. These geometric attributes of the object are described in a way such that computers can interpret and store the data. Geometric modeling is inherently reliant on computer-assistance, and in many ways geometric modeling techniques have advanced concurrently with development of new computer technology.

According to Mortenson[1], there are three distinct phases in the process of geometric modeling. They are:

1. *Representation* of the physical size and shape of the object using the model builders inherent in the computer system;
2. *Designing* or changing the model to meet some functional engineering criteria, usually based on the outcome of computer analysis; and
3. *Rendering* of the image for visual interpretation and documentation using computer graphics.

All of these aspects have some interrelationship, since they use the same common data base. In addition, for future successful application of geometric modeling to engineering practice, a fourth phase to modeling which must be addressed is identified as:

4. *Detailing* the model so that adequate information exists for

fully automated manufacturing of the object.

When applying computer-aided geometric modeling to a specific engineering problem, different approaches to the development of the model are available. For three-dimensional modeling, wire-frame, surface, and solid modeling packages have their distinct attributes. For design of mechanical parts, solid modeling is preferable since it describes precisely the space enclosed and occupied by the object rather than the boundary-surfaces or edgelines, which only imply object space.

The Solid Modeling System

The solid modeling system consists of an interactive graphics workstation and associated software for building the model, displaying it on the screen, and storing the model data base. The workstation consists of a processing unit, high-resolution color display, and interactive devices, such as a mouse and tablet, for user input commands. The modeling software, through its internal representation scheme, accepts the designer's commands and mathematically creates or modifies the solid model. The model itself consists of a systematically arranged set of data files residing in computer memory. The rendering software consists of programs used to view the model, such as projection algorithms, hidden surface algorithms, and shading routines.

The way the solid model can be represented in computer memory can vary from one system to the next. However, most systems will employ one of three possible techniques:

1. Boundary Representation (B-Rep),
2. Constructive Solid Geometry (CSG), or
3. Spatial Subdivision.

The boundary representation solid model is formed using a detailed topological data file that relates all faces, edges, and vertices of an enclosed space. The faces can be simple planes, hollow cylinders, or more complex patches. The B-Rep approach is convenient for positioning and moving objects in space since model re-draw is quick. The CSG approach uses a tree data structure consisting of all primitive operations, in proper order, that are used to build the model. This results in a logical and efficient use of computer memory. Spatial subdivision systematically divides an object space or universe into 3-D volume leaf cells called "voxels". A voxel then becomes the smallest solid piece of the larger solid object. The solid object is built into a large data structure which simply identifies which voxels in space are filled and which are empty. These various methods for internal representation have been delineated earlier by Barr and Juricic[2].

Base Primitives for Solid Modeling

The most recognizable feature of a solid modeling system is a set of base primitives used for constructing the model. Although there is no universal standard for this set of 3-D primitives, most systems are agreeable within the most fundamental solids (box, cylinder, cone, and sphere). One set of primitives for geometric wireframe modeling on a small CAD system was proposed by Barr, Juricic, and Lam[3]. This set of seven primitives consists of a box, wedge, pyramid, cylinder, cone, cone frustum, and sphere. Each primitive is defined by a set of parameters and outlined by a basic number of graphical data points that are used to draw the wireframe outline. With the addition of unary operations, the primitives can be sized and positioned anywhere in space. Some typical primitive sets used by various modeling systems are listed in Table 1.

User-Defined Primitives

In addition to providing a set of base primitives, a large majority of newer, commercially available solid modeling systems provide also solid primitives that can be custom-created by the user. The available routines make it possible to design an infinite variety of different solid forms. But in order for them to be solid primitives, which means amenable to all unary operations and Boolean (binary) operations between all other primitives and any combinations of them, these custom-made solid forms must be defined only according to some precisely formulated rules. Any geometric element created by following these formal rules is then supported by its modeling system. Included with any complete modeling system are all the necessary analytical tools for manipulation and combination of geometric elements, such as surfaces and edge-lines, of the basic and the custom-created solid primitives.

Because of the complexity of analytical tools needed, which increases with the square of the number of different geometric elements involved, the present modeling systems have very restricted rules for creating custom solid primitives. The lines are usually limited to straight lines, circular arcs, and a few, if any, spline-types. The arbitrary sculptured surfaces, if available, are usually one specific patchtype. The rules im-

Barr, et al[3]	IBM CATIA	Hewlett-Packard ME 30
Box	Cuboid (Box)	Cube
Wedge	Prism	Block
Pyramid	Pyramid	Prism
Cylinder	Pipe (Cylinder)	Cylinder
Cone	Cone	Cone
Cone Frustum	Sphere	Sphere
Sphere	Torus	Torus

Table 1: Base Primitives

posed on defining the primitives lead to only a few simple families of custom primitives which are today the industry standard. Nevertheless, the available custom primitives are a very powerful addition to present modeling systems.

The following operation rules produce the custom solid primitives frequently found in present modeling systems.

1. *Sweeping* is the most frequently available operation for generating custom primitives. It involves a two-dimensional element, a surface defined by a closed line (a section), that is "swept" along perpendicularly to the surface, creating an extrusion, or it is revolved about an axis defined in the same plane, creating a turned object. The definition of the surface boundary is usually limited to a specific type of spline in addition to straight lines and circular arcs. As an extension to basic sweeping operations, the following variations can be found:

(a) Sweeping a surface along a curved line (a spline) keeping the surface either parallel to itself of keeping it perpendicular to the local tangent of the curved line;

(b) Sweeping a surface along a straight or curved line and scaling the surface along the way.

Figs. 1 and 2 illustrate the process of generating and finishing a simple custom primitive made by using the sweeping technique.

2. *Lofting* operations used in creating solid primitives are analogous to lofting done in aircraft and ship-building industries to define precisely the curved surfaces enclosing ribs and bulkheads. A series of two-dimensional surfaces is defined as cross-sections of an envisioned primitive, and a surface is then generated, with a prescribed technique, to "skin" smoothly the positioned cross-sections. The solid primitive is then defined by having the surface closed on itself and capped by the two end cross-sections, or by giving some thickness to an open surface.

3. *Sculpturing* or face generation is an operation that generates an arbitrary surface and assigns it to a simple primitive (for example, a block) as one of its faces. A solid primitive generated in this way can then be used to transfer this sculptured surface to other primitives or to a combination of primitives. The generated surface is arbitrary in the sense that any arbitrary surface can be approximated, but this has to be done only with those particular techniques that are built into that particular modeling system. The techniques frequently include Bezier patches, bicubic patches, or surfaces generated by lofting (de-scribed above).

Unary Operations

Unary operations are performed on one primitive at a time. Some of the more common unary operations are:

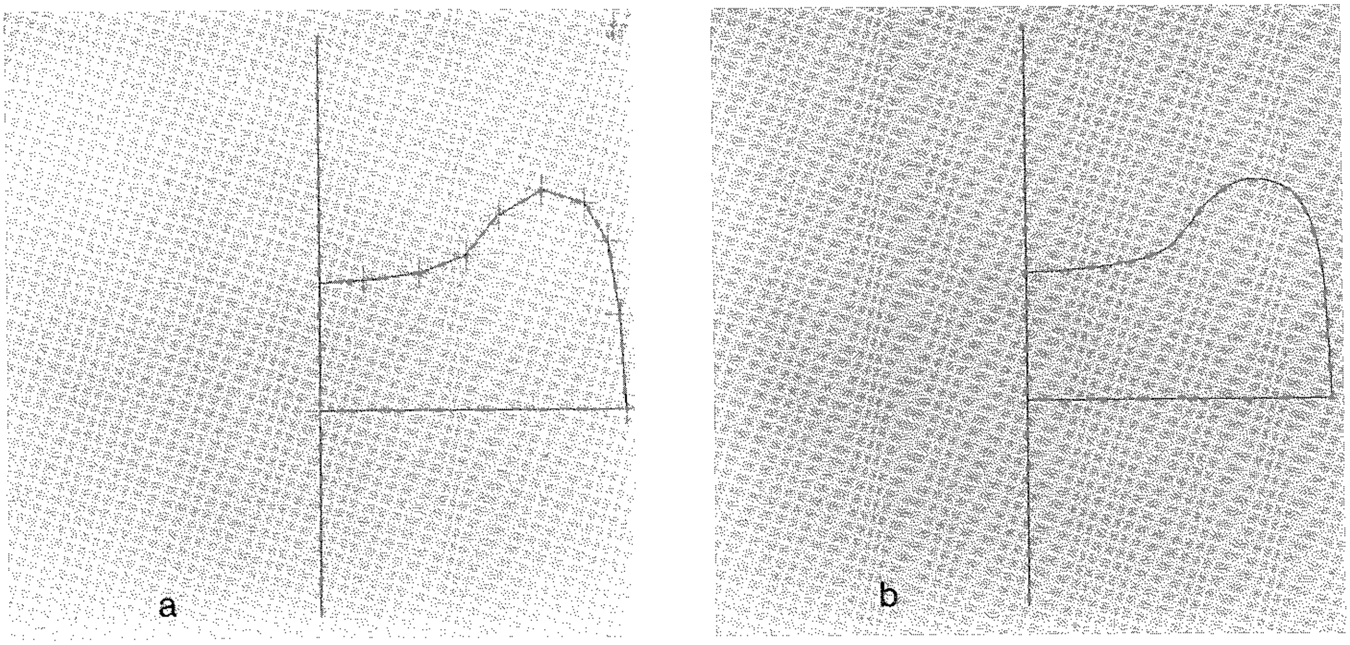


Fig. 1 The sequence of generating and finishing a custom solid primitive using the sweeping technique is shown in this figure and Fig. 2. A curved line, to be the top boundary of the generating surface, is specified by several points (a), through which a cubic spline is drawn (b). The rest of the boundary is a straight line. Thus, a cross-section, in this case a half-section of a body of revolution, is defined with available standard elements - straight lines and cubic splines.

1. Copy
2. Mirror
3. Scale
4. Stretch
5. Transform

When a primitive is first placed on the screen, it will most likely not be in the correct position and/or orientation. The transform operation is used to rotate the primitive and to translate its center to a new X,Y,Z-coordinate. If more than one primitive of the same kind are needed, the copy operation is used to replicate the initial primitive. The mirror command is used if a second primitive is a reflection of the first primitive. The reflection can be about any major axis. The primitives are all initially normalized to a default size. Hence, a scale operation is used for uniform sizing in all three dimensions, or a stretch operation can be used to selectively scale differently in the X, Y, and Z directions.

Binary (Boolean) Operations

Operations that involve two lower-order primitives are called binary or Boolean operations. These operations are based on set theory which has a well-founded and compact mathematical basis. The standard Boolean operations

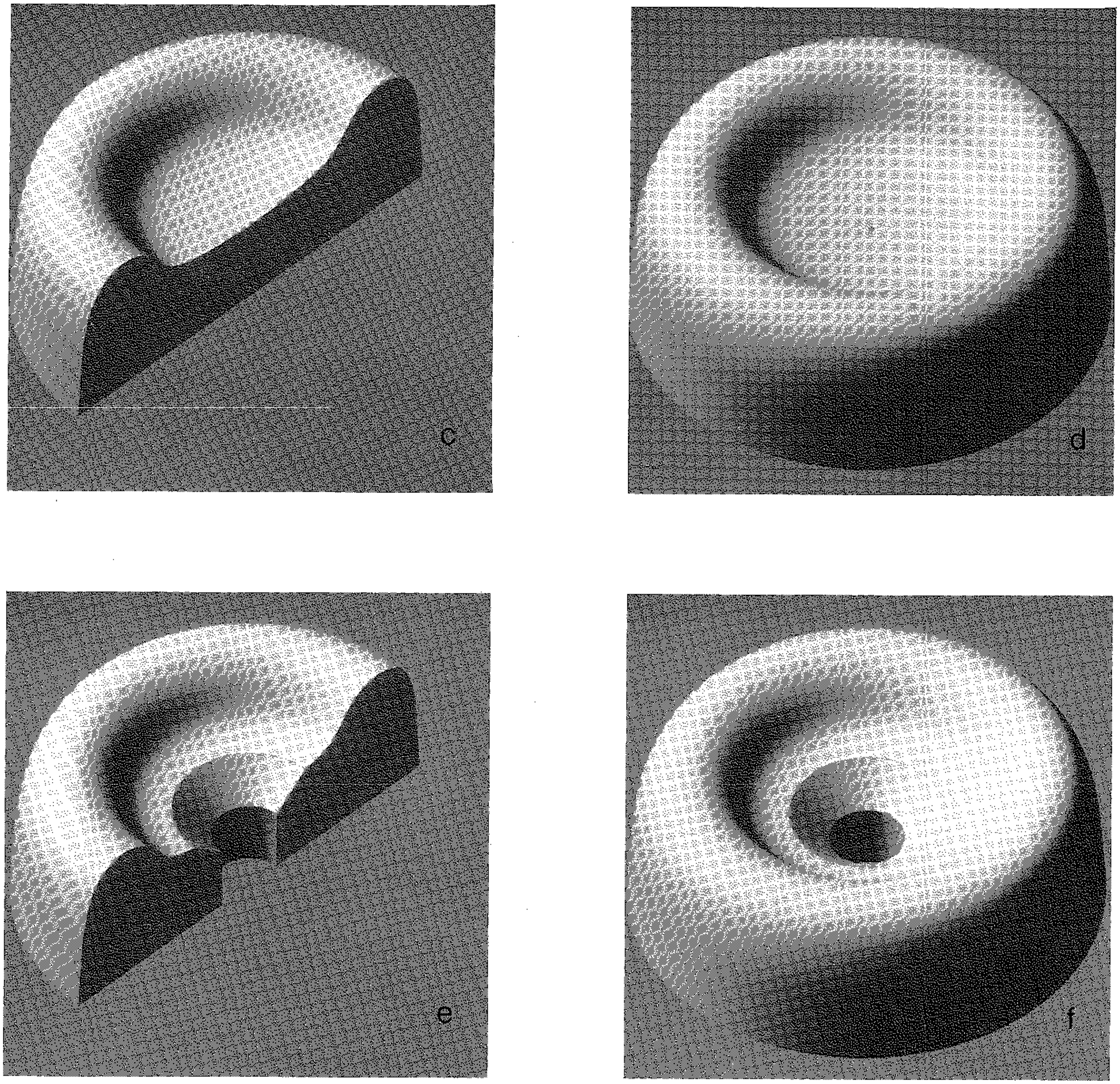


Fig. 2 The 2-D section, which was obtained as described in Fig. 1, is swept by revolving it either for a given angle (c) or for a full turn (d), so as to generate the necessary solid primitive. The primitive is used to build the final part. Here, it was obtained in a difference operation with a cylinder first to obtain the hole, and then with an inverted cone for countersinking, (e) and (f). The illustrated procedure was intended to produce the shape of a rubber bumper shown here in isometric projection (f).

are:

1. Union
2. Intersection, and
3. Difference.

A union operation is the joining of two objects to occupy all space previously occupied by either object. Intersection is the joining of two objects to occupy only that space common to both. Difference, or subtraction, requires first the ordering of the two objects, and retaining only the first object after the space common to the two objects (intersection) is subtracted from it.

Detailing and Machining Operations

Boolean operations on base primitives permit the creation of a vast array of geometric parts. However, some finishing operations are better handled by specific detailing functions. *Blending* is the rounding of trihedral vertices of an object. *Chamfering* is the convex rounding of the intersection of two faces, while *filleting* is the concave rounding of the intersection of two faces. *Tapering* is the gradual narrowing of longitudinal objects.

Some systems have substituted machining functions for their equivalent Boolean operations. *Drilling* or *boring* is an operation equivalent to the Boolean subtraction of a cylinder from a block. *Turning* is a machine operation similar to revolving a cross-section. *Punching* and *stamping* are methods to remove a 2-D cross-section from the object. *Tweaking* is a general term for slight modification of an object, such as pulling one side or changing the radius of a hole.

Solid Modeling Example Using CATIA

The CATIA (Computer-Graphics Aided Three-Dimensional Interactive Application) system is a solid modeling package produced by Dessault Systems of France and licensed by IBM. CATIA uses both CSG and B-Rep techniques for internal representation. The designer can build a model using a library of basic building blocks, such as cubes, pipes, and spheres. Solids can also be specified using revolution and extrusion operations. CATIA produces a history file of the Boolean operations used to construct the model, and this history can be replayed later to modify the object. Advanced color shading enhances on-screen visualization of the solid model, which is normally displayed in wireframe form during the construction phase.

The CATIA system was used to construct a mechanical part similar to the one illustrated on page 441 in Mortenson's text *Geometric Modeling*[1]. A shaded picture of the part is shown in Fig. 3, and the sequence of steps used to build the model are illustrated in Figs. 4 - 11.

The CATIA workstation presents the user with a number of interactive input devices. The devices have specific keywords which are used throughout the captions of the example illustrated in Figs. 4-11. The term *PRESS* means the user presses

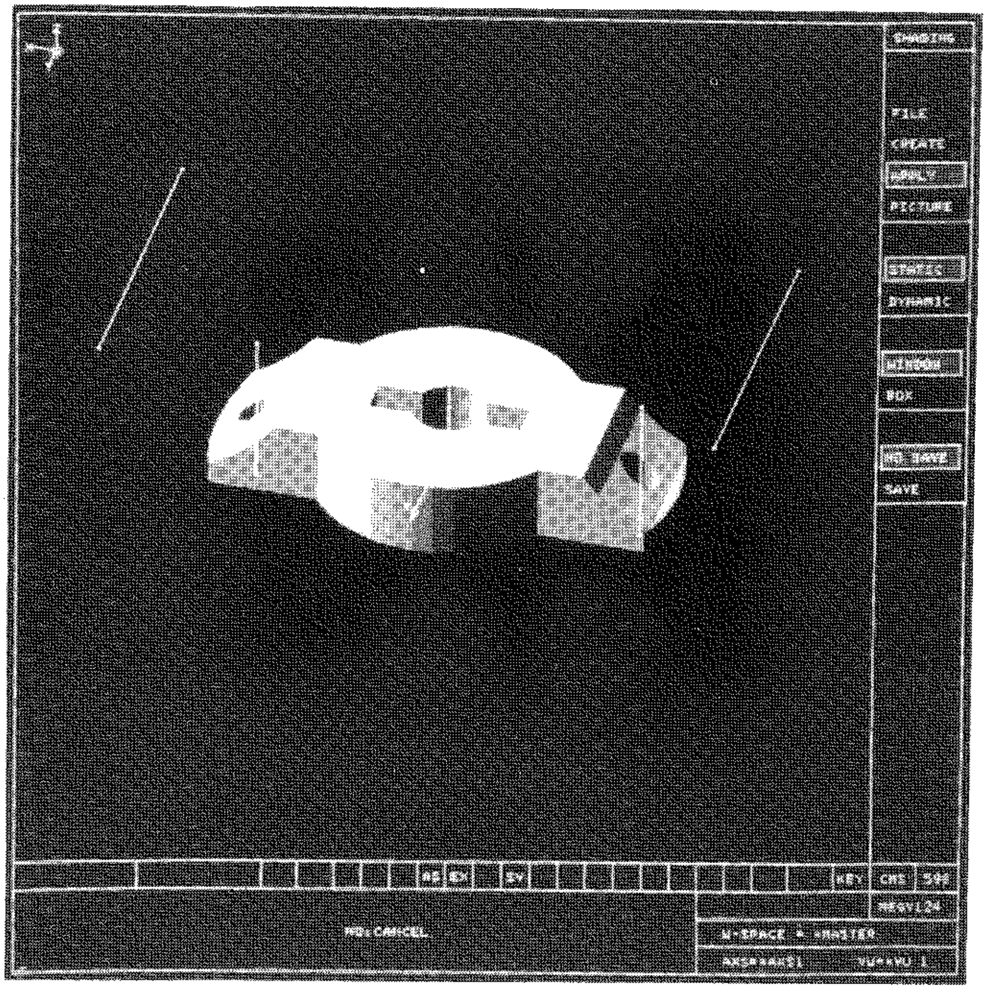


Fig. 3 The shaded picture of the part modeled by using the CATIA system as described in Figs. 4 - 11.

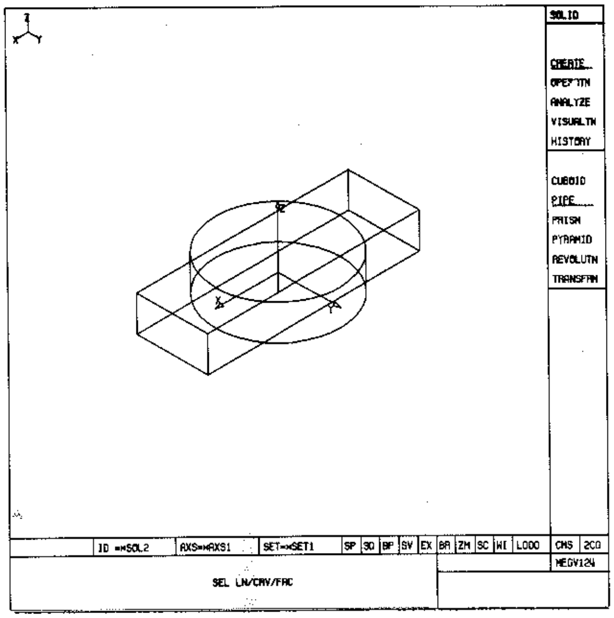
down one of the labeled function buttons on the Program Function Board. The term *SELECT* means that the user moves the cursor on the screen (using a puck on a tablet) to a menu item on the screen, and then presses the button on the puck. This effectively selects that menu item to be the current command or operating mode. The term *KEY* means that the user types a number or command from the keyboard.

References

[1] Mortenson, M., *Geometric Modeling*, John Wiley and Sons, New York, NY, 1985.

[2] Barr, R. and Juricic, D., "Three-Dimensional Graphics Modeling", *Engineering Design Graphics Journal*, Vol. 50, No. 2, 1986, pp 13-19.

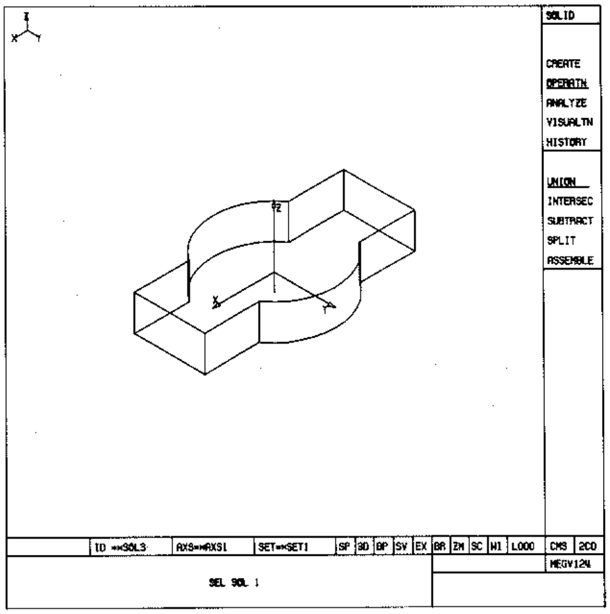
[3] Barr, R., Juricic, D., and Lam, T., "Interactive Procedures for Geometric Data Entry and Modeling on a Small Educational CAD System", *Engineering Design Graphics Journal*, Vol 47., No. 2, 1983, pp 15-24.



ID =*SOL2 AXS=*AXS1 SET=*SET1

SEL LN/CRV/FAC

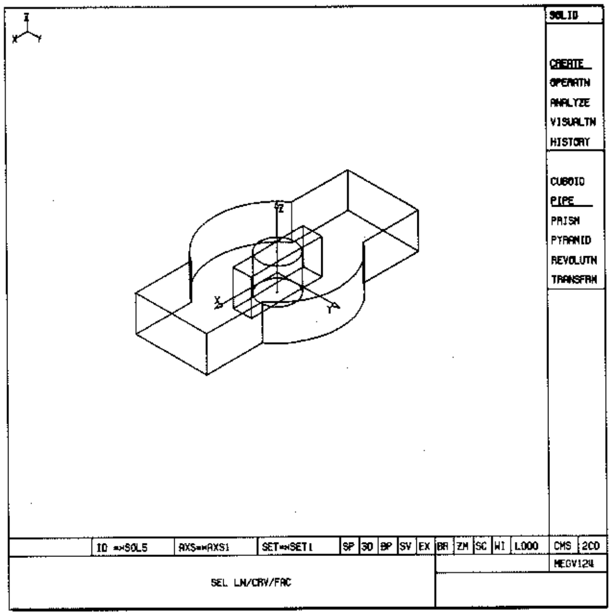
Fig. 4 The user **Presses** the **Solid** button to get to the **Create** menu. Two primitives, a **Cuboid** (box) and a **Pipe** (cylinder) are selected. The size dimensions of the primitives are keyed-in at the keyboard. They are both centered at the origin.



ID =*SOL3 AXS=*AXS1 SET=*SET1

SEL SOL 1

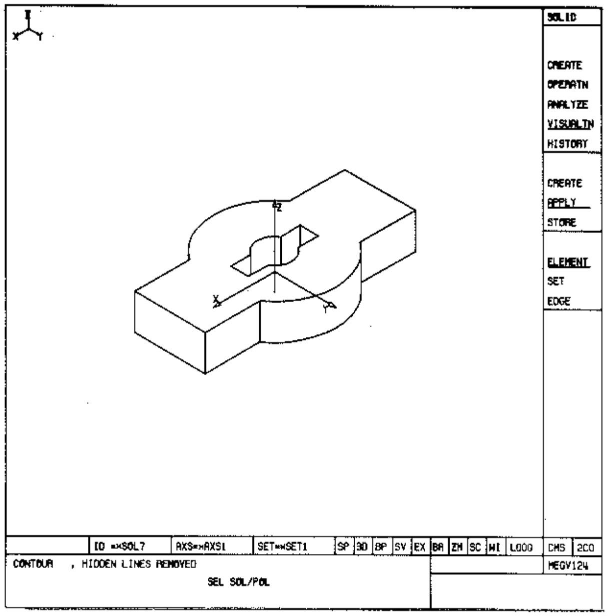
Fig. 5 The user selects the **Operation** menu. The cuboid and pipe are joined using a **Union** operation.



ID =*SOL5 AXS=*AXS1 SET=*SET1

SEL LN/CRV/FAC

Fig. 6 A smaller **Cuboid** and smaller **Pipe** are selected in the **Create** menu to form a keyhole at the origin. The sizes are keyed in at the keyboard.



ID =*SOL7 AXS=*AXS1 SET=*SET1

CONTOUR , HIDDEN LINES REMOVED

SEL SOL/POL

Fig. 7 The keyhole solid is formed using the **Union** operation, and the keyhole is then **Subtracted** from the larger base solid. To assist in visualizing the object, hidden lines are removed by selecting the **Visualization** feature.

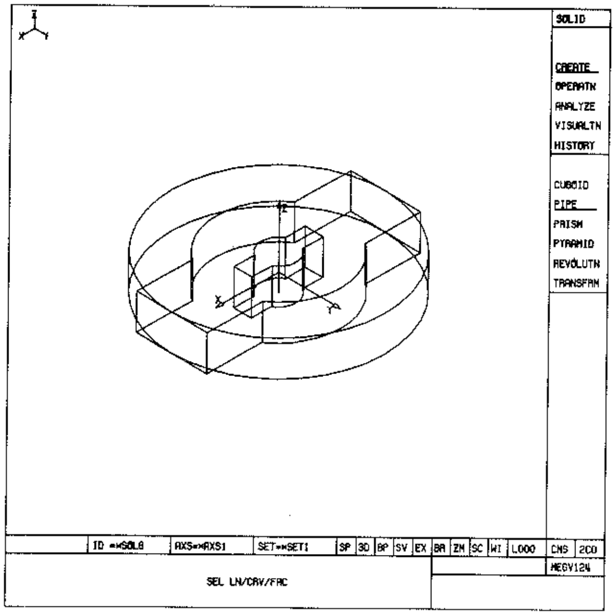


Fig. 8 A large thin **Pipe** is **Created** and centered on the solid object. The pipe is **Intersected** with the solid to round the ends of the lugs.

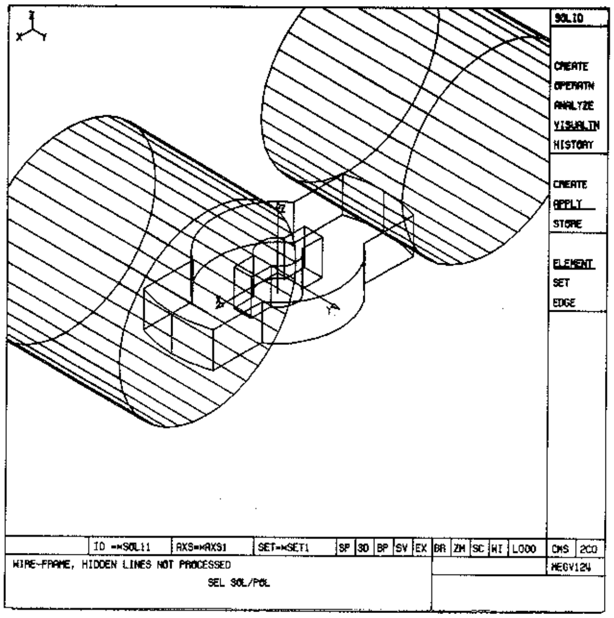


Fig. 9 Two large **Pipes** are centered over the two lugs. The pipes are then **Subtracted** from the model to create filleted lugs.

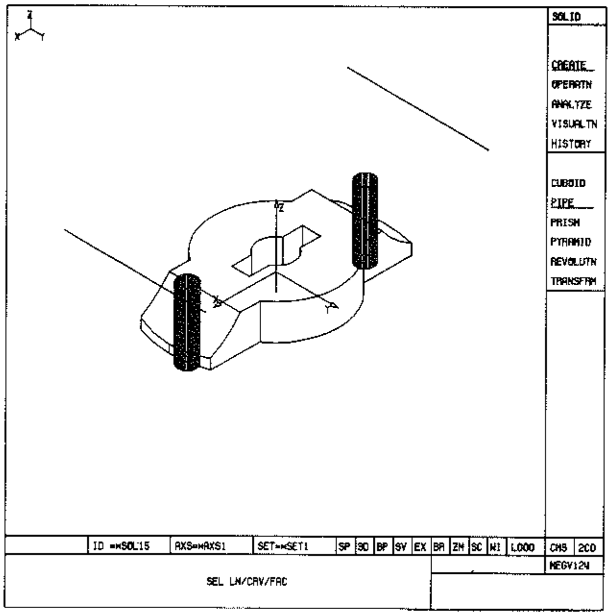


Fig. 10 Two **Pipes** are **Created** and centered at the end lugs. The pipes are then **Subtracted** from the solid model in order to drill holes in the lugs.

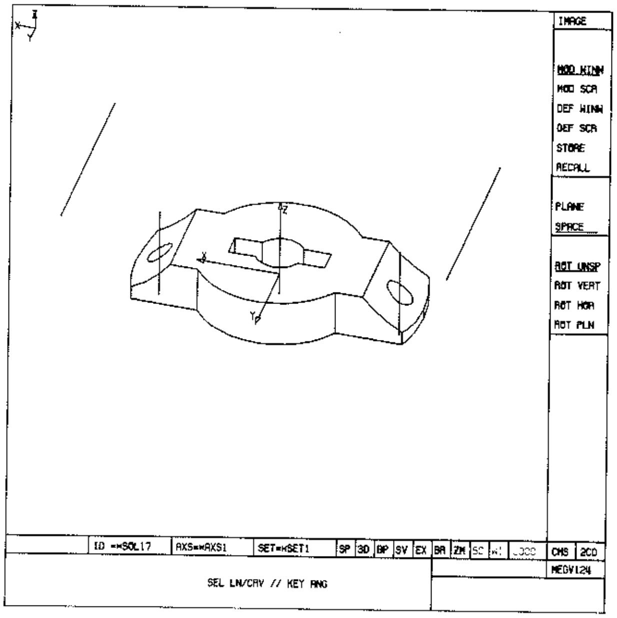


Fig. 11 The user **Presses** the **Image** button. The **Space Rotation** menu is **Selected** to view the final model.

Design for Success

Gary R. Bertoline

Engineering Graphics
The Ohio State University
Columbus, Ohio

Integrating design projects into a curriculum can be an excellent opportunity for students to develop creativity, experience the design process, and apply engineering graphics principles. An existing course at The Ohio State University has been integrated with design problems from a local school for the mentally and physically disabled. The design problems were developed to give meaningful design experience to students and at the same time provide assistance to disabled students at the Franklin County Early Childhood Education Center. The relationship with the school, which provided design projects and financial support, is described. The details of "Design for Success" are provided so that others can implement or use some of the ideas from this technique of teaching engineering graphics and design.

Introduction

Design for Success has been used successfully on two different campuses by the author. It was started about six years ago at the branch campus of Wright State University in Celina, Ohio. This was a small campus of approximately 1000 students, half of which were enrolled as two-year engineering technology majors. It is also being successfully used at The Ohio State University in Columbus, Ohio. This university has approximately 50,000 students. Design for Success has been integrated into the second graphics course in a three course sequence for industrial design and industrial technology education majors. In addition, this method has successfully been used at other universities, such as Northern Michigan University, and the branch campus Indiana University/Purdue University of Fort Wayne, Indiana[1].

At a time when instructors of engineering graphics are looking for widespread acceptance of this area as a necessary component in engineering education, activities such as the one described here can enhance the image of the design graphics profession. Engineering graphics is an important part of a designer's education. In the past some have taught graphics without regard to its application for the designer. Is there any wonder why some in engineering education and industry feel that engineering graphics is a subject that can be left out of the curriculum?

The Problems with Traditional Design Projects

One recurring problem has been finding design problems that are both challenging and meaningful to the students. There are a few good textbook problems, but many of these have little value or meaning to the student. Their motivation for completing the design problem is to obtain a "good" grade. With this type of problem students go through the motions in an artificial design environment created by the instructor. Another problem with textbook design projects, such as the very successful egg-drop problem, is that the students never have a chance to interact with persons concerned with the project, such as the client, engineer, or those on the shop floor. These are some of the reasons that a different approach to teaching the design process was sought.

One reason for integrating the design process into a traditional engineering graphics course is to give meaning to the subject through practical applications. Engineering graphics is a required course for many students in engineering, technology, architecture, interior design, product design, and other areas. For these students engineering graphics can become just another required course. At The Ohio State University, the student is encouraged to understand why engineering graphics is such an important subject for their success as a designer or graphic communicator.

For years the second course in graphics at The Ohio State University taught dimensioning, tolerancing, section views, and pictorial drawings. This was followed by a textbook design problem. The author has taken the approach that engineering graphics is the tool used to communicate designs graphically for production and/or communications. Therefore, the design projects should integrate as many of the engineering graphics concepts taught in class with the experiences and personal goals of the students. This is accomplished by introducing the design problem early in the ten week course. As new engineering graphics topics are introduced, the students are told how they are useful for documenting their design solution. For example, when dimensioning is introduced, the students are instructed on why and how dimensions are used on their design projects. An attempt is made to totally integrate engineering graphics and design.

The Normal Needs of a Special Population

The second goal of Design for Success is much more subtle but just as important as the first. Higher education of any kind should be a liberating experience for the student. Engineering design graphics can teach students more than the standards and techniques required to communicate graphically. Graphics can become the tool used to apply human technology to the solution of problems. Ideally the use of technology in society can be used to solve social problems that cannot be solved by other means. Thus, the second goal of Design for Success is to provide assistance to the disabled population. This population can benefit directly from the technical expertise of our students and faculty. As E. Paul Goldenberg[2] stated:

> "However, it is not their 'special' needs with which I am primarily concerned, but their 'normal' needs. What links these children together also binds them to the rest of humanity: their needs to have an enjoyable and estimable life and to be able to interact satisfyingly with their environment and its people, things, and demands. Sometimes we require special techniques and technology to help us meet our needs. Only when these are wanting are we truly handicapped."

Design projects based on the needs of mentally and physically disabled students can be found in most states through the local school for the mentally disabled. A rich source of design projects was found at the Franklin County Early Childhood Education Center in Columbus, Ohio, which serves the mentally disabled from birth through age six. It was found that the disabled children had a tremendous need for adaptive devices and design changes of existing toys and apparatus, as well as general needs within the classroom. Students will not only benefit from working on the design problems, but also they will become more aware and share common interests with disabled children. For many students and children, this would be a new and hopefully a positive and liberating experience.

Developing the Design Projects

The engineering graphics course director met with administrators and teachers form the Early Childhood Education Center to discuss possible design projects. From this meeting a number of project ideas were developed. One design project is selected for each term. The class is divided into design teams consisting of five or six students. The design problem is presented orally to the class by the instructor and in written form (Fig. 1). In the future, a representative for the Center will help with the presentation to the class. Fig. 1 shows that the students are given some background information about the Center, the purpose of the design, the problem statement, the design criteria, the design process, and the expectations of each of the design teams.

A group leader is chosen by each design team and the team is given approximately five weeks to solve the problem. During that five week period, each team can arrange a time to visit the Center to ask questions and present possible design solutions for their evaluation. They are encouraged to look to others on campus or in the community for ideas and possible solutions. This is the opportunity for the students to experience working with a client and searching for the expertise necessary to solve the design problem.

Grading Criteria

Each design team is expected to give a professional oral presentation of their design. They are also expected to create a set of

EG 204 DESIGN PROBLEM
Autumn 1988
INFANT & MULTIHANDICAPPED ACTIVITY CENTER

The Early Childhood Education Center offers an early intervention program for infants and children from birth to age 6 in Franklin County. These children have delays or special needs in any area of development. Research has shown that early intervention is effective in helping children develop to their fullest potential. Each child has an individual educational program for all areas of development including; language and communication, problem solving, social emotional, motor, play and self-help skills.

For children who have significant disabilities, conventional toys, educational material, and adaptive devices may not be appropriate or are inadequate. If properly designed, toys, educational material, or adaptive devices can be used successfully. Your challenge is to use your talents and experiences in engineering graphics and design to solve the problem explained below. This is an opportunity for you to become involved in a "real" design problem that will be of direct benefit to your educational experience and for the children and teachers at the Early Childhood Education Center. Although the time and effort will be significant, the experience will be valuable and gratifying.

PURPOSE OF THE DESIGN

The design problem assigned to EG 204 is to apply engineering graphics to the communication of a design solution. This is accomplished by creating a set of working drawings that will be used for the production of a product. Working drawings combine many of the engineering graphics techniques that have been learned into a single integrated set of drawings.

PROBLEM STATEMENT

So, you want to be a designer or teach design! This problem will give you an opportunity to experience the design process, and use the engineering graphics communication techniques you have learned. The Early Childhood Education Center is in need of an infant and multihandicapped activity center. Its purpose is to encourage parallel play activity (kids playing near each other/noticing each other but not cooperating with each other). You might think of this activity center as a large "Busy Box" (see attached photocopy). Basic play schemes included are: pushing, pulling, opening, shutting, sliding and rolling. This activity center must be accessible to children who are standing, sitting, prone on floor, and with or without motor limitations. The activity center must also be easy to clean and not easily tipped over.

Fig. 1 The design problem

DESIGN CRITERIA

1. Accommodate 0-3 year old developmentally and/or cognitive delayed children.
2. Enough room for two or three children including one wheelchair or walker.
3. Must be safe and durable, easily cleaned and not easily tipped over.
4. Encourage independent play but each child must be in sight of each other.
5. Include pushing, pulling, opening, shutting, sliding, and rolling activities.
6. Provide for self awareness with a mirror.
7. Provide for tracking activities by looking at moving objects.
8. Some auditory activities.
9. Exploring space.
10. The activities must be accessible to children who are:
    Standing (with support)
    Sitting independently
    Prone or on floor
    Sitting in adaptive chairs with or without motor limitations (some walking, some rolling, or crawling).
11. Material should be relatively cheap, and easy to fabricate, such as plywood.
12. Integrate as many existing toys into the activity center as possible.

THE DESIGN PROCESS

The design problem will be solved using the team design approach. Four to six students will be assigned to each design team. Each member of the design team will be responsible for "actively" developing design solutions. Each design team must appoint a spokesperson who will present the design solution to the class verbally and in written form. The remaining members will be responsible for graphically communicating the design to the class and providing a set of engineering drawings to be used for production of the design solution. **The design solution, class presentation, and all drawings are due Tuesday November 29, 1988.**

THE DESIGN TEAM REQUIREMENTS

1. An oral presentation of the design solution presented in a professional manner.
2. Development of appropriate visual aids and other media using your expertise as designers, illustrators, for the oral presentation.
3. A "brief" written report to include:
   a. The problem statement
   b. Assumptions
   c. Analysis
   d. Description of the final design solution

Fig. 1 (continued)

4. A complete set of working drawings following proper engineering graphics conventions using traditional tools and/or CADD. The drawings to be included are:
   a. Detail drawings of non-standard parts including dimensions, sections, and other techniques necessary to produce the part.
   b. Assembly drawing(s) and parts list.
   c. Pictorial drawing(s) where appropriate to further communicate the manufacture or assembly of the design.
5. Develop a design notebook containing:
   a. Abstract- title, school, names, total hours.
   b. Written report
   c. Design sketches

GRADING

All right, enough about the problem! The bottom line is how is this assignment going to be graded? We are glad you asked. Each individual in the group will be given a grade based upon the group's design solution and their individual contribution to the group effort. The group spokesperson will be evaluated primarily on their oral presentation and written report.

1. Individual grade- 25 points, based upon the contributions to the visual aids and the working drawings and the quality of the work. It may work best to have each individual of the group take responsibility for completion of a certain part of the required drawings or visual aids.

2. Group grade- 25 points, based upon the design solution using the design criteria listed above.

The best design solution will be voted by secret ballot. Sorry, you will not be able to vote for your own group. Decision of the judges is final. Ties will be broken by the instructor. Undo efforts to influence the voting of individuals by bribery, threats, or other unlawful acts will result in the group's immediate expulsion from the competition.

SUMMARY

Part of this learning experience is to develop your ability to work in a group. You are expected to give your best effort and contribute fully to your group. This is a very difficult design problem that will take time and all of your creative genius to solve. Your group is required to think independently to solve the problem. Given the design criteria solve the problem. Ask your instructor for guidance but do not expect answers to the design problem. Your instructor does not have the solution to this problem because it is a unique problem that no one has ever solved. This is your opportunity to solve a "real world" problem. The ultimate goal of this design problem is to construct the winning design for the Early Childhood Education Center. GOOD LUCK AND HAVE FUN!

The Early Education Center will allow the EG 204 classes to visit the school to assist you in developing your designs. Your instructor will make arrangements for the date and time.

Fig. 1 (continued)

working drawings, including detail drawings, assembly drawings, parts lists, pictorials, and appropriate visual aids. They are required to develop a design notebook containing a written report and sketches.

Presentations are given to the class and representatives of the Center. The instructor collects the design reports and drawings for grading and each team is evaluated and given a final grade by the instructor. Each design is also carefully evaluated by the representatives from the school and they decide the winning design, usually the only one which is actually built.

Constructing the Design

To be useful for the Early Childhood Education Center, the design must be built. This is the most difficult part of Design for Success. The winning design team is motivated to see the design construction completed because they are extremely proud of their work and would like to see it being used at the school. They also see the value of having this type of learning experience in their design portfolio and their resumes when searching for employment. Arrangements have been made with the Center to pay for all the materials necessary to build the projects.

Advantages of Using Design for Success

There are many advantages to using this approach for design projects. Design for Success made the students aware of the special needs of disabled children in our society. Students were given the opportunity to solve real problems and interact with the client and other experts. Students had to use resources both on and off campus and had to develop expertise in areas necessary for successful design solutions. For example, in order to solve the design for a project assigned last year, it was necessary that at least one member of each design team learn about bearings. Motivation was much greater when using Design for Success compared to traditional textbook problems. Students also experienced the team approach to design problems. Feedback from the student's course evaluations has been positive and their attitudes toward the design problem is better than they were prior to using practical design problems.

Conclusions

The primary reason for using Design for Success is to provide meaningful design projects for engineering graphics students. However, a secondary and no less important intent is to introduce "normal" students to disabled children in our society. One of the primary reasons that disabled people are not readily accepted into our society is that the "normal" population is rarely exposed to the needs, wants, and aspirations of the disabled.

What is the difference between the handicapped and normal population? One view that can be taken is that there are no handicapped people, only handicapped conditions. That is, if the conditions are right, a disabled person can function normally.

What better use of technology and engineering design than to apply them to the improvement of the human condition? People with common interests and experiences have something to share and it builds the foundation for further improvement. Design for Success has demonstrated that designing for the disabled can be a rewarding experience for all those involved in the process.

Most agree that the need to stress engineering graphics technique is not as important when CADD (Computer-aided design/drafting) is used. It is time to start concentrating on the reasons that engineering graphics is important for design. Teaching a course in engineering graphics without making the student aware of the importance and application of the subject is poor education. Engineering graphics is used to graphically communicate a design for production or illustration. Design for Success can be the vehicle used to illustrate to the students how graphics is used by the designer.

The day that the design project is given to the students, the words of George Washington Carver are shared:

"How far you go in life depends
On your being
Tender with the young,
Compassionate with the aged,
Sympathetic with the striving and
Tolerant of both the weak and the strong
Because someday in life
You will have been one or all of these."

Design for Success can be used successfully to teach the applications of engineering graphics from high school to graduate school, to provide meaning to engineering graphics principles, and to provide a liberating experience for the students, instructor, and the disabled.

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Vectors as a Foundation for Spatial Reasoning

J. Alan Adams

Department of Mechanical Engineering
United States Naval Academy
Annapolis, Maryland

Geometric modeling based upon vector mathematics has developed along with computer graphics and computer-aided design/manufacturing to a high level of capability. It consists of a broad range of theory and techniques used to define shape and other geometric characteristics of objects which are represented by various means within a digital computer. Defining shape and geometric properties has long been the task of descriptive geometry and engineering graphics. These traditional disciplines provide the spatial reasoning necessary to reconstruct three-dimensional information obtained from geometric projections produced on paper. The vector approach to spatial reasoning is the most useful paradigm for many geometry problems which begin with data stored in computer memory. Geometric solutions based upon elementary vector algebra can be presented early in a technical educational program, along with traditional material in graphics and descriptive geometry, in order to lay a stronger foundation for design and manufacturing within a geometric modeling environment. Selected descriptive geometry problems are solved analytically to illustrate how spatial solutions can be obtained without the need for calculus or other advanced mathematics.

Introduction

Most of today's engineering students will work in an environment which provides CADD packages that enable designers to create and analyze highly detailed three-dimensional models. A friendly computer interface that separates the user from the complexities of the modeling and rendering details will be used. Visual displays will be central to the design process, from beginning to end. Documented hard copy drawings may or may not be used in the information transfer process. However, proper reaction to what one sees in a two-dimensional representation of spatial objects is the crux of the entire design process.

What fundamental knowledge must a user have in order to properly interpret and use these visual displays? Spatial reasoning, as well as a basic understanding of information that can be obtained from both visual displays and computer memory, is an obvious requirement. This reasoning and understanding can be enhanced by a vector analysis capability applied to spatial geometry problems. Elementary mathematics can be used for interpretation and interrogation of visual displays, independent of complex mathematics that may be used in the actual geometric modeling of objects. Use of vectors to solve geometry problems closely parallels the use of vectors in engineering mechanics and leads to mathematical techniques useful in both geometrical and analytical design.

Vector algebra can be used to obtain information from two-dimensional visual displays which may aid the designer in making decisions about the suitability of a configuration under consideration. By reasoning in terms of points, lines, and planes, the user can avoid the complexities of calculus associated with curves, surfaces, and solids and can still obtain useful information about the spatial geometry of the proposed design. Geometric modeling is normally presented in advanced texts[1,2], but the basic theory of vector algebra is fundamental to many engineering problems normally associated with descriptive geometry[3,4].

Bounded Lines and Planes

The shortest distance from Point **P** in space and a line passing through points **A** and **B** is given by the equation[3],

$$d = |\mathbf{C} \times \mathbf{D}|/|\mathbf{D}| \qquad (1)$$

where $\mathbf{C} = \mathbf{P} - \mathbf{A}$ and $\mathbf{D} = \mathbf{B} - \mathbf{A}$. Fig. 1 shows the vectors involved. The shortest distance to the bounded line segment between **A** and **B** is equal to d only if the perpendicular from **P** to $\mathbf{B} - \mathbf{A}$ falls at a point within the bounded segment. A point within the line segment is defined by $\mathbf{Q} = \mathbf{A} + t\mathbf{D}$; $0 < t < 1$.

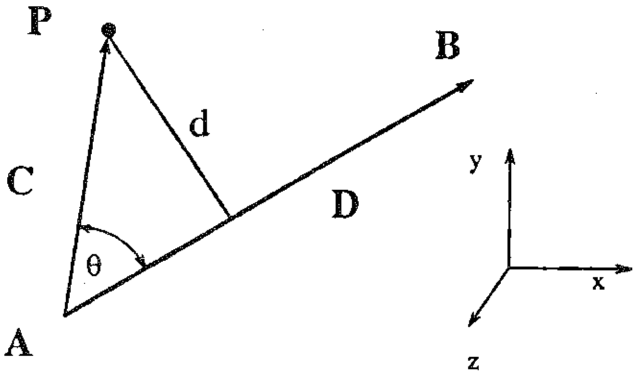


Fig. 1 Shortest distance point to line

If $\cos\theta = \mathbf{D}\cdot\mathbf{C}/|\mathbf{D}||\mathbf{C}|$, then $t = |\mathbf{C}|\cos\theta/|\mathbf{D}|$. If $t < 0$, then distance $\mathbf{P} - \mathbf{A}$ is the shortest distance from **P** to the line. If $t > 1.0$, then $\mathbf{P} - \mathbf{B}$ is the shortest distance.

The shortest distance from a point to an infinite plane is given by:

$$\begin{aligned} d &= |\mathbf{R}|\cos\theta \\ &= |\mathbf{R}\cdot\mathbf{N}|/|\mathbf{N}| \qquad (2) \end{aligned}$$

Here **N** is the normal to the plane and $\mathbf{R} = \mathbf{S} - \mathbf{P}_1$. Fig. 2 shows these vectors.

Lines and planes considered from a mathematical point of view are infinite in extent unless a limit is placed on the scalar parameters in the equations. In most practical problems, however, one is interested in a line segment of a fixed length, or a finite plane facet with specified boundaries. For example, does the point **Q** in Fig. 2 lie within

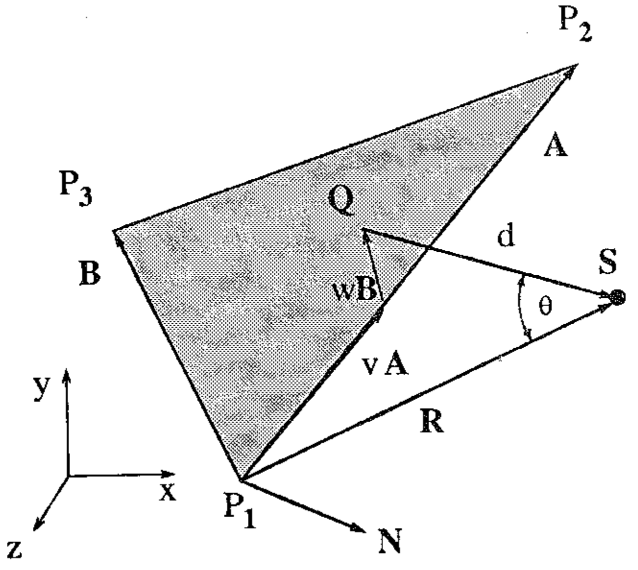


Fig. 2 Distance to triangular facet

the bounded, triangular plane facet shown?

Quite often a system of triangular plane facets are used in geometric modeling or finite element analysis. It is desirable to formalize a general method for determining the location of a piercing point relative to the boundaries of the facet. For this purpose, use the parametric vector equation for a plane given by (Fig. 2):

$$\mathbf{S} = \mathbf{P}_1 + v\mathbf{A} + w\mathbf{B} + d\mathbf{n} \qquad (3)$$

where **n** is the unit normal to the plane defined as

$$\mathbf{n} = \mathrm{N} / |\mathrm{N}|$$

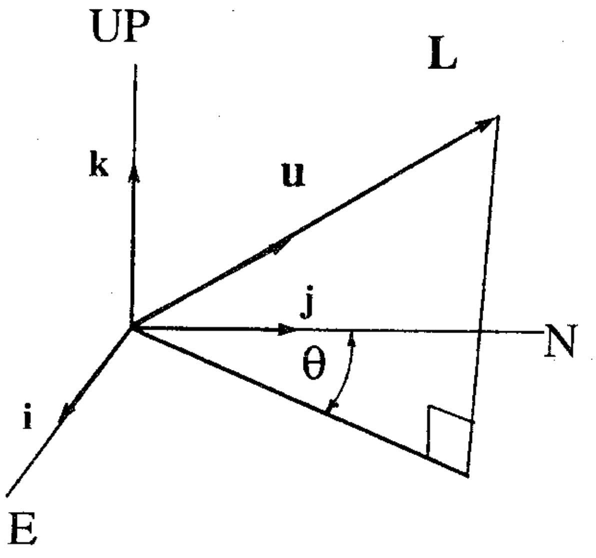
and d is the distance given by Eq. (2). This distance is the shortest distance from the point **S** to the bounded, triangular, plane facet if the parameters v and w, which define the location of the piercing point **Q**, fall within the ranges $0 < v < 1-w$, and $0 < w < 1-v$. If the bounded facet is a parallelogram, then the suitable ranges are $0 < v < 1$ and $0 < w < 1$. If the v,w pair indicate that **Q** is not on the bounded facet, then the distance d given by Eq. (2) is not the shortest distance from S to the facet. One of two possibilities still exists. The shortest distance might be the perpendicular distance to a point on one of the edges, or it might be the actual distance from S to one of the three facet corners. These two possibilities are investigated using calculations for the shortest distance from a point to an edge line as given by Eq. (1), for each edge in turn. If the parameter value t, which defines the point of intersection, is outside the range {0,1} for each edge, then the shortest distance to the facet is the distance to the closest corner.

Directional and Angular Properties of a Line

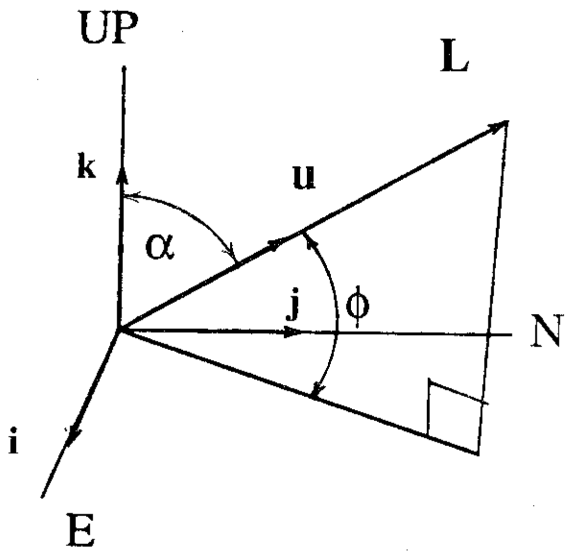
The bearing of a line is independent of the angle that the line makes with the horizontal. If a line is represented by a vector, then its bearing is best expressed in terms of a unit vector. To avoid confusion, a careful choice of unit vector alignments must be made. Choose the unit vector **k** to be vertical and let **j** point North. Then, a right hand coordinate system requires that i point East, as shown in Fig. 3.

The vector **L** in Fig. 3 is expressed in terms of a unit vector **u** in the direction of **L** by

$$\mathbf{L} = |\mathbf{L}|\,\mathbf{u} \qquad (4)$$



(a) Bearing



(b) Slope

Fig. 3 Bearing and slope

where the unit vector is expressed in terms of the coordinate system using

$$\mathbf{u} = u_1\mathbf{i} + u_2\mathbf{j} + u_3\mathbf{k} \tag{5}$$

The scalar components for the unit vector **u** are indicated by $[u_1\ u_2\ u_3]$.

The bearing of line **L** is indicated by angle θ in the horizontal plane in Fig. 3, where

$$\theta = |\tan^{-1}(u_1/u_2)|$$

If $u_2 > 0$ and $u_1 > 0$, as shown, then the bearing is N θ deg E. If $u_2 > 0$ and $u_1 < 0$ then N θ deg W gives the bearing, and if $u_2 < 0$ and $u_1 > 0$, S θ deg E. If $u_3 = 1$, then $u_1 = u_2 = 0$ and bearing is not defined.

The slope of a line collinear or parallel to the vector **L** is the angle ϕ between the line and the horizontal as shown in Fig. 3. The angle α with the vertical is also shown in Fig. 3 and is given by

$$\begin{aligned}\cos\alpha &= \mathbf{u}\cdot\mathbf{k}\,/\,|\mathbf{u}|\,|\mathbf{k}| \\ &= \mathbf{u}\cdot\mathbf{k}\end{aligned} \tag{6}$$

The slope ϕ is then calculated using

$$\phi = 90^\circ - \cos^{-1}(\mathbf{u}\cdot\mathbf{k}) \tag{7}$$

where all angles are expressed in degrees. The value of $\tan\phi$ is expressed as a percent to determine the grade. For example, a slope of 35 degrees upward is a grade of +70%.

In mining and geology the terms *strike* and *dip* are used to define the position of earth strata. A *strike line* is a horizontal line on a plane, and the strike is the compass bearing of that line. If a strata plane is defined (such as by three non-collinear points), then the unit normal **n** to the plane can be calculated and used to help define the strike line.

If the unit vector $\mathbf{k}$ is vertical, then the cross product of $\mathbf{k}$ with any other vector will produce a vector in the horizontal plane (perpendicular to $\mathbf{k}$). The cross product of a unit normal vector to a plane with any other vector will lie in the plane (which is perpendicular to $\mathbf{n}$). Thus, the cross product $\mathbf{n} \times \mathbf{k}$ will produce a horizontal vector lying in the plane normal to $\mathbf{n}$. This vector is on the line along which the strike is defined by giving its bearing. The upward normal($n_3 > 0$) is used so that the angle β between $\mathbf{k}$ and $\mathbf{n}$ will fall between 0 and 90 degrees.

Fig. 4 shows the strike line along vector $\mathbf{S}$ lying horizontally in the plane ABC, where

$$\begin{aligned} \mathbf{S} &= \mathbf{n} \times \mathbf{k} \\ &= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ n_1 & n_2 & n_3 \\ 0 & 0 & 1 \end{vmatrix} \\ &= n_2\mathbf{i} - n_1\mathbf{j} \qquad (8) \end{aligned}$$

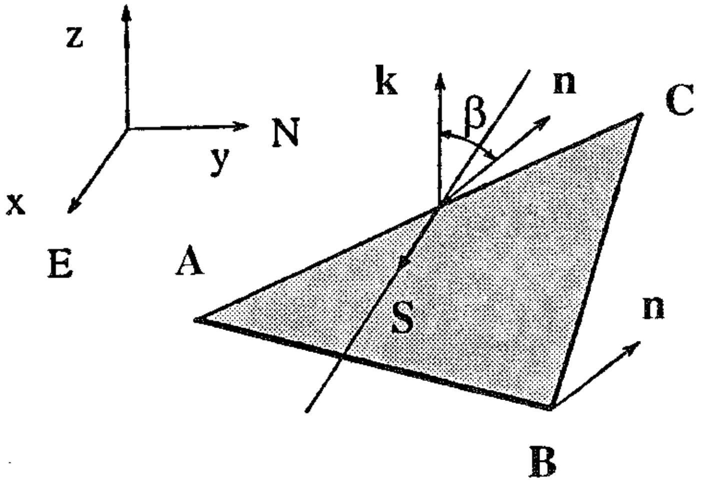


Fig. 4 Strike line

One can also write

$$\begin{aligned} \mathbf{S} &= \mathbf{k} \times \mathbf{n} \\ &= -n_2\mathbf{i} + n_1\mathbf{j} \end{aligned}$$

In order to reference the strike to the north direction (y-axis in Fig. 4), define the bearing angle $\theta = |\tan^{-1}(n_2/n_1)|$. The strike is then specified as N θ deg W. In general, if $n_1 n_2 > 0$ use N θ deg W, and if $n_1 n_2 < 0$ use N θ deg E to specify the strike.

The *dip* is the angle the edge view of a plane makes with the horizontal plane. Let $\mathbf{n}$ be the unit normal to the plane, and let $\mathbf{k}$ be perpendicular to the horizontal plane. Then, the dip is also the angle between $\mathbf{n}$ and $\mathbf{k}$. This angle is indicated by β in Fig. 4, and is calculated using the equation

$$\beta = \cos^{-1}(\mathbf{n} \cdot \mathbf{k}) \qquad (9)$$

The general direction of the plane is part of the dip specification. If $n_2 > 0$, use N, otherwise use S; and if $n_1 > 0$ use E, otherwise use W. A typical dip specification is β deg SE.

A physical interpretation of dip is useful. Place a marble at the top of an inclined plane. When the marble is released, it rolls down the line of steepest descent. This line is also called the *fall line*. The angle that the fall line makes with the horizontal is the same as the dip angle.

Conclusion:

Two problems from classic descriptive geometry, related to the shortest distance from a point to a finite line and from a point to a finite plane facet, have been analyzed from a mathematical perspective to contrast this approach to that of descriptive geometry. Also, the directional and angular properties of a line have been approached in the same manner. The Appendix contains sample solutions which make use of this theory. Other types of geometry problems can be approached in a similar manner.

Most computer codes which produce solutions to these types of geometry problems dealing with points, lines, and planes are based upon similar vector mathematics. Application of basic mathematics allows the user to obtain answers to geometric modeling questions either with or without the aid of a computer or drawing board. It should be a part of the "tool kit" which students take with them after successful completion of a foundation geometry course. The spatial awareness so necessary to correctly interpret engineering drawings will be enhanced by a fundamental understanding of elementary vector algebra.

Appendix

Example 1

Given: An undersea earthquake has created a seabed shift and a new surface is measured by three non-collinear points given by **A** = [0 25 -10], **B** = [30 35 -3], and **C** = [13 10 -23]. (Fig. 5)

Task:

(a) Find the strike and dip for the given plane. The coordinate system used is x(East), y(North), and z(vertical).

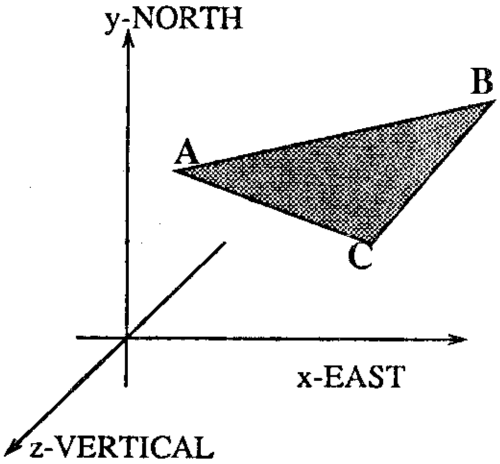


Fig. 5 Planar surface

(b) Find the bearing, grade, and slope of the plane edge from **B** to **C**.

Solution:

(a) $\mathbf{N} = (\mathbf{C} - \mathbf{A}) \times (\mathbf{B} - \mathbf{A})$

$$= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 13 & -15 & -13 \\ 30 & 10 & 7 \end{vmatrix}$$

$$= 25\mathbf{i} - 481\mathbf{j} + 580\mathbf{k}$$

Hence,

$$|\mathbf{N}| = 753.9$$

and

$$\mathbf{n} = 0.033\mathbf{i} - 0.638\mathbf{j} + 0.769\mathbf{k}$$

Therefore

$$\mathbf{S} = \mathbf{n} \times \mathbf{k}$$

$$= \begin{vmatrix} \mathbf{i} & \mathbf{j} & \mathbf{k} \\ 0.033 & -0.638 & 0.769 \\ 0 & 0 & 1 \end{vmatrix}$$

$$= -\ 0.638\mathbf{i} - 0.033\mathbf{j}$$

and

$$\theta = \tan^{-1}(0.638/0.033) = 87.04 \text{ degrees}$$

Since $n_1 n_2 < 0$,

strike = N 87.04 deg E.

$$\mathbf{n}\cdot\mathbf{k} = [0.033\ -0.638\ 0.769][0\ 0\ 1]^T = 0.769$$

and

$$\beta = \cos^{-1}(-0.769) = 39.7 \text{ degrees}$$

Note that $n_2 < 0$ and $n_1 > 0$, and hence dip = 39.7 deg SE.

(b) The unit vector along the edge BC is

$$\mathbf{u} = (\mathbf{C} - \mathbf{B})/|\mathbf{C} - \mathbf{B}| = -0.469\mathbf{i} - 0.689\mathbf{j} - 0.552\mathbf{k}$$

The bearing is then

$$\theta = |\tan^{-1}(0.469/0.689)| = 34.2 \text{ degrees.}$$

Since both u_1 and u_2 are negative, bearing = S 34.2 deg W.

$$\mathbf{u}\cdot\mathbf{k} = -0.552$$

Therefore,

$$\cos^{-1}(\mathbf{u}\cdot\mathbf{k}) = \cos^{-1}(-0.552) = 123.5 \text{ degrees}$$

Hence,

$$\text{Slope} = 90° - 123.5° = -33.5 \text{ degrees}$$

In addition,

$$\tan(-33.5°) = -0.662$$

Thus, grade = -66.2%

Example 2

Given: Calculation of the shortest distance from point **S** to an infinite plane containing $\mathbf{P}_1$, $\mathbf{P}_2$, and $\mathbf{P}_3$ gives d = 3.265. See Example 7-16 in Ref. 3.

Task: Determine whether this is the actual shortest distance to the finite, bounded triangular facet defined by the corners $\mathbf{P}_1$, $\mathbf{P}_2$, and $\mathbf{P}_3$. (Fig. 6)

Solution:

Given

$$\mathbf{S} = [3\ 1\ 1]$$

$$\mathbf{R} = \mathbf{S} - \mathbf{P}_1 = [2\ 3\ -1]$$

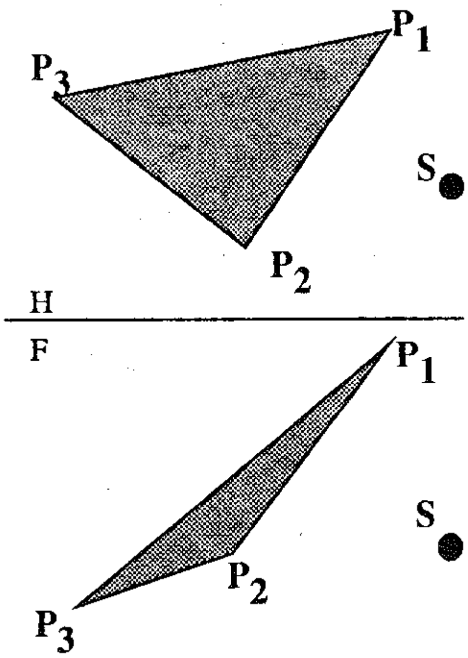


Fig. 6 Horizontal and frontal views

$$\mathbf{A} = \mathbf{P}_2 - \mathbf{P}_1$$

$$\mathbf{B} = \mathbf{P}_3 - \mathbf{P}_1 = [-2\ \ 3\ \ -1]$$

$$\mathbf{N} = [10\ \ 7\ \ 1]$$

$$\mathbf{N} = 12.2$$

From Example 7-16[3], calculations give $\mathbf{n} = [0.816\ \ \ 0.571\ \ \ 0.082]$ for the unit normal vector to the plane.

To check whether $\mathbf{N}$ points toward $\mathbf{S}$, check the dot product of $\mathbf{N}$ with $\mathbf{R}$.

$$\begin{aligned}\mathbf{N}\cdot\mathbf{R} &= [10\ \ 7\ \ 1]\ [\ 2\ \ 3\ \ -1]^T \\ &= (20 + 21 - 1) \\ &= 40 > 0\end{aligned}$$

Since $\cos \theta = \mathbf{N}\cdot\mathbf{R} / |\mathbf{N}|\,|\mathbf{R}|$ is positive, the angle $\theta < 90$ degrees.

To test whether "d" is the actual minimum distance from $\mathbf{S}$ to the bounded, triangular facet, write the vector parametric equation for the plane as

$$\mathbf{S} = \mathbf{P}_1 + v\mathbf{A} + w\mathbf{B} + d\mathbf{n} \quad \text{(Fig. 2)}$$

The three scalar components of this vector equation are:

x:
$$3 = 1 - v - 2w + 3.265(0.816)$$

y:
$$1 = -2 + 2v + 3w + 3.265(0.571)$$

z:
$$1 = 2 - 4v - w + 3.265(0.082)$$

Use any two equations to solve for parameters v and w.

From x: $v = -2w + 0.664$

From z: $4v = -w + 1.268$

The solution to these two equations gives $v = 0.2674$ and $w = 0.198$.

Since $v > 0$, $w > 0$, and $v + w < 1$, the piercing point $\mathbf{Q}$, which is the intersection with the line drawn from $\mathbf{S}$ perpendicular to the infinite plane, does lie within the bounded, triangular facet and is measured along the perpendicular. If these conditions had not been met, the shortest distance from the point to the plane would not be along the line perpendicular to the plane facet. The next step is to use Eq. (1) and calculate the shortest distance from $\mathbf{S}$ to each facet edge. The smallest distance which also satisfies the parameter condition $0 < t < 1$ gives the correct answer. If the parameter t is outside the required range for each boundary, then one must calculate the distance from $\mathbf{S}$ to each facet corner and determine which is closer. This distance will then be the shortest distance from the point to the finite, triangular facet.

The two examples given above illustrate how vectors are used for spatial reasoning. Algorithms can be written to implement these and similar methods to enable the user to interrogate a computer data base and determine geometrical relationships. Vector methods can also be used when the endpoint data for the necessary points, lines, and planes are contained in drawings, tables, or other non-electronic format.

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Visualization in Graphics: Time for a Change?

James C. Shahan and Roland D. Jenison

Freshman Engineering
Iowa State University
Ames, Iowa

The advent of computers and computer graphics has placed a heavy burden on introductory graphics courses. There are too many topics but not enough time. An important part of graphics is visualization. At Iowa State University a more intuitive approach to visualizing 2-D and 3-D geometries is being adopted. Past approaches are described, new approaches are presented, and results from initial classroom use are shown.

Introduction

Engineering graphics continues to undergo rapid and dramatic change as the influence of computers on engineering education increases. Descriptive geometry, which has been the basis for enhancing the visualization skills of engineering students, is coming under scrutiny in many engineering programs. For this paper, descriptive geometry is defined to be the material which provides a set of graphical problem-solving procedures to the engineering designer that enable the definition and analysis of geometric configurations. From the text *Descriptive Geometry*[1] by Frank W. Bubb, this definition is supported by the following quote:

> "The purpose of descriptive geometry is to provide graphical methods of showing three-dimensional objects and problems. Since we cannot draw lines in empty space, our graphics is necessarily limited to plane two-dimensional figures. We have to think in three dimensions and draw in two."

The set of procedures taught in descriptive geometry using orthographic projection principles provides the graphics student with a means to understand three-dimensional geometry using two-dimensional media to represent objects. Computer-based methods for the definition and analysis of geometry are mathematical and thus seem to be more abstract when compared with the step-by-step pencil and paper techniques. The question that must be addressed is, "Do the computer-based procedures provide the needed visualization enhancement gained through application of orthographic projection principles?".

The impact of computer graphics and computational power is significant in areas which are very difficult and time consuming for graphical solutions to be obtained. Definition of sculptured surfaces, computation of optimum shapes for moving through a fluid medium, and precise definition of intersections of complex objects are now commonplace in engineering. Greater accuracy for solutions to geometric problems is now available. An interesting observation regarding accuracy is found in an excerpt from *Descriptive Geometry*[2] by Watts and Rule:

> "Graphical solutions are not capable of absolute accuracy. However, most engineering problems are capable of being solved graphically, and such solutions are, in general, considerably quicker and simpler than algebraic solutions".

Watts and Rule, of course, did not have the benefit of the computer-aided-design (CAD) hardware and software of the 1980s. Today, almost any desired accuracy is available in less time and at less cost for all but the simplest geometric problems. The three-dimensional data base capability in modern CAD systems makes it impractical in most instances to develop graphical solutions for specific problems. The major difficulty at this time is overcoming the momentum of pencil and paper graphics education. Change is not new in descriptive geometry, as noted by F. M. Warner in *Applied Descriptive Geometry*[3]:

> "Perhaps no other subject in the entire engineering curriculum has been discussed, revised, and rewritten as many times as the subject of descriptive geometry. Yet this constant activity, on the part of the teachers of this subject, has provided no appreciable change in the array of fundamental principles that are presented."

The computer brings a change in the methods of descriptive geometry, but it does not change the basic principles of engineering graphics which must be a cornerstone of all engineering programs.

The perceived dichotomy of descriptive geometry and computer graphics lies in the methodology. Descriptive geometry (graphical methods) is not machine dependent and proponents argue that performing the graphics by hand reveals hidden relationships among the elements of objects which cannot occur if one "watches" the solution appear on a video display monitor. Computer graphics provides instantaneous solutions, thereby enabling a much more in-depth study of a given problem, as well as the solution of more complex and, in many instances, more "real world" problems. Computer graphics advocates believe that visualization enhancement is evident in the process of selecting views, varying the parameters in the problem, and selection of the correct procedure to solve a problem.

The ability to visualize enables one to recognize a three-dimensional object in a manner that permits appropriate representation of the object for design and analysis purposes. This ability is enhanced in the study of both traditional graphics (descriptive geometry and orthographic projection theory) and computer graphics. The evolution of the graphics course at Iowa

State University and the adaptation of the course to take advantage of the potential of the computer, while at the same time providing the means for an engineering student to understand and apply the fundamentals of geometry definition and analysis, are described in the following sections.

The Effect of the Computer on Graphics Education

The introductory graphics course at Iowa State is divided into three parts: introductory material, visualization and representation of solid objects, and conventional practices of engineering graphics. The history of topical coverage in each of these categories is listed in Table 1.

The introductory graphics course taught has been in a state of continual change for the past two decades. The first graphics course offered by the Freshman Engineering Department was FR.E. 161, which was taught from the fall of 1974 through the spring of 1981. This graphics course was the first part of a two-course sequence. The second course, FR.E. 162, was primarily an introduction to design. In the fall of 1981 Iowa State University switched from the quarter system to the semester system, at which time the two courses were combined into a single course, FR.E. 165. About the same time, the computer was beginning to have an impact on engineering graphics. In an attempt to incorporate computer graphics with the traditional graphics, an experimental course, FR.E. 166X, was offered. FR.E. 166X was first offered in the fall of 1982 and was continued until the fall of 1985, when the name was changed to FR.E. 170 and the course was adopted as the introductory graphics/design course for all engineering students.

Table 1 shows the number of periods allotted to the topics normally considered a part of a traditional graphics course. A traditional graphics course is defined here as one that does not include any computer-related material. The two major factors affecting the time available for covering the topics were (a) the switch from quarters to semesters and (b) the increase in computer-related topics. The computer-related topics had a double impact. Not only did time have to be allowed for teaching the selected topics, but also additional time was required for an introduction to the computer system.

The computer-related topics that have been included in the graphics course, listed in Table 2, can be separated into two categories. The first category includes topics that show how computers are used to model geometries and perform drafting functions. Other topics are presented to show not only what the computer does, but also how it does it.

An example topic from Table 2 is Properties/Viewpoints. The student spends time performing computations to gain insight into how the computer uses a data base to compute geometric properties. After the students are familiar with the procedure used, they are then able to be an intelligent user of the software.

	FR.E. 161		FR.E. 165**		FR.E. 166X		FR.E. 170		
	F'74	S'81	F'81	S'85	F'82	S'85	F'85	S'88	F'88
INTRODUCTORY MATERIAL	(4)	(4)	(5)	(3)	(5)	(4)	(3)	(6)	(5)
Introduction	0.5	0.5	0.5	0.5	0.5	0.5	0.33	0.5	0.5
Lettering	0.5	0.5	0.5	0.5	0.5	0.5	0.33	0.5	0.5
2D Sketching	1	0.5	0.5	0	1	1.5	0.83	1.5	2
3D Sketching	1	0.5	1	0	1	1	1	1.5	0
Equipment	1	2	2.5	2	2	0.5	0.5	2	2
VISUALIZATION & REPRESENTATION OF SOLID OBJECTS	(16)	(12)	(12)	(12)	(8)	(5)	(6)	(7)	(8)
Points	1	1	1	2	0.5	2	2	1	0
Lines	3	2	2	2	1.5	1	1	1	0
Planes	2	2	2	2	1	1	1	1	0
Clearances & Connections	2	1	0	0	1	0	0	0	0
Lines & Planes (Intersection)	2	1	2	2	2	0	0	0	0
Solids (Intersections)	3	3	3	4	0	1	2	3	7
Pictorials	3	2	2	0	2	0	0	1	1
ENGINEERING DRAWINGS	(13)	(11)	(9)	(14)	(7)	(7)	(7)	(9.5)	(11)
Sections	2	1	2	4	2	0.5	2	1.5	2
Dimensioning	2	2	2	3	1	1.5	1	5***	3
Detail Drawing	3								
Production/Limit Dimensioning	3*	4	3	4	2	2	1	0	1
Fasteners	1*	1	1	1	1	1	1	0	0
Design/Working Drawings	2*	3	1	2	1	2	2	3	5
TOTAL CLASS PERIODS	[33]	[27]	[26]	[29]	[20]	[16]	[16]	[22.5]	[24]

Note: * These topics were included in the introductory design course, FR.E. 162
** FR.E. 165 is the combination two quarter classes (161, 171) into a single semester course.
*** One period added to include dimensioning with CAD

( ) Topic Subtotals
[ ] Course Totals

Table 1 Coverage of traditional graphics at Iowa State University

The Effect of the Computer on Visualization

As the graphics course at Iowa State has evolved, the visualization part of the course has lost the most periods (Table 1), with a reduction of eight of the sixteen periods. The introductory topics have not changed significantly and it still takes the same amount of time to introduce the basics of drawing by freehand and instrument methods. The only difference is that currently some time is spent on computer-aided-drafting and less time on other advanced drafting equipment use and application. The number of

	FR.E. 166X		FR.E. 170		
	F'82	S'85	F'85	S'88	F'88
COMPUTER RELATED TOPICS	(3)	(7)	(9)	(10)	(8)
Shape Description	2				
Surface Definition/ Modeling	1	2		1.5	
Vector Methods		1	1	1	1
Computer Modeling			3		2
Computer Drafting			3	2	2
Properties, Viewpoints		2	2	3.5	3
Computer Graphics Drawing				2	

Table 2 Coverage of nontraditional graphics at Iowa State University.

conventional practices (or standards) that apply to engineering drawings has not changed drastically. Therefore, it takes approximately the same amount of time to cover this material. The visualization and representation of objects is the area of graphics that has been affected the most by the computer and the coverage has changed accordingly.

The approach commonly used to teach visualization was deeply rooted in descriptive geometry. The student was able to follow a set of procedures for first projecting points, then lines, then planes, and finally solids. Each step built directly on the previous work. Visualization was first approached through descriptive geometry with the use of orthographic projection, using a series of perpendicular views to arrive at a given solution. The projection of points served to introduce the basics of the orthographic system and the two-dimensional representation of a simple object, the point. An example problem is shown in Fig. 1. The next step was the projection of lines, simply an extension of the projection of points. There are some identifiable properties that are associated with lines, namely true length and point view. A typical problem (Fig. 2) demonstrates the projection of the true length (TL) and the point view (PV). The orthographic projection of a plane, shown in Fig. 3 in the construction of the edge view (EV) and true shape (TS), is an extension of the work done with points and lines. The theory continually builds on itself; e.g. the edge view of a plane is found by projecting perpendicularly to a true length projection of a line on the plane. Combining planar surfaces leads to the next step, the projection of solids (Fig. 4). The projection of solids shows the relationship between the orthographic views (labeled H and F) and the isometric projection (labeled 2).

The steps outlined above were stated to emphasize the mechanical, step-by-step procedure. It is important, from an instructional point of view, to help the students develop confidence if they follow the procedures. Af-

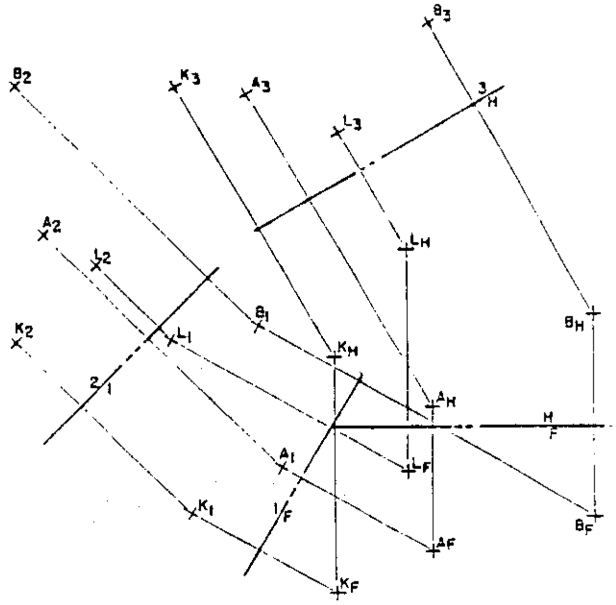


Fig. 1 Orthographic projection of points

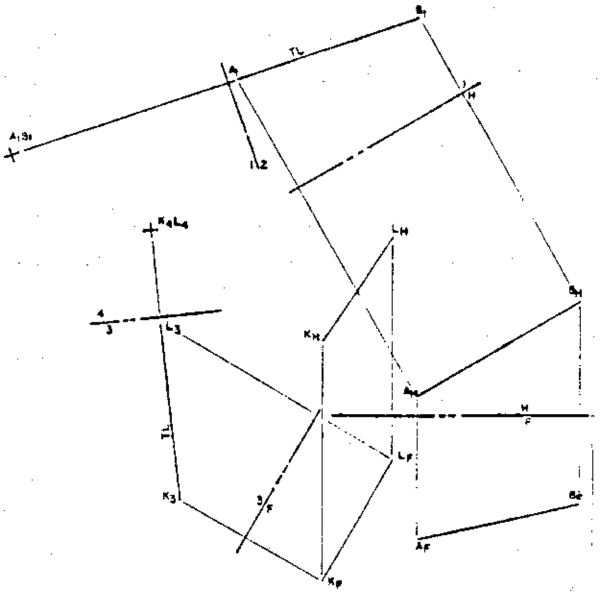


Fig. 2 Orthographic projection of lines

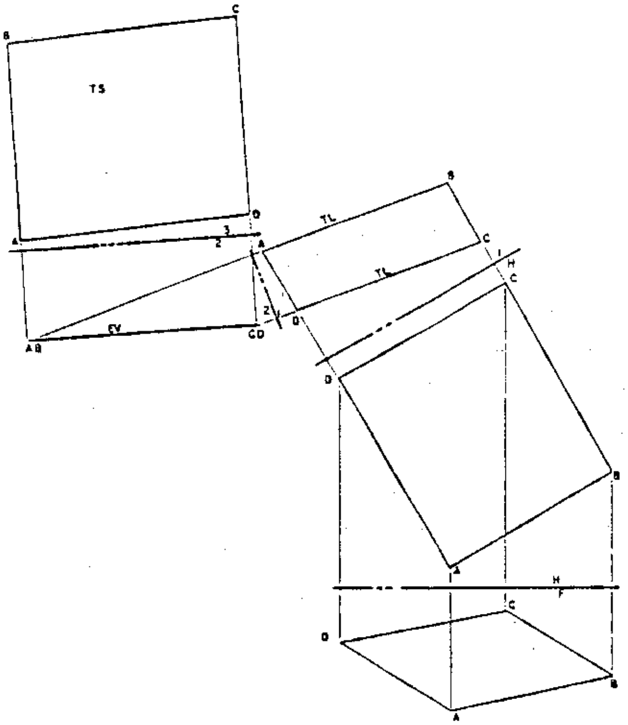


Fig. 3 Orthographic projection of planes

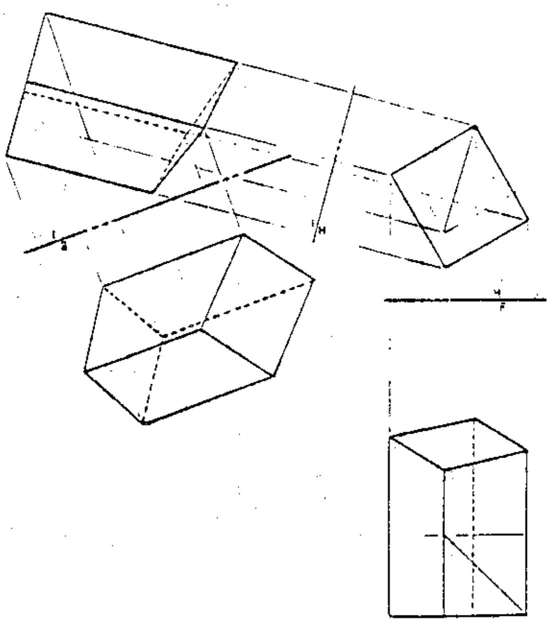


Fig. 4 Orthographic projection of solids

ter becoming comfortable with projecting objects, the next step is to determine intersections (Figs. 5 and 6). At this stage it is very important for the student to be able to use projection theory to be able to construct the correct views and visualize the object in each view. A basic procedure for finding the intersection is to project an appropriate edge view, then project the intersection, and finally use the perpendicular views to determine visible and hidden lines.

The methods outlined in the previous paragraphs form a logical, systematic approach to visualization. Unfortunately, these methods are very time consuming. The pressure for integrating the computer into graphics education necessitated decisions by the graphics faculty at Iowa State regarding the coverage of tradi-

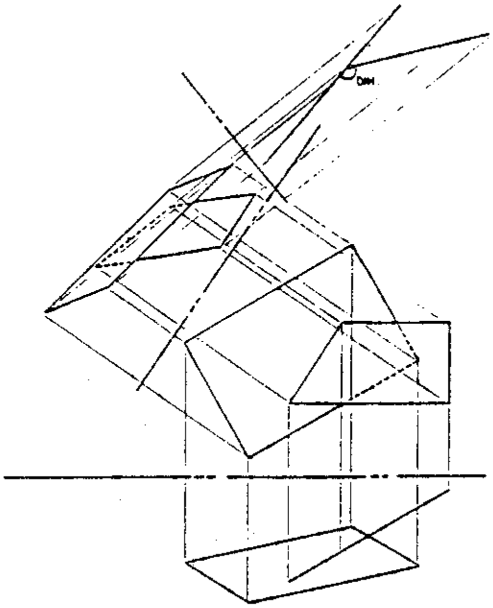


Fig. 5 Intersection of plane surfaces

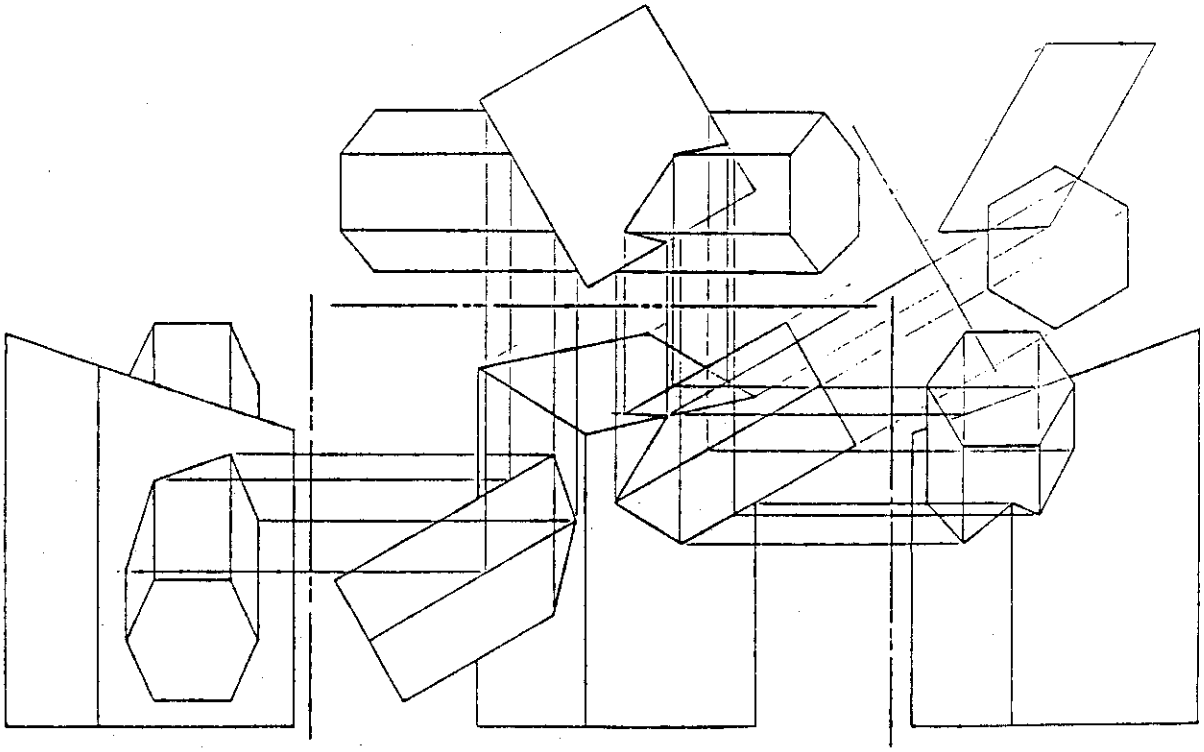


Fig. 6 Intersection of solid objects

tional topics. The result is clearly shown in Table 1 , which indicates that the time spent on visualization and projection theory has steadily decreased. As computer methods for geometric modeling and analysis gain acceptance, it is less likely that projection theory will be used to solve problems. There is also documentation that students have some visualization ability when they begin the course, and this ability can be enhanced in a well-designed computer-based graphics course.

As the number of periods spent on projection theory declined to four, the faculty decided that it was not accomplishing the course objectives for developing visualization and problem solving capability. A better method of relating orthographic, detailed-oriented views to pictorials was required. The new method must relate to the fundamental concepts of computer modeling in order to ensure the continuity of the topical coverage.

The first step in the new approach involves identifying and illustrating the types of drawings used to represent objects graphically. An example is shown in Fig. 7. Visualization is required when students look at the pictorial drawings and multiview representation and realize that all depict the same object. While discussing a particular orthographic view, it is important to point out the other five surfaces in each view that either appear as edges or hidden surfaces. It can also be noted that the back edge has to be the same distance from the front edge in all cases. That becomes the starting point for the discussion of locating features.

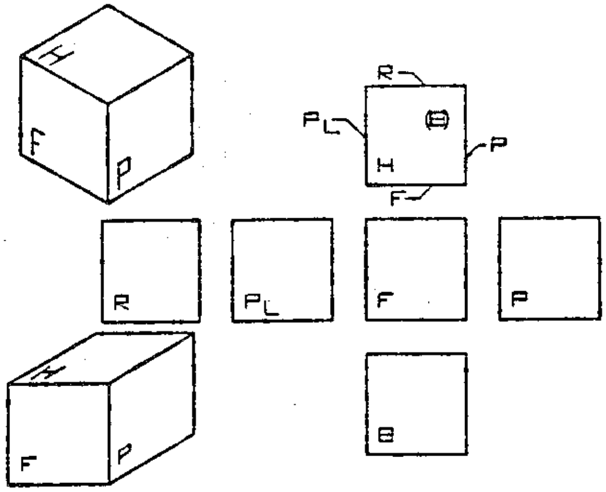


Fig. 7 Graphical representation of simple objects

After the basics have been introduced, the multiview description of the various types of surfaces is presented. Flat surfaces that are parallel to the coordinate planes are discussed first (Fig. 8) These surfaces will be seen, other than as an edge, in just one view. The next surfaces introduced are sloping, flat surfaces, as shown in Figs. 9 and 10. Oblique flat surfaces (Fig. 11) complete the discussion of flat surfaces in multiview presentations.

Other features are introduced in a timely fashion. Hidden features, Fig. 12, and the use of hidden lines to represent hidden features help show the importance of multiview drawings and the use of conventional practices in engineering drawings. Circular features and other complicated surfaces are added to show the extension of the basics to more

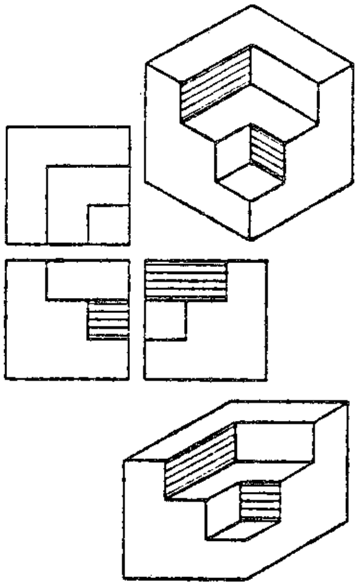


Fig. 8 Principal surfaces

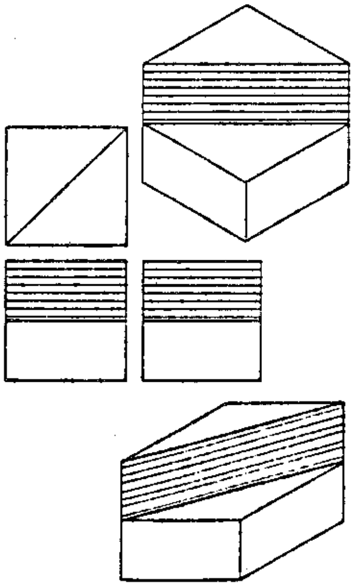


Fig. 9 Vertical/nonprincipal surfaces

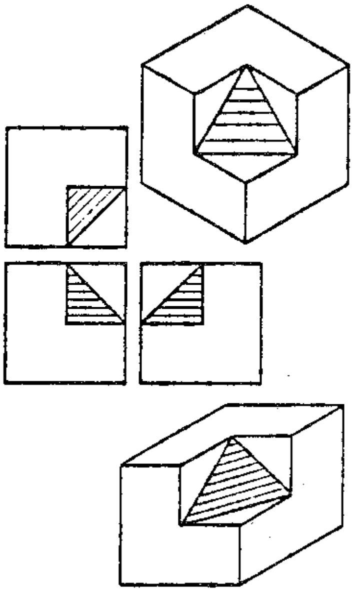


Fig. 10 Sloped surfaces

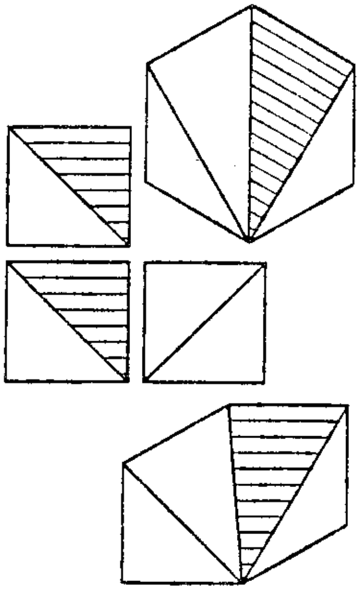


Fig. 11 Oblique surfaces

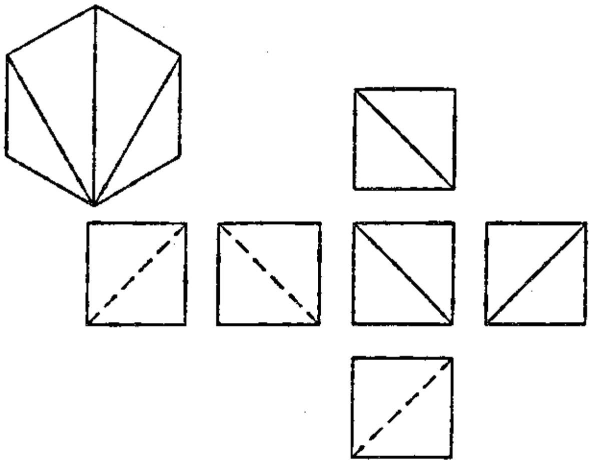


Fig. 12 Hidden surfaces

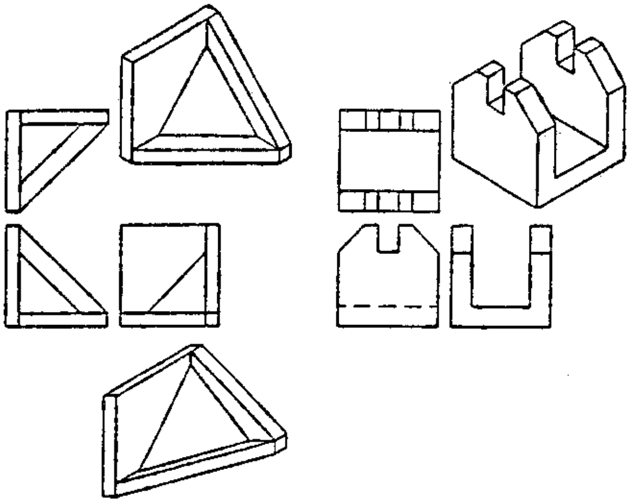


Fig. 13 Combined surfaces

complicated objects.

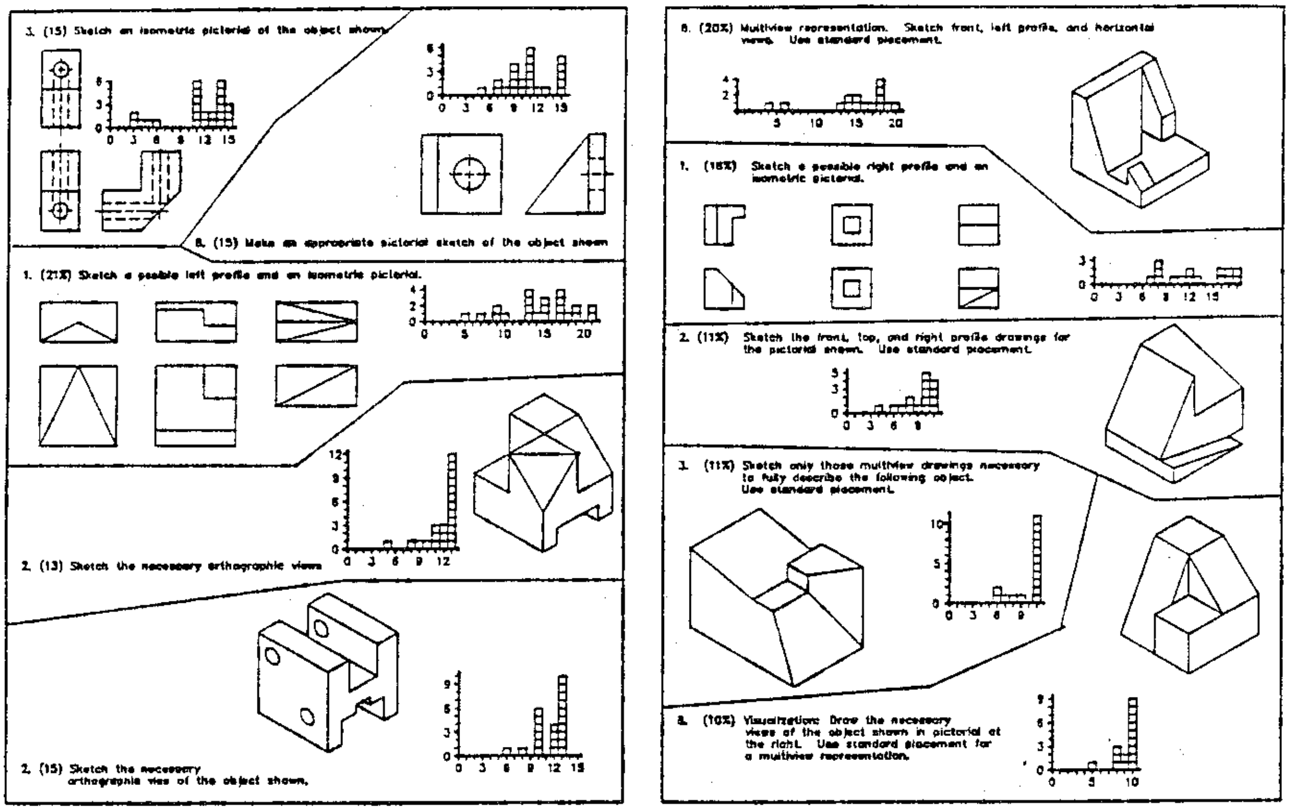
Any of the previously mentioned features and surfaces may be combined (Fig. 13) to create any desired object. Visualization is continually emphasized by feature identification and positioning relative to the outline of the object in the multiview representation.

Student Work

This new approach to visualization was tested at Iowa State University during the 1988 summer session. A sample of the visualization problems used spring semester is given in Fig. 14(a). At this time, projection theory was still used as the starting point for visualization. Similar problems for the summer session are presented in Fig. 14(b). A bar chart is presented with each problem to indicate student scores. All indications are that the method of instruction had little effect on class performance, that is, the grades given on projects and exams. Average scores on all of the problems were between 70% and 90% of the value of the problem. Some of the students obtained the correct solution; others missed varying amounts. The effect of the change on individual students is considerably harder to measure.

Conclusion

The instruction of visualization is enhanced by this new method. The sequencing of topics is simplified by not having to discuss orthographic projection. The students work with solid objects throughout the course; they have something to which they can relate and thus more easily visualize. The process of visualization starts at the very beginning. With descriptive geometry, methods of projecting points, lines, and planes are mechanical and require little visualization. For the purposes of an introduc-



a b

Fig. 14 Student examples, summer 1988

tory graphics course, the intuitive approach to visualization works for approximately 90% of the problems. The decision to change the approach used to teach visualization depends on the amount of computer-related topics being covered in the same course. The use of computers dictates a certain amount of class time for introduction and instruction. Each period spent with the computer is time taken away from other topics. The new approach supports the idea that simple objects can be handled by both graphical and computational methods, while complicated objects need to be handled by a computer. While even complicated problems could also be handled graphically, it is becoming less likely. And without doubling the credits, it is impossible to teach both graphical and computational methods.

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Rotating Transformations in Four-Dimensional Space*

Zuji Wan
Dalian University of Technology of China

Qidi Lin
Anhui Institute of Technology of China

Josann Duane
The Ohio State University

Properties of rotating transformations and the invariant properties of four-dimensional unit coordinate systems are presented. Such properties are part of a new method developed for solving four-dimensional engineering problems.

Introduction

This is the second paper presenting the results of the research on a new method of solving four-dimensional engineering problems. The new method simplifies solution of such problems by the use of the following procedures:

First, the problem is cast in three-dimensional space by projecting the four-dimensional system into a three-dimensional projection space and by establishing a Cartesian coordinate system in this three-dimensional projection space.

Then, by using the invariant properties of four-dimensional geometric elements projected into a three-dimensional space and by using the invariant properties of rotation transformations in four-dimensional space, solutions are obtained to the four-dimensional governing equations in the three-dimensional Cartesian projection space.

A previously published paper, "Invariant Properties of Four-Dimensional Geometric Elements Projected into Three-Dimensional Space"[1], treats the properties of projection. This paper presents the properties of rotating transformations and the invariant properties of four-dimensional unit coordinate systems. Further work on methods for computer implementation of the new method is underway.

The geometry of four-dimensional and higher-order space has evolved from a theoretical curiosity to become a practical engineering discipline involving higher-order space. As examples: 1) chaotic systems, such as turbulent flow, are best understood

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if described in multidimensional phase space, and 2) systems, such as particle accelerators, that exhibit relativistic effects, are described by classical mechanics if the equations of motion are cast in four-dimensional space.

Four-dimensional engineering problems, while increasingly common, are not easily or conveniently solved using traditional methods four-dimensional space is not easily visualized. The needed aid is provided by projecting the geometric elements of four-dimensional problems into three-dimensional orthographic projections; this permits an indirect visualization of four-dimensional space.

An additional problem is that geometry of four-dimensional space is not as well understood as geometry of the three-dimensional world. The Lorentz transformation, an essential part of the special theory of relativity, provides an example of confusion about four-dimensional space that once existed in the physics community; many physicists mistook the Lorentz transformation as a translational transformation[2]. It is now accepted as an example of a once rotating transformation in four-dimensional space[3]. As shown in this paper, the research on four-dimensional space confirms acceptance of the Lorentz transformation as a once rotating transformation.

This research on rotating transformations in four-dimensional space is based on the writings of Manning[4], Lindgren and Slaby[5], and Brisson[6]; it establishes the distortional coefficients and rotating angles of four-dimensional orthographic isometric projections. These angles and coefficients are computed and presented in this paper. Computation of these angles is fundamental to computer implementation of the new method.

This new method, combined with contemporary computer graphics, provides a powerful new tool for solving four-dimensional engineering problems.

Once Rotating Transformation

Basic Principles

Rotation of geometric elements in three-dimensional space is carried out about a straight line as an axis. In four-dimensional space, however, rotation is about a plane[4]. Four linearly independent axes establish a four-dimensional coordinate system. In the special case of Euclidean space, the four linearly independent axes are mutually perpendicular.

When the first coordinate plane, which is composed of two axes, is stationary, the second coordinate plane, which is absolutely perpendicular to the first coordinate plane, will rotate at an angle about it (Fig. 1).

In the O-XYZU coordinate system, if the unit vector of the u axis is $\mathbf{l}$, then any vector R can be formed from the R_x, R_y, R_z, and R_u components of the vector as follows:

$$\mathbf{R} = R_x\mathbf{i} + R_y\mathbf{j} + R_z\mathbf{k} + R_u\mathbf{l} \qquad (1)$$

In the O-X'Y'Z'U' coordinate system,

$$\mathbf{R'} = R'_x\mathbf{i'} + R'_y\mathbf{j'} + R'_z\mathbf{k'} + R'_u\mathbf{l'} \qquad (2)$$

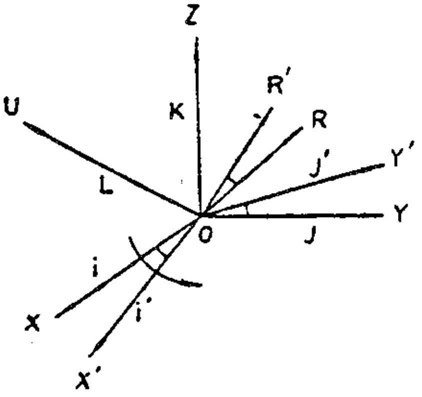

Fig. 1 Transformation of a four-dimensional unit coordinate system

Because each of the four axes is perpendicular to the others, they are all mutually perpendicular. Taking the dot product, using Eqs. (1) and (2), the magnitude of each vector component may be obtained after coordinate system rotation about OZU:

$$R'_x = R_x(\mathbf{i}'\cdot\mathbf{i}) + R_y(\mathbf{i}'\cdot\mathbf{j})$$

$$R'_y = R_x(\mathbf{j}'\cdot\mathbf{i}) + R_y(\mathbf{j}'\cdot\mathbf{j})$$

$$R'_z = R_z$$

$$R'_u = R_u \qquad (3)$$

As shown in Fig. 1, assuming that counterclockwise rotation is positive:

$$\mathbf{i}'\cdot\mathbf{i} = \cos A$$

$$\mathbf{j}'\cdot\mathbf{j} = \cos A$$

$$\mathbf{i}'\cdot\mathbf{j} = \sin A$$

$$\mathbf{j}'\cdot\mathbf{i} = -\sin A$$

Substituting these equations into Eqs. (3) and using a matrix to express the results yields:

$$[T_{xy}(A)] = \begin{bmatrix} \cos A & \sin A & 0 & 0 \\ -\sin A & \cos A & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \qquad (4)$$

where

$$\mathbf{R}' = [T_{xy}(A)]\,\mathbf{R}$$

Rotating coordinate plane OUX about its absolutely perpendicular coordinate plane OYZ yields:

$$[T_{ux}(A)] = \begin{bmatrix} \cos A & 0 & 0 & \sin A \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -\sin A & 0 & 0 & \cos A \end{bmatrix} \qquad (5)$$

The Lorentz Transformation

The Lorentz Transformation describes relative motion in space-time. Dimensions appear to change when the velocity of the observed coordinate system (v) relative to the observer approaches that of the speed of light (c).

If the angle A in Eq. (5) is assumed to be an imaginary angle iA, then

$$\cos^2 iA + \sin^2 iA = 1$$

And as shown in Fig. 2, the following equations also exist

$$\sin iA = (vi/c)/(1-v^2/c^2)^{0.5}$$

$$\cos iA = 1/(1-v^2/c^2)^{0.5}$$

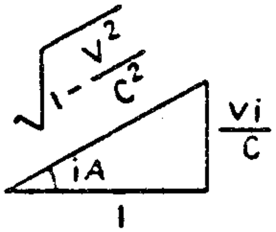

Fig. 2 Relationship of imaginary angles

Substituting this into Eq. (5) gives

$$R'_x = R_x/(1-v^2/c^2)^{0.5}$$

$$R'_y = R_y$$

$$R'_z = R_z$$

$$R'_u = (-R_x vi/c)/(1-v^2/c^2)^{0.5} + R_u/(1-v^2/c^2)^{0.5} \qquad (6)$$

Let

$$R_u = icR_t$$

$$R'_u = icR'_t \quad \text{and}$$

and

$$\Gamma = 1/(1-v^2/c^2) \qquad (7)$$

Substituting Eqs. (7) into Eqs. (6) yields

$$R'_x = \Gamma\ (R_x - vR_t)$$

$$R'_y = R_y$$

$$R'z = R_z$$

$$R'_t = \Gamma\ (R_t - vR_x/c^2) \qquad (8)$$

Eqs. (8) are the famous Lorentz transformation from the theory of special relativity. Hence, the Lorentz transformation is a once rotating transformation in four-dimensional space-time. This result is consistent with contemporary thought on the formulation of the Lorentz transformation in four-dimensional space-time[3].

Triple Rotating Transformation

Basic Principles

In order to visualize and measure the orthographic projection of geometric elements in four-dimensional space into three-dimensional space, the projections of the four linearly independent axes in the three-dimensional projection space must be obtained. To begin, rotate the four-dimensional coordinate system three times sequentially in a counterclockwise direction (Fig. 1) through angles A, B, and C, respectively. The transformation matrix is:

$$[T_3] = [T_{xy}(A)]\ [T_{yz}(B)]\ [T_{zu}(C)]$$

as shown in Eq (9) (Fig. 3). From Eq. (9), obtain the invariant properties of rotating transformations in four-dimensional space.

Invariant Properties

Property 1: In four-dimensional space after rotating transformation the dot product of two vectors is invariant.

Proof:

Let $\mathbf{R}_a$ and $\mathbf{R}_b$ be vectors in four-dimensional space. Eq. (1) gives:

$$[T_3] = \begin{bmatrix} \cos A & \sin A\cos B & \sin A\sin B\cos C & \sin A\sin B\sin C \\ -\sin A & \cos A\cos B & \cos A\sin B\cos C & \cos A\sin B\sin C \\ 0 & -\sin B & \cos B\cos C & \cos B\sin C \\ 0 & 0 & -\sin C & \cos C \end{bmatrix}$$

Fig. 3 Equation 9

$$\mathbf{R}_a \cdot \mathbf{R}_b = R_{ax}R_{bx} + R_{ay}R_{by} + R_{az}R_{bz} + R_{au}R_{bu} \qquad (10)$$

Similarly,

$$\mathbf{R}'''_a \cdot \mathbf{R}'''_b = R'''_{ax}R'''_{bx} + R'''_{ay}R'''_{by} + R'''_{az}R'''_{bz} + R'''_{au}R'''_{bu} \qquad (11)$$

Substituting Eq. (9) into Eq. (11) gives

$$\mathbf{R}'''_a \cdot \mathbf{R}'''_b = \mathbf{R}_a \cdot \mathbf{R}_b$$

The dot product of two vectors in four-dimensional space thus equals the dot product of the two transformed vectors in three-dimensional space.

Take the dot product of two equal vectors to obtain the following property:

Property 2:

In four-dimensional space the magnitude of the module of a vector is invariant.

$$\mathbf{R}'''^2 = R'''^2_x + R'''^2_y + R'''^2_z + R'''^2_u$$
$$= R^2_x + R^2_y + R^2_z + R^2_u \qquad (12)$$

Substituting Eqs. (7) into Eq. (12) yields

$$R^2_x + R^2_y + R^2_z - c^2R^2_t = R'^2_x + R'^2_y + R'^2_z - c^2R'^2_t$$

This explains why the module of R under Lorentz rotating transformation is invariant^5.

From this property, the following property can be developed.

Property 3:

In triple rotating transformations in four-dimensional space, the identical result is obtained only if the rotation sequence is identical and the projection is into the corresponding three-dimensional projection space. As in three-dimensional space, rotation is not commutative.

Distortional Coefficients and Rotating Angles

In order to simplify the problem, (1) let the four-dimensional coordinate system be a unit coordinate system, (2) rotate it three times sequentially, and (3) project it on O-XYZ three-dimensional projection space. Using Eq. (9), obtain (1) the following distortional coefficients for each axis and (2) the angles between any two axes.

$$R'''_x = (\cos^2 A + \sin^2 A \cos^2 B + \sin^2 A \sin^2 B \cos^2 C)^{0.5}$$

$$R'''_y = (\sin^2 A + \cos^2 A \cos^2 B + \cos^2 A \sin^2 B \cos^2 C)^{0.5}$$

$$R'''_z = (\sin^2 B + \cos^2 B \cdot \cos^2 C)^{0.5}$$

$$R'''_u = \sin C \qquad (13)$$

$$K_{ij} = \cos^{-1}\left[\frac{R'''_i \cdot R'''_j}{|R'''_i||R'''_j|}\right].$$

$$(i_{x,y,z,u} \cdot j_{y,z,u,x}) \qquad (14)$$

In general (in certain cases, no practical solution exists), if the magnitude of A, B, and C are given arbitrarily, the accurate distortional coefficient of each axis and the angles between any two axes are obtained. For example, let A = 60°, B = 45°, and C = 60°. Substituting into Eqs. (13) and (14) yields

$R'''_x = 0.951971638$

$R'''_y = 0.847791247$

$R'''_z = 0.790569415$

$R'''_u = 0.866025403$

$K_{xy} = 101.6069444°$

$K_{yz} = 118.9825°$

$K_{zu} = 116.565°$

$K_{ux} = 100.7016667°$

$K_{xz} = 104.4263889°$

$Kyu = 111.171388°$

The foregoing means:

1. Coordinate plane OXY of a four-dimensional unit coordinate system rotates by 30° about its absolutely perpendicular coordinate plane OZU in the four-dimensional space.

2. Coordinate plane OYZ of a four-dimensional unit coordinate system rotates by 45° about its absolutely perpendicular coordinate plane OUX.

3. Coordinate plane OZU of a four-dimensional unit coordinate system rotates by 60° about its absolutely perpendicular plane OXY.

If the result is projected on O-XYZ three-dimensional projection space, the distortional coefficients and angles between axis pairs are as shown in Table 1 and Table 2.

To obtain the distortional coefficient of each axis and the angle between any two axes of a four-dimensional unit coordinate system after four-dimensional orthographic isometric projection, let the distortional coefficient of all three be equal and solve Eqs. (13). The result is:

$$A = 45°$$
$$B = 54.73555556°$$
$$C = 60° \qquad (15)$$

Substituting Eqs. (15) into Eqs. (13), the distortional coefficient of any axis after four-di-

Axis	Distortional Coefficient
X	0.951971638
Y	0.847791247
Z	0.790569415
U	0.866025403

Table 1

Between Axes	The Angle is (in degrees)
X and Y	101.6069444
Y and Z	118.9825
Z and U	116.565
U and X	100.7016667
X and Z	104.4263889
Y and U	111.171388

Table 2

mensional orthographic isometric projection is:

$$R'''_x = R'''_y = R'''_z = R'''_u = 0.866025403$$

Substituting Eqs. (15) into Eq. (14), the angle between any two axes after four-dimensional orthographic isometric projection is:

$$K_{xy} = K_{yz} = K_{zu} = K_{ux} = K_{xz} = K_{yu} = 109.4711111°$$

This means that in four-dimensional space,

> if the coordinate plane OXY of a four-dimensional unit coordinate system is rotated by 45°, and
>
> if the coordinate plane OYZ of a four-dimensional unit coordinate system is rotated by 54.73555556°, and
>
> if the coordinate plane OZU of a four-dimensional unit coordinate system is rotated by 60°, and
>
> if the four-dimensional unit coordinate system that is rotated three times is projected on O-XYZ three-dimensional space,
>
> then each individual axis has the same distortional coefficient (0.866025403) and the same angle between any two axes (109.4711111°).

The above result is believed to supplement the content of the four-dimensional graphology of reference (7) and to put it on a strict theoretical basis.

In order to visualize the projecting result, care must be taken in the selection of the three-dimensional projection space used in solutions of four-dimensional problems. For example, if the three-dimensional O-XYZ space which is perpendicular to three-dimensional O-XYZ space is used, A = 45°, B = 54.73555556°, and C = 30°. This produces projections that are easily visualized. However, as shown below, if the three-dimensional space O-YZU or O-XZU is used as a projection space, the result is not visualized. When projecting the four-dimensional unit coordinate system on a three-dimensional O-YZU space after a rotating transformation, A = 45°. Thus, cos A = sin A. From Eq. (9), the R'''_x and R'''_y are collinear; $R'''_x = R'''_y$ and the projection can't be visualized, and is of no practical use. Similarly, if the four-dimensional unit coordinate system is projected on O-XZU three-dimensional space, $R'''_z = -R'''_u$. Hence, the two vectors are collinear but in an opposite direction. This result is also of no practical use.

Summary and Conclusions

The work presented in this paper and the first paper[1] establishes the theoretical basis for the new method of solving four-dimensional engineering problems. An analytic method is used to investigate rotating transformations of four dimensions and to establish several invariant properties of rotating transformations. This work establishes the triple sequential matrix of rotating transformation. Orthographic projection of the four-dimensional coordinate systems on a three-dimensional space gives the distortional coefficients of each axis and the angles between any two axes. These coefficients are used in the computer implementation of the new method of solving four-dimensional engineering problems. This work supplements the content of the four-dimensional graphology of reference (7) and puts it on a strict theoretical basis.

The practical basis for display of a four-dimensional diagram using computer graphics is also established. The steps that are taken to display the four-dimensional diagram in two dimensions are as follows:

Obtain the distortional coefficients of each axis and the angles between axes of the orthographic isometric projection of the four-dimensional unit coordinate system.

After four rotations, obtain the orthographic projection of four-dimensional coordinate systems on the two-dimensional projection plane.

If required by the engineering application at hand, an additional transformation can be developed for translation and rotation in n-dimensional space using the method presented in this paper.

Symbols

· Dot product

i, j, k, l Mutually orthogonal unit vectors in four-dimensional space.

Definitions

1. Absolutely Perpendicular: In four-dimensional space two lines perpendicular to a plane at a point determine a second plane. The planes are related such that every line of one plane passing through the point is perpendicular to every line of the other

plane also passing through the point. If this point is the only one common to both planes (that is, their intersection), they are absolutely perpendicular.

2. Line: A linear geometric element of one dimension. Lines are elements of space of two or more dimensions[1].

3. Plane: A linear geometric element of two dimensions. Planes are elements of space of three or more dimensions[1].

4. Point: A geometric element of dimension = 0. Points are elements of space of one or more dimensions[1].

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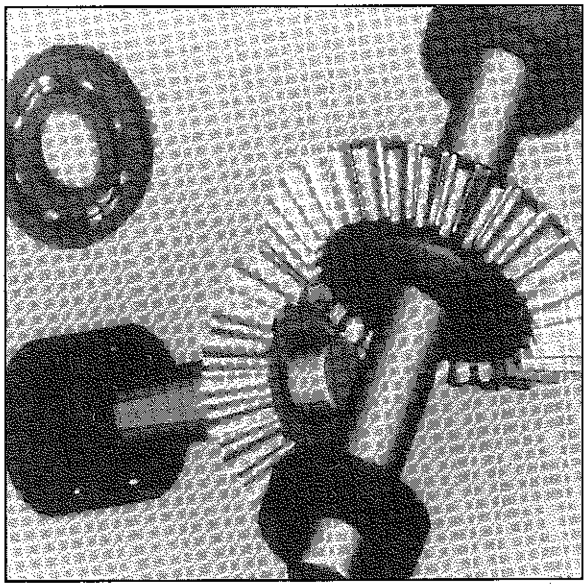

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Reader's Comments

Remarks on "Axonometric Projections"

by
L. J. Chastain

To the Editor:

While not too damaging, a square root symbol is missing on page 20, column 2, line 17 (Vol. 53, No. 2). The sentence containing the omission should read:

"..., and a maximum value equalling $\sqrt{6}$ for the isometric projection."

In the next-to-last line of column one of page 23, the phrase should read:

"..., but any one of the variables may be the <u>dependent</u> variable."

In addition, the third paragraph on page 25 should read:

"These equations, in turn, allow programs to be developed (in BASIC) for finding solutions, <u>both integer and non-integer</u>, for A, B, C, and D in terms of all f, g, and h."

Lem Chastain
Mtn. Rest, SC

Remarks on "Formulas for Quickly Determining the Area of Regular Polygons"

by
W. H. Waters, Jr.

To the Editor:

Mr. Waters has omitted the factor $n = 8$ in the final calculations of the example in column 1, page 17 (Vol. 53, No. 2). The area of the bolthead should be the same order of magnitude as that of the first example (i.e., where $K = 259.8$ mm^2), and certainly larger than $\pi d^2 / 4 = 201.1$ mm^2. Thus $26.50 \times 8 = 212.0$ mm^2.

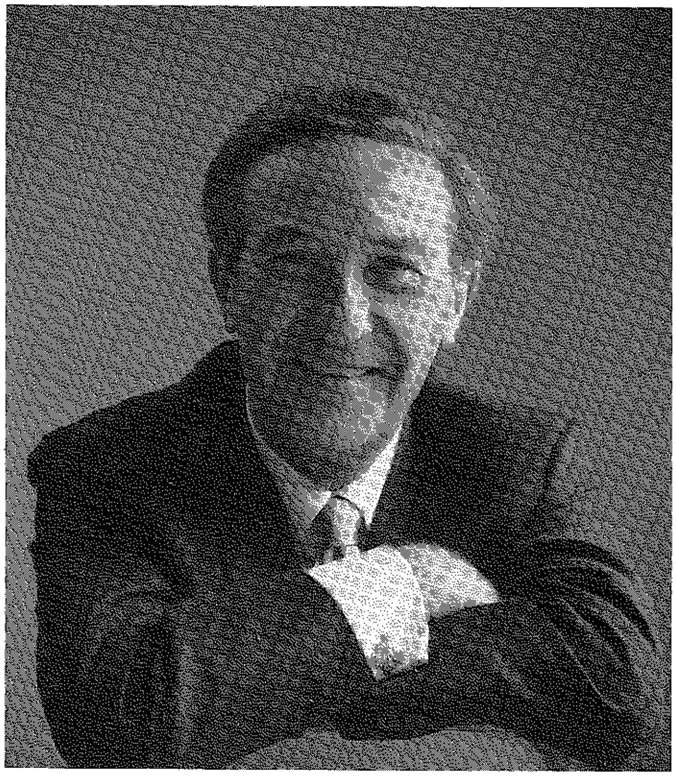
Lem Chastain
Mtn. Rest, SC

Distinguished Service Award

Presented to

Frank Oppenheimer

June 27, 1989
ASEE Annual Conference, Lincoln, Nebraska



Introductory Remarks
by
Bob LaRue

Frank Oppenheimer has been a member of the Engineering Design Graphics Division since 1948. That is considerably longer than most of us who are here tonight have been members. And, since he has been retired for several years, there are probably persons here tonight saying "Who is Frank Oppenheimer?" Frank and I have been friends since we met at the 1956 Annual Conference at Iowa State - let me tell you about him.

Frank was born and educated in Mannheim, Germany. An early interest in music resulted in his studying the violin and becoming first violinist with the *Stamitz-Geminde*, a semiprofessional orchestra in Mannheim. He also played chamber music in trios and quartets. Even today I suspect Frank would perform with a stringgroup if the opportunity presented itself.

He also studied theater and between 1926 and 1933 was acting and directing in a number of German theaters. From 1933 until 1939, when he came to the United States, he worked in a wholesale metals business. Here he obtained basic knowledge of materials used in the manufacture of drawing instruments.

Frank met his wife, Gladys, when he carried her baggage as a bellhop at a mountain resort in New York.

Gramercy Guild Group, Inc. was originally organized by Frank in 1947 as Gramercy Import Company. The specialty of the New York City company was high quality drafting instruments for use by students in university and college drawing courses. Gladys managed the office while Frank was traveling to campuses seeing bookstore managers and teachers of courses in which the instruments were used.

Actually, on these trips, Frank was visiting his friends. He was the world's lowest pressure salesman. He would not talk about merchandise unless the person he was visiting brought up the subject.

In 1962 the company moved to Denver. Frank and Gladys loved the mountains. The central location and excellent air transportation provided better communication and distribution. I like to think I had a little to do with this move since I introduced Frank to the Engineering Drafting School in Denver. Flora Goforth, the owner and operator of the school, owned property near the school which was suitable for office and warehouse space. Eventually, Gramercy built its own building in Denver.

While in Denver, Frank became a member of the Aspen Institute of Humanistic Studies and in 1966 participated actively in a convocation for Albert Sweitzer. During this time he served as a member of the Graphics Division as well as being an Associate Representative on the Board of Trustees of the National Association of College Stores.

Among many recognitions was the citation presented Frank by the Junior Engineering Technical Society (JETS) after he had awarded two four-year scholarships at Texas A&M University.

After retiring in 1977, Frank and Gladys moved to West Germany where they lived for several years. They have recently returned to the United States where they reside in Sun City West, Arizona. As could be expected, Frank is active in music, drama, and poetic literature. He is also a Life Member of ASEE.

Now I want to tell you of Frank as a business man and as a member of the Engineering Design Graphics Division.

Frank was an innovator in the drafting instrument field. He supported new ideas, such as the REIFLER Quickaction Bow compass and developed many new ways of packaging instruments. On one occasion (about which he will tell you), his instincts let him down.

His philosophy was to furnish instruments of high quality at a reasonable price. After one of Frank's visits to the Engineering Drafting School, the faculty asked me, "What shall we tell our students?" It seems that Frank had sent several sets of instruments to the School. The School had tested them extensively and not only was the price lower than the instruments they had been selling in the School store, but also, in their opinion, the instruments were of higher quality than those they had been selling their students. The obvious answer was to announce that they had found a new supply source and from now on students would be using a higher quality instrument for which they would pay less.

Frank believed in service to the customer. On one occasion when I visited Gramercy in Denver, Gladys was handling paper work while Frank was on the phone checking airline schedules. They had received an order for instruments from a bookstore that morning. The order would be shipped that afternoon and would be received by the customer, The Ohio State University bookstore, the next morning. Twenty-four hour service, without computers!

He has always been an extremely loyal member of the Division. He supported the *Journal of Engineering Design Graphics* with advertising. His ads were the first color that appeared in the Journal. On numerous occasions he helped the Journal out of financial difficulties by purchasing additional advertising.

He and his friend Alfred Kreidler, a German industrialist, made substantial financial contributions to support Division summer schools. Frank missed only one or two Division conferences (including both Annual and Midyear) and these were when he was ill.

Gladys and Frank took a very active part (along with the graphics faculty of the University of Colorado) in planning and running the 1973 Midyear conference in Denver. As I recall, during this meeting Gladys was honored at the banquet for completing a degree in International Law at the University of Denver.

On numerous occasions Frank would host special events for members of the Division. One such occasion occurred during the January 1974 conference in New Orleans when he reserved practically all of Pete Fountain's for an evening's entertainment. The sessions the following morning were very quiet, for most of us wandered around the French Quarter until about 3:00 a.m.

He improved the quality of paper presentations, especially at midyear conferences, by establishing the Oppenheimer Award in 1965. One reason Frank established the award was to discourage presenters from striding to the podium and <u>reading</u> their papers. Frank demonstrated how a paper should be presented at the Midyear Conference in Williamsburg in December, 1974, when he won the award for the best paper.

Finally, Frank liked to see the Division function properly. As many of you know, a tradition of the Annual Conference business meeting is the presentation of a plaque to the outgoing chairman by the incoming chairman. When this did not happen at the 1976 business luncheon, Frank publicly chastised the incoming chairman for his shortcomings. The plaque was delivered at the following Mid-year Conference in Montreal. That presentation was probably more impressive than the usual one would have been.

And now, Frank, we present this plaque. The citation reads:

The Division of Engineering Design Graphics of the American Society for Engineering Education presents its highest honor, The Distinguished Service Award, to

Frank Oppenheimer

for his dedicated service to the Division in making available tools of exceptional quality for use by students of engineering graphics, for providing an incentive to improve the quality of Division meetings, for unflagging support of the Journal of Engineering Design Graphics, and as an expression of admiration and respect of his friends and fellow Division members.

Acceptance Remarks
by
Frank Oppenheimer

Mr. Chairman, Bob LaRue, Ladies and Gentlemen!

When Bob Foster called and told me I was to be the recipient of the "Distinguished Service Award" - I was speechless!

Distinguished Service Award! - even now I cannot find adequate words to express my deepest thanks and appreciation for being considered worthy of this most prestigious award, an award which so many highly qualified people received before me.

Many friends who do not live on this earth any more, like Cecil Spencer, Howard Porsch, Irwin Wladaver, Ralph Paffenbarger, Steve Coons, Jack Rule, Jim Rising, Charles Skelley, and Art Risser, would be delighted to know that with their help and encouragement, I received this crowning recognition of my many years' endeavors in the service of Engineering Graphics Education! It is impossible to name the many friends who are still active in the field today who share this extraordinary high point of my life. And certainly without my wife Gladys' selfless assistance and patience, I would not be here today in this place of honor!

The saying goes: "Honors like this come only once in a lifetime!" - Well - with my 84 years going on 85 - that seems to ring true!

In 1948 I visited with Prof. Cecil Spencer at Illinois Tech and he, together with Prof. Gene Paré, sponsored my membership in the ASEE. This gave me tremendous confidence, that I was on the right track!

When I visited with Prof. Porsch at Purdue in the beginning of 1949, he handed me a list of specifications, without comment. At this time drawing sets still included three little bows and two ruling pens, expertly sharpened preferably by hand from German craftsmen. The faculty at Purdue, however, took steps to write specifications for more useful instruments, compactly packaged.

Going over these specifications on my flight back to New York, I visualized that this new design could revolutionize the drawing instrument industry. At home, I immediately put in an overseas call to Mr. Hans Riefler, owner of the Riefler factory in Nesselwang, Germany. Calling Germany at that time shortly after the war was quite a problem. I had to hang around for about five hours. But this gave me an opportunity to map a strategy with which I hoped I would be able to convince Herr Riefler's stubborn mind, steeped in Neanderthal tradition! Luckily, I succeeded and Mr. Riefler promised to follow the specifications exactly - even though he was strongly opposed to them.

Within a few weeks I received samples which I then exhibited during my first ASEE meeting at RPI in June of 1949.

My hunch was right. The idea caught on and it set the standard for future instrument design.

I always recognized my work in the engineering education field to be an avocation! Improvement of instrument design and serving faculties and students alike has been my prime aim. Following my instinct in this regard has been more important to me than material business considerations.

Therefore - when the faculty at MIT had some suggestions for a new type drafting table and none of the American manufacturers were interested - I searched for and found a small manufacturer in Germany who considered the idea worthwhile. A new type drafting table - a combination desk and drafting table at that time nonexistent, equipped with a Riefler drafting machine - was born!

My instinct, however, was not always so sure! Way back in 1948 Mr. Danyczek, at that time General Manager of Koh-I-Noor, showed me samples of a German fountain pen - the "Tinten Kuli" - suggesting that this could be developed into a technical pen, replacing the ruling pen. My answer was "NO"!!! To do away with the ruling pen! That seemed to be an absolute sacrilege!

How wrong could I have been! The development and usage of this technical pen is history!

I certainly enjoyed being a member of the Executive Committee of the Graphics Division on which I served from 1967 to 1972. During part of the same period from 1967 to 1969, I also served as the Associate Representative on the Board of Trustees of the National Association of College Stores.

Not only was I interested in the development of new and better designs of drawing equipment, but also I was equally very actively concerned that the students be able to obtain the finest quality tools at prices they could afford.

My interest in student welfare was further manifested by my granting two four-year scholarships at Texas A&M University, within their JETS (Junior Engineering Technical Society) program, conducted by Prof. Jim McGuire.

Over the years I noticed that the presentation of papers, although of high quality, could not always hold the interest of the audience. Therefore, in 1965 I suggested the establishment of certain requirements which the speaker has to observe, and I volunteered to sponsor an award for the best presentation of a paper. In 1967 the Executive Committee approved the idea and from then on the "Frank Oppenheimer Award" has been presented every year.

Since my retirement in 1977, my interest in the Graphics Division has been undiminished and I have noticed that, obviously, some instruments and scales are still being used - and not ONLY computer software!

Outside of my deep concern during the past forty years with the manifold activities of the Graphics Division, life has always had many beautiful things to offer. Since my time is now my own, I am more keenly involved in music and poetic literature, both of which have been my love all through my adult life.

Let me close by quoting the last four stanzas of Robert Frost's poem, "Stopping by Woods on a Snowy Evening":

"The woods are lovely dark and deep,
But I have promises to keep,
and miles to go before I sleep,
and miles to go before I sleep!"

Thank you!

Chairman's Message
by
Frank Croft

The Engineering Design Graphics Division of the American Society for Engineering Education is the oldest division of the Society. It offer a unique forum for graphics educators through the *Journal* as well as the national meetings held biannually. It is the major professional organization to which a graphics educator can belong. Presently, our membership is approximately 500 and seems to have been at this number for some time.

The Director of Zone Activities, Billy Wood of the University of Texas at Austin, has assumed the important responsibility of recruiting new members to the division. He has a solid plan that targets possible new members in geographic regions of the country which coincide with the locations of the ASEE Annual Conference and the Mid-year Conference of the EDGD. Presently, new members are being targeted in the Southeastern United States due to the fact that the 1989-90 Mid-year Conference of the Division is in Tuscaloosa, Alabama. The idea is simple. We invite prospective new members to the meetings in hopes of persuading those that attend to join ASEE and the EDGD.

Billy's recruiting efforts have been somewhat hampered due to lack of support from ASEE headquarters in Washington, DC. As each of you probably know, ASEE has had some problems of late and has not been running in the most effective manner; however, it now

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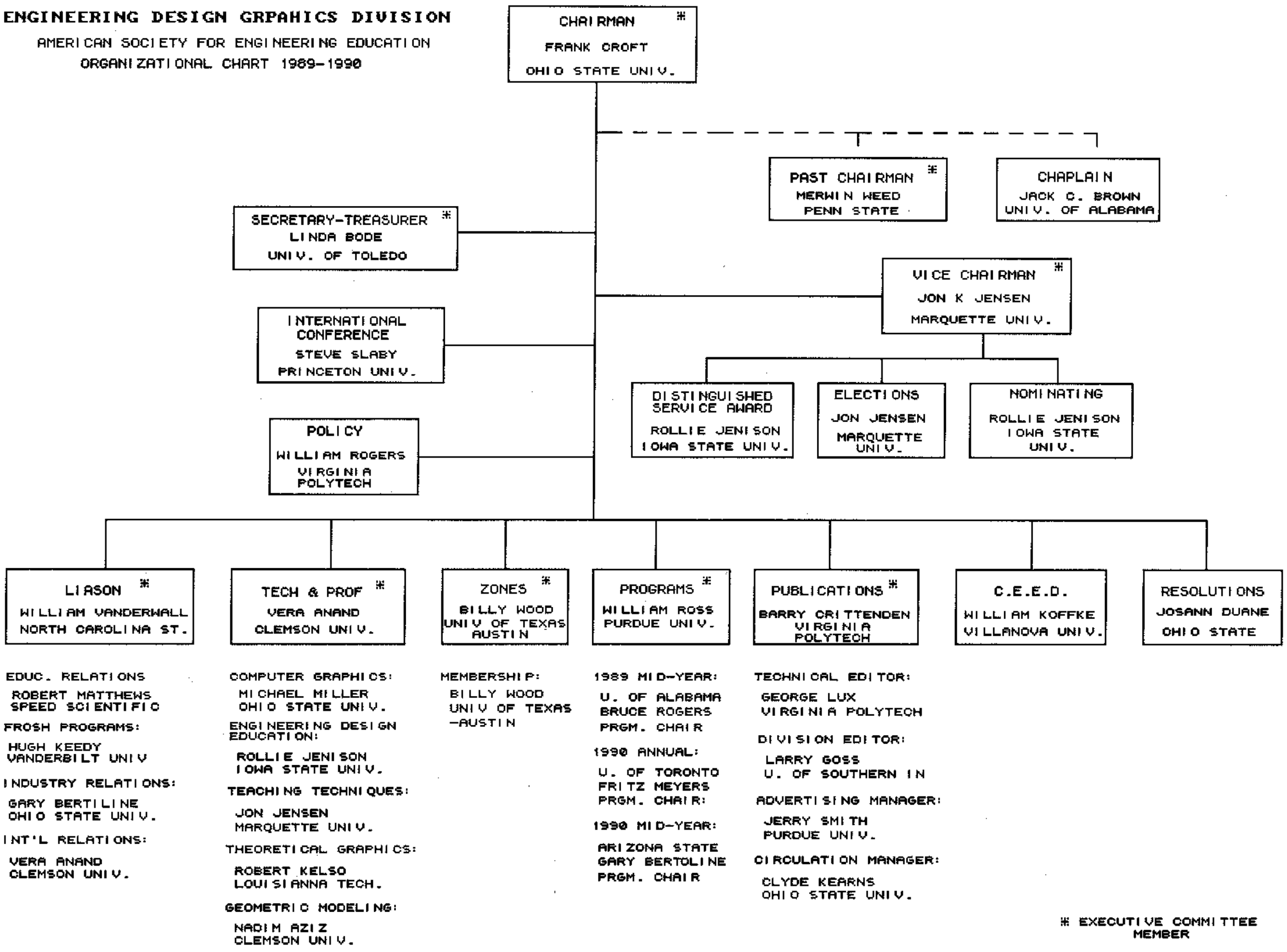


appears that things are improving and that the Division should be able to obtain the materials required to carry on this recruiting effort.

Each current member of the EDGD can help in the overall recruiting effort. ASEE and the EDGD have much to offer professional engineering/technical graphics educators. First of all, we offer a forum for expressing one's views. There have been many occasions at meetings and conferences where an exchange of diverse opinions has taken place and the membership has benefitted greatly from these exchanges. Also, the esprit de corps that the Division exudes is highly unique within ASEE. I feel I have many close friends within the Division and I know each of you feels the same.

If each of us can bring one person into the Division and ASEE, our numbers would not only double, but we would be doing the Division a financial favor. Currently, the Division dues are $3.00 per year. The purpose of the dues is to guarantee that every member in the Division receives the *Journal*. Each printing of the *Journal* (1000 copies) costs approximately $2000. This cost has roughly doubled since the summer of 1988. We no longer have the printing services of the William C. Brown Company, which has for years been publishing the *Journal* at cost. Our current dues structure almost pays for one out of three annual printings. Additional Division members would help offset some of these costs since additional copies of the *Journal* beyond the first 1000 copies are relatively inexpensive to publish. Fortunately, advertising revenue as well as nonmember and library subscriptions are maintaining the financial stability of the *Journal*, for the present.

To aid in the recruitment of new members, the Division has developed a brochure that outlines its activities. These brochures are available through Billy Wood (Mechanical Engineering Dept., Univ of Texas at Austin, Austin, TX 78712). He has over 600 copies in stock and can obtain more if needed. So, if you have new faculty joining your department, point out the advantages of being a member of ASEE and the EDGD and bring them into the fold. Also, if there is a community college or technical school in or near your city, pay them a visit and encourage their technical graphics people to join ASEE and the EDGD. I believe the Division can become stronger through a great recruiting effort by the present membership.

Calendar of Events

by
Bill Ross

1989-90 EDGD Mid-year Conf.
November 5-7, 1989
Tuscaloosa, AL

1990 4th International Conference on Engineering/Computer Graphics and Descriptive Geometry
June 11-15, 1990
Miami, FL

1990 Annual ASEE Conference
June 24-28, 1990
Toronto, Canada

1990-91 EDGD Mid-year Conf.
Tempe, AZ

1991 Annual ASEE Conference
New Orleans, LA

1991-92 EDGD Mid-year Conf.
Norfolk, VA

1992 Annual ASEE Conference
Toledo, OH

1992 5th International Conference on Engineering Graphics and Descriptive Geometry
August 17-21, 1992
Melbourne, Australia

1992-93 EDGD Mid-year Conf.
San Francisco, CA (tentative)

Fourth International Conference on Engineering/Computer Graphics and Descriptive Geometry

by

Steve Slaby

Sponsored by ASEE's Engineering Design Graphics Division and the Florida International University, Miami, Florida.

June 11-15, 1990.

Topics: Descriptive geometry, theoretical graphics, computer graphics, kinematic geometry and other applications of geometry, engineering computer graphics, computer-aided design, computer-aided geometric design, computerized descriptive geometry, graphics and computer graphics teaching techniques, graphics exercises and computers in engineering graphics education.

Deadlines: October 31, 1989 for 500-word abstracts. Full papers will be due March 1, 1990. Typed manuscripts should not exceed ten pages, single-spaced.

Contacts: Steve M. Slaby, Civil Engineering & Operations Research Department, Princeton University, Princeton, NJ 08544, (609) 452-4654 and/or Dr. Oktay Ural, Civil & Environmental Engineering Dept., Florida International University, Miami, Florida 33199, (305) 554-2824.

International Computer Graphics Calendar

by

Vera Anand

Nov 5 - 10, 1989

Visual Communications and Image Processing 89, Adams Mark Hotel, Philadelphia, PA. Contact: Society of Photo-Optical Instrumentation Engineers, P. O. Box 10, Bellingham, WA 98227-0010. Ph. (206) 676-3290.

Nov 7 - 9, 1989

Computer Graphics 89, Alexandra Palava Exb. Ctr., London. Contact: Julia Barker, Blenheim Online, Blenheim House, Ash Hill Dr., Pinner, Middlesex HA5 2AE, England. Ph. 01-868-4466.

Nov 27 - 29, 1989

Conf. on Interpretation of 3D Scenes, Austin Marriott at the Capital, Austin, TX. Contact: Anil K. Jain, Dept. of Computer Science, A-714 Wells Hall, Mich. State Univ., E. Lansing, MI 48824. Ph. (517) 353-5150.

Dec 4 - 7, 1989

ICENSOFT '89 - International Conf. on Engineering Software, New Delhi, India. Contact: Prof. C. V. Ramakrishnan, Int. Conf. on Engr. Software, Indian Institute of Technology, New Delhi, 110016, India.

Mar 12 - 15, 1990

EDAC '90 - The European Design Automation Conf., Glasgow, U. K. Contact: EDAC 90 Secretariat, CEP Consultants Ltd., 26-28 Albany St., Edinburgh EH1 3QH, U. K.

Jul 8 - 12, 1990

CATS '90 - Internat. Conf. on Computer Aided Training in Science and Tech., Barcelona, Spain. Contact: Prof. E. Onate, Centro Internacional de Metodos Numericos en Ingenieria, Jorge Girona Salgado, 31. 08034 Barcelona, Spain. Ph. 34-3-205 70 16/204 82 52.

Aug 6 - 10, 1990

SIGGRAPH 90, Dallas, TX, Contact: David D. Loendorf. Ph. (505) 665-0866.

Aug 28 - 30, 1990

ICED 90, International Conf. on Engineering Design, Dubrovnik, Yugoslavia. Contact: HEURISTA, Conf. Dept., Postfach 102, CH-8028 Zurich, Switzerland.

Sep 3 - 7, 1990

Eurographics '90 - A conf. and exhibition sponsored by the European Assoc. for Computer Graphics, Montreaux, Switzerland. Contact: Eurographics '90, Conf. Secretariat, Paleo Arts et Spectacles, Case postale 177, CH-1260 Nyon, Switzerland. Ph. (41) 22 62 13 33.

For further information, contact Vera Anand, 302 Lowrey Hall, Clemson Univ., Clemson, SC, (803)-656-5755.

Creative Engineering Design Competition and Display

by

Bill Koffke

The 22nd annual Creative Engineering Design Competition and Display (CEDCD), sponsored by our division, was held during the Annual ASEE Conference in Lincoln, Nebraska. Tom Baker of Villanova directed this year's competition.

The CEDCD is open to engineering students in the Freshman, Sophomore, Junior, Senior, and Graduate categories. Each institution may submit two design projects in the Freshman category and one project in each of the four other categories. The project reports are judged on problem statement, conceptualization, creativity, and analysis (all appropriate to the level of competition). Besides possible first, second, and third place awards in each category, depending on the number of entries, separate awards are given for "Most Creativity" and "Best Use of Computer Graphics".

The award winners of the 1989 competition are:

Freshman and Most Creativity Categories

1st place - J. Bryce Ferguson, Daniel M Jakopin, Patrick T. McGowan, and William W. Ver Kuilen
Marquette University
Faculty Advisor - Mrs. Stacy Geherd
Project - Aluminum Can Crusher

Senior Category

1st place - Michael Davis, Thomas Gottemoller, David Haruch, and Robert Jacobs
Villanova University
Faculty Advisor - Dr. T. Radhakrishnan
Project - Vegetable Oil Press for Mexico

Best Use of Computer Graphics

Mark Jerkering
OMI College of Applied Science, Univ. of Cincinnati
Faculty Advisor - Dr. Muhtar Al-Ubaydi
Project - Hull Design of a High-speed Open Water Air Entrapment Powerboat

Each member of the winning team of the Freshman category received a copy of AutoCAD Release 10 and AutoShade. Their university received a copy of AutoSolid. Each member of the Senior category received a copy of AutoCAD Release 10. Mark Jerkering, winner in the Best Use of Computer Graphics category, was awarded a copy of AutoCAD Release 10 and AutoShade and his university received a copy of AutoSolid.

The Division is most grateful to Autodesk, Inc. for their generous support of the CEDCD. This support has been made available to our division for the past two years.

Begin planning now for your university to be represented in the next CEDCD to be held at the ASEE Annual Conference in Toronto. An Entry and Information Guide for the CEDCD will be mailed in March with complete instructions and guidelines. If you desire such information immediately, contact:

William C. Koffke
Chairman, 1990 EDGD/ASEE CEDCD
Villanova University
Tolentine Hall, Box 102
Villanova, PA 19085
(215) 645-7308 (office)
(215) 275-8807 (home)

Report of the Theoretical Graphics Research Task Force

by

Walter Rodriguez

Theoretical and computational graphics research should nourish engineering design graphics education. To support such an endeavor, the ASEE/EDGD's Theoretical Graphics Committee, chaired by Pat Kelso of Louisiana Tech, created a subcommittee named the Theoretical Graphics Research Task Force. This note reports on the background, goals, and current activities of this Task Force.

The Task Force proposed to integrate the theoretical and computational graphics components of engineering design graphics by establishing the following goals for the Task Force: (1) define a mission statement, (2) compile a list of corporations interested in graphics research and development, (3) identify several sources of funding and the mechanisms to obtain such funding, (4) provide leadership in the initiation of a consortium of U.S. universities, government, and industries to increase the level of research funding for theoretical and computational graphics, (5) participate in the development of a new journal to communicate research ideas as well as the progress and product of the research efforts, and (6) define areas of research interest. Tasks 1, 2, and 5 have been completed and the information is available from the author. Tasks 3, 4, and 6 are in progress.

On June 6, 1988 the task force completed goal (1) by drafting the following mission statement:

The Graphics Research Task Force represents the interest of theoretical and computational engineering graphics researchers/ academicians in the private and public sectors. The Task Force was created by the Theoretical Graphics Committee to identify graphical research needs and sponsored research opportunities. Its mission is to facilitate the development of new approaches to visual communication and assist the Theoretical Graphics Committee in advancing the principles and theory of engineering graphics, descriptive geometry and computational graphics.

In order to accomplish this stated mission, the Task Force is organized to assist in: (1) identifying graphical research opportunities, (2) developing new approaches to visual communication, and (3) advancing the principles and theory of engineering graphics, descriptive geometry, and computational graphics.

Pursuant to the stated goals and mission statement, the Task Force is currently: (1) promoting graphics research and development, (2) searching for private funding sources within the U.S. computer graphics industry, (3) planning a theoretical graphics development prize in coordination with the newly organized Society for Theoretical and Computational Graphics (STCG), (4) collaborating with the STCG in the publication of graphics research project ideas and results in the new *Journal of Theoretical Graphics and Computing* (i.e., this journal is financially supported and published by STCG), (5) compiling annotated bibliographies to assist in graphics literature search, and (6) encouraging the development of new courses, programs, and books on theoretical and computational graphics.

Presently, theoreticians of computational graphics are conducting research projects that will influence the future of the visual communication and engineering design field. If part of this research effort is generated by engineering design graphics educators, it will unquestionably be more responsive to the needs of our students. Therefore, educators should support and promote graphics research and development projects that will respond to both industrial and university environments. However, this is not a simple task due to the lack of resources and the historical realities of the engineering graphics field. Notwithstanding, academicians should attempt to create the organizational structures and a fertile environment to foster such development projects within our area. One way to promote this effort is through the existing Task Force.

The creation and propagation of new graphics knowledge allows the academic spectrum of the engineering design graphics field to enrich its curricula, broaden its scope, and expand its influence. The Theoretical Graphics Task Force is working towards expanding the theoretical and computational graphics knowledge. It is building on the critical mass of human and material resources that already exists in the EDGD through a cohesive development of clear and concise activities.

For additional information, contact Walter Rodriguez through electronic mail at:

ce 102aa @ nve2.gatech.edu

or write to:

Dr. W. Rodriguez
Graphics/Mason Bldg.
Georgia Tech
Atlanta, GA 30332-0355 USA.

Survey Results – EDG Curriculum Modernization Project

by

Ron Barr and Davor Juricic
Project Co-directors

An NSF-sponsored project has been initiated to design, develop, test, and promote a modern curriculum for engineering design graphics. The project focuses on the modern definition of the discipline in light of the rapid transition from the old manual 2-D design medium to the new 3-D design medium based on solid modeling systems. The project involves early interaction and advice from advisory groups representing industry, engineering graphics educators, and engineering deans. As part of this early interaction, an extensive survey of all aspects of engineering design graphics was conducted and compiled. Those advisors who participated in the survey are listed in Table 1. The results of the survey were presented and discussed for the first time at the 1989 ASEE Summer Conference in Lincoln, Nebraska. The discussion included the suggestion that the survey results be published in an appropriate section of the *EDG Journal*.

The topics of Table 2 were posed to the panel. A response scale of 1 to 5, as indicated with each section of the survey, was requested. The compiled results follow each topic. For further information or comments, write the project co-directors at:

Univ. of Texas at Austin
ME Dept.
ETC 5.160
Austin, TX 78712-1063
(512) 471-3008 or
(512) 471-3009

The work on the new engineering design graphics (EDG) curriculum is supported by the NSF, Office of Undergraduate Science, Engineering, and Mathematics Education (USEME), Directorate for Science and Engineering Education (SEE), Grant No. USE-8854623.

Vera Anand	Clemson Univ.
Del Bowers	Arizona State Univ.
Barry Crittenden	VPI&SU
John Demel	Ohio State Univ.
Jon Duff	Purdue Univ.
Robert Foster	Penn State Univ.
Rollie Jenison	Iowa State Univ.
Jon Jensen	Marquette Univ.
Hugh Keedy	Vanderbilt Univ.
Michael Pleck	Univ. of Ill. at Urbana
Walter Rodriguez	Georgia Tech
Dipendra Sinha	San Francisco State Univ.

Table 1 - Panel Surveyed

A <u>The types of equipment and working environment for modern EDG should include</u>
(5 = high priority, 1 = low priority):

	Mean	Standard Deviation
Combined 2-D CADD and 3-D Solids	4.333	0.624
Freehand Sketching Media	4.167	1.280
3-D Solid Modeling System	4.083	1.187
3-D Wireframe Modeling System	3.583	1.320
2-D CADD System	3.333	1.179
Computer Sketching Media	3.000	1.472
Manual Instruments	2.000	0.913
Drafting Machine and Table	1.667	0.745
T-Square and Drafting Board	1.500	0.764

Table 2 - The Survey

B. The philosophical teaching goals of the new EDG curriculum should include (5 = high priority, 1 = low priority):

	Mean	Standard Deviation
Visualization (3–D Solid Model)	4.667	0.624
Visualization (Natural Free–Form)	4.500	0.645
Knowledge/Use of 3–D Solid Modeling	4.333	0.745
Solid (3–D) Geometry	4.333	0.745
Visual Relationship (3–D to 2–D)	4.333	0.850
Freehand Sketching (Natural Free–Form)	4.167	1.067
Visualization (2–D Pictorial)	4.167	1.143
Visualization (3–D Wireframe)	4.091	1.240
Freehand Sketching (2–D Pictorial)	4.083	0.954
Visualization (2–D Multiview)	4.000	1.080
Plane (2–D) Geometry	3.917	0.954
Visual Relationship (2–D to 3–D)	3.833	1.213
Design Methodology (Introduction)	3.833	1.213
Knowledge/Use of 3–D Wireframe Modeling	3.750	1.010
Knowledge/Use of 2–D CADD	3.500	1.041
Freehand Sketching (2–D Multiview)	3.500	1.258
Design Projects	3.417	1.256
Drafting Practices and Standards	3.250	1.479
Descriptive Geometry	3.091	1.443
Working Drawing Set	3.083	1.037
Knowledge of Computer Graphics Hardware	3.000	1.080
Line Quality, Lettering, Neatness	2.833	1.213
Theoretical Graphics	2.818	1.266
Manual Instrument Drawings	2.000	1.225
Computer Graphics Programming	1.833	0.687
Drafting Machine Techniques	1.417	0.640

C. The contents of the course should include (5 = extensive coverage, 1 = no coverage):

(i) Traditional Engineering Graphics

	Mean	Standard Deviation
Sketching	4.500	0.957
Pictorials	4.250	0.829
Dimensioning	4.083	0.954
Sections and Conventional Practices	3.917	0.954
Multiview Drawing	3.917	1.037
Auxiliary Views	3.667	1.106
Tolerances	3.417	1.115
Production and Assembly Drawings	3.083	0.862
Geometric Constructions	3.000	1.155
Manufacturing Processes	2.667	0.943
Threaded Fasteners	2.583	0.954
Charts and Graphs	2.545	1.157
Lettering	2.167	0.687
Manual Tools	2.167	0.799
Gears and Cams	1.583	0.640

Table 2 (continued)

(ii) Descriptive Geometry

	Mean	Standard Deviation
True Length of Lines	3.167	1.462
True Shape of Planes	3.167	1.462
Revolution	3.083	1.706
Intersection of Lines and Planes	3.000	1.414
Intersection of Planes	2.917	1.382
Intersection of Solids	2.917	1.498
Intersection of Lines	2.833	1.280
Primary Auxiliary Views	2.833	1.518
Line Projection in Space	2.833	1.572
Plane Projection in Space	2.833	1.572
Successive Auxiliary Views	2.750	1.422
Point Projection in Space	2.750	1.479
Parallelism and Perpendicularity	2.583	1.256
Developments	2.417	1.256
Conic Sections	2.167	1.280
Vector Graphics	2.083	1.037

(iii) 2–D Computer–Aided Design and Drafting (CADD)

	Mean	Standard Deviation
Editing Features	3.750	1.164
2–D Geometric Construction Techniques	3.667	1.106
Geometric Primitives	3.636	1.150
2–D Object Transformations	3.583	1.187
Plotting Capabilities	3.545	1.076
Dimensioning Features	3.500	0.957
Copy or Duplicate	3.417	1.187
Coordinate and Grid Systems	3.333	1.374
File Management	3.200	0.872
Annotation	3.083	0.862
Patterns, Templates, and Modules	3.083	1.037
Line Attributes	2.833	0.986
Screen Display Controls	2.833	1.280
Compute and Analyze	2.750	0.829
Input and ID Modes	2.750	1.010
User Interface Schemes	2.583	1.498
Set–Up Parameters	2.417	0.954
Customization and Macros	2.167	0.799

Table 2 (continued)

(iv) 3–D Wireframe and Solid Modeling

	Mean	Standard Deviation
3–D Geometric Construction	4.583	0.493
3–D Object Transformations	4.500	0.645
Base 3–D Primitives	4.333	0.943
3–D Line and Plane Generation	4.333	1.106
Editing Features	4.083	0.954
Extruding and Turning	3.917	0.759
Shaded Solids Viewing Control	3.667	0.943
Design Detailing Features	3.583	0.640
Boolean Operations	3.583	0.954
Surface Mesh Generation	3.500	1.041
Wireframe Viewing Controls	3.500	1.258
Machining Operations	3.455	0.891
Interfaces to 2–D CADD	3.417	0.862
Internal Representation Schemes	3.250	1.362
Properties Calculation	3.083	0.862

(v) Engineering Computer Graphics: Theory and Computations

	Mean	Standard Deviation
Interactive Graphics Techniques	3.250	1.233
Projections	3.208	1.145
Hard–Copy Output Devices	3.167	1.143
Interactive Input Devices	3.167	1.213
GKS, IGES, and PHIGS Standards	2.833	0.986
Graphics Systems and Processors	2.833	1.067
Graphics Display Technology	2.833	1.143
2–D Viewing Transformations	2.792	1.108
3–D Curves and Surfaces	2.750	1.010
Hidden–Line/Surface Algorithms	2.667	0.943
Classification of Graphics Software	2.583	0.954
2–D Matrix Transformations	2.583	1.115
3–D Matrix Transformations	2.583	1.115
Shading and Rendering	2.545	0.891
Segmentation and Data Structures	2.500	0.957
Principles of Color Graphics	2.417	0.954
2–D Bezier and Spline Curves	2.375	0.893
History of Computer Graphics	2.250	1.090

Table 2 (continued)

(vi) Engineering Design Methodology

	Mean	Standard Deviation
Design Communication	3.667	1.374
Decision Making	3.583	1.320
Creativity	3.583	1.382
Morphology of Engineering Design	3.583	1.441
What is Engineering Design?	3.583	1.441
Problem Solving Techniques	3.500	1.258
Analytical Tools	3.333	1.179
Freshman Design Project	3.333	1.247
What is Engineering?	3.000	1.354
Planning and Scheduling	2.750	1.164
Manufacturing Considerations	2.583	0.640

D. How many hours per week should be spent on (# = number of hours):

	Mean	Standard Deviation
Lecture	1.692	0.834
3-D Solid Modeling Use	1.664	0.866
3-D CADD Wireframe Use	1.410	0.541
Manual Freehand	1.083	0.759
2-D CADD System Use	1.050	0.960
Testing/Administration	0.436	0.452
Manual Instruments	0.210	0.396
Drafting Machine	0.000	0.000
Total	7.545 hours/week	

Table 2 (continued)

Axis Systems - Something New?

by

W. G. G. Blakney

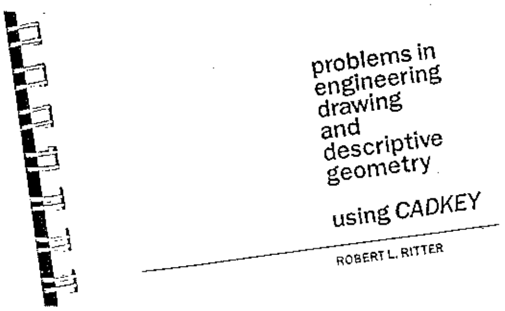
Cartesian coordinates, both 2 and 3-dimensional, have been around a long, long while. There has been very little, if any, ambiguity associated with their use. Those oldest-of-all engineers of the civil and military type, to whom maps (plan and top views) were and are so important, have no difficulty pretending that x is East and that y is North. Those users, deciding that height or elevation would be z, may have noticed that the thumb, index finger and middle finger of the right hand pointed in these directions if the index finger pointed in the x (East) direction. Who knows who noticed it first? It has turned out to be such a useful idea that it is indeed unfortunate that the person has not been memorialized by having his/her name attached. Likely, no single person is responsible, and it would not be surprising if it were not called right-handed until someone tried to decide the best way to assign a positive sense of rotation about an axis. It seems so sensible to consider a clockwise rotation, looking in the direction of the positive axis, that one would hardly suggest otherwise.

Other users assigned to their tools and machines and drawings x-y's , if in 2-D, and x-y-z's, if in 3-D, in the most straightforward and useful way they could. When numerical control (NC) came along, it was already abundantly clear to mechanical engineers (and now manufacturing engineers) as to what the user found convenient about the useful direction of axes and whether or not they departed in any way from the right-handed system. Those engineers who are deliberate about making the front view the most informative would find it natural to put x in the width direction, y in the height direction, and z in the depth direction. The fact that depth is positive from back to front in a right-handed system is not the most desirable situation but a small price to pay for not complicating matters by the introduction of a new system.

So there is not problem, right? Wrong! Who has not noticed the power computers have to change conventional language by their infernal insistence on special names spelled in special ways? Now, "the fat is in the fire"! Lines formerly called visible will be called continuous. Letters called Gothic or Reinhardt will be called Roman, or whatever. Axes known as right will be called "world" and axes set up in a useful way by the user will be called "user". In all cases it hardly matters if all the names are equivalent. Fortunately, this is the case. The world and user system are right-handed. There still seems to be no problem, but these names are taken so seriously that some suggest new names are needed to clarify something, which indeed really has not been made any more complicated than by the assignment of these new names. It is unfortunate that computers need all these special words, but society by-and-large accepts the bugs and idiosyncrasies of the computer world.

Just how seriously these labels are taken is witnessed by a recent text[1] that has six pages on coordinate systems, and, as if there weren't enough names for coordinate systems, the name "device" is offered to clarify some imagined difficulty in the computer world. Also, it is stated that mathematics and physics has a system different than right-handed! If this is so, I have missed something very important and fundamental! Coordinate orientations are assigned by users, not devices. Civil engineers will have no trouble with maps on cathode ray tubes, nor will mechanical engineers calling for an x-y on a front view and a y-z on a side view.

As a teacher of graphics, I am painfully aware of my lack of success in doing everything in my power to remove the inabilities students have with geometry and graphics. I can seek refuge in the knowledge that the textbook used is as up-to-date as any and more relevant to course content



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than most. No way would I expose them to material which might question the knowledge I assume they have of a right-handed coordinate system by suggesting anything other than the fact users orient that system according to their own need. In which way are these views inappropriate to a majority to which I may not belong?

These views are directed to institutions that offer a course in graphics designed to teach graphics to every engineering student, regardless of specialty. Because problems solved by the students are predominantly oriented towards mechanical engineering, one has to look deliberately for opportunities to demonstrate the use made by others of a topic when the opportunity arises. It is highly likely that the sensitivity to this ME orientation explains the concern these comments have shown about keeping things as general as possible.

[1] Luzadder, W. J. and Duff, J. M., *Fundamentals of Engineering Drawing*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1989.

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Editor

John Barrett Crittenden
Division of Engineering Fundamentals
VPI&SU
Blacksburg, VA 24061

Division Editor

Larry D. Goss
Engineering Technology
University of Southern Indiana
Evansville, IN 47712

Technical Editor

George R. Lux
Division of Engineering Fundamentals
VPI&SU
Blacksburg, VA 24061

Advertising Manager

Jerry V. Snith
363 Knoy Hall
Purdue University
West Lafayette, IN 47907

Circulation Manager

Clyde H. Kearns
The Ohio State University
2070 Neil Avenue
Columbus, OH 43210

Scope

This Journal is devoted to the advancement of engineering design graphics technology and education. The Journal publishes qualified papers of interest to educators and practitioners of engineering graphics, computer graphics, and subjects related to engineering design graphics in an effort to (1) encourage research, development, and refinement of theory and application of engineering design graphics for understanding and practice, (2) encourage teachers of engineering design graphics to experiment with and test appropriate teaching techniques and topics to further improve the quality and modernization of instruction and courses, and (3) stimulate the preparation of articles and papers on topics of interest to the membership. Acceptance of submitted papers will depend upon the results of a review process and upon the judgement of the editors as to the importance of the papers to the membership. Papers must be written in a style appropriate for archival purposes.

Submission of Papers and Articles

Submit complete papers, including an abstract of no more than 200 words, as well as figures, tables, etc. in quadruplicate (four copies) with a covering letter to J. B. Crittenden, Editor, Engineering Design Graphics Journal, EF - VPI&SU, Blacksburg, VA 24061. All copy must be in English, type double-spaced on one side of each page. Use standard 8 1/2 x 11 inch paper only, with pages numbered consecutively. Clearly identify all figures, graphs, tables, etc. All figures, graphs, tables, etc. must be accompanied by a caption. Illustrations will not be redrawn. Therefore, ensure that all line work is black and sharply drawn and that all text is large enough to be legible if reduced to single or double column size. High quality photocopies of sharply drawn illustrations are acceptable. The editorial staff may edit manuscripts for publication after return from the Board of Review. Galley proofs may not be returned for author approval. Authors are therefore encouraged to seek editorial comments from their colleagues before submission of papers.

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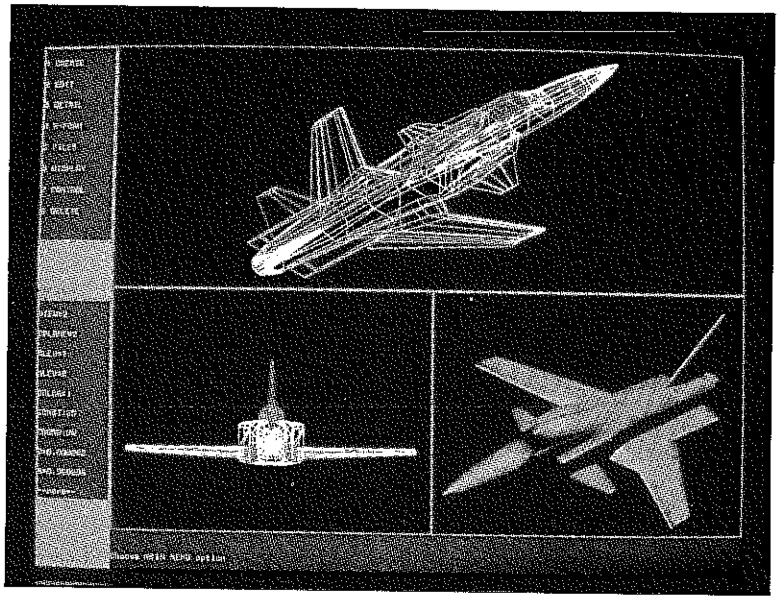
Deadlines

The following deadlines apply for submission of articles, announcements, and advertising: Fall issue - August 15, Winter issue - November 15, Spring issue - February 15.



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The CADKEY Videos were developed by Dr. Gary Bertoline and Dr. Leonard Nasman of the Ohio State University Engineering Graphics Department. They have introduced hundreds of engineering students to CADKEY, and have carefully planned the scope, pace, and sequence of the tapes to help new CADKEY users become proficient in a minimum amount of time. The tapes offer the following applications and advantages.

- **The tapes can be used to supplement lectures for large group instruction.**
- **The tapes provide consistent delivery of instruction in multiple section classes.**
- **The CADKEY Videos are a great help in situations where classes are assigned to new Graduate Teaching Assistants, or to instructors who are teaching CAD for the first time.**
- **The tapes, along with the Study Guide, provide a ood foundation for individualized instruction .**
- **The tapes can be made available in a learning resource room to students who miss class sessions.**
- **Provides the opportunity for students to review the tapes several times to build CADKEY skills.**

There are currently ten tapes in the series. Tapes one through four cover the most commonly used CADKEY features. Five through seven cover advanced dimensioning, cross-hatching, and editing. Tape eight provides a foundation for the powerful 3D capabilities of CADKEY. Tape nine contains a brief review of the CADKEY configuration process, and tape number ten covers the extensions found in CADKEY version 2.1.

The tapes vary between 30 and 40 minutes in length, and are designed to be fit within a normal lecture period and still allow some time for the instructor to cover local assignments and problems.

The price of the tapes is $90 each except for tape #9, which is $40. A set of tapes 1 through 4, or 5 through 8 is $300 per set. A set of tapes 1 through 8 is $560, and the complete set of tapes 1 through 10 is $680. ASEE members are eligible for a 50% discount off these prices. The Study Guide is priced at $10 per single copy (quantity discounts are available).For more information on the CADKEY Videos, contact:

Microcomputer Education Systems Inc.
3867 Braidwood Drive
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