THE ENGINEERING DESIGN GRAPHICS JOURNAL

ENGINEERING DESIGN GRAPHICS DIVISION ASEE

Autumn, 1994
VOLUME 58,
NUMBER 3

ENGINEERING DESIGN GRAPHICS DIVISION
AMERICAN SOCIETY FOR ENGINEERING EDUCATION

engineering design graphics division
american society for engineering education 1928

THE ENGINEERING DESIGN GRAPHICS JOURNAL

Volumn 58 Number 3 Autumn 1994

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The *Engineering Design Graphics Journal* is the official publication of the Engineering Design Graphics Division of ASEE. The scope of the Journal is devoted to the advancement of engineering design graphics, computer graphics, and subjects related to engineering design graphics in an effort to (1) encourage research, development, and refinement of theory and applications 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.

ISSN 0046 - 2012

. . . from the EDGE

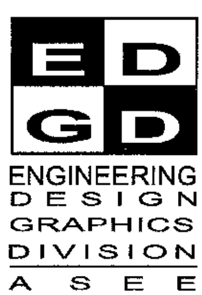
Engineering • Design • Graphics • Editor

Instead of a new editor, you will see more of my handiwork for the next three years. Someone asked me the other day if I thought I would run for a third term. Well, I really have enjoyed publishing the Journal for the first three years, and although I might be a bit nuts to do it a second term, but I am not totally deranged. After six years, I will be ready to pass the *Journal* torch to someone else. Maybe by that time transfer of electronic graphics across programs and across platforms will be transparent, therefore eliminating some of the day-to-day problems of producing the *Journal.*

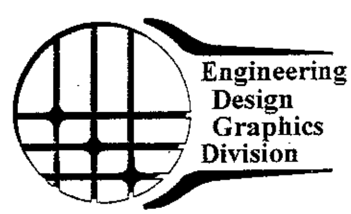
Last spring, we ran a contest for an EDG logo to be used especially in conjunction with the 50th anniversary of the Engineering Design Graphics Division. The winners were announced at the ASEE annual meeting and I would like to let all of you know.

The winning logo was designed by Bill Fletcher of Purdue University. If you close your *Journal*, you can get a good look at the winning design. Second place was won by Shawn Coffing, also from Purdue. Kyle McMains (Purdue), tied with Sue and Craig Miller (Purdue) for third place. Now, I realize that this looks bad because all of the winners have Purdue connections, and would guess that you're thinking that the voters were biased. However, I want you to know that there was only one Purdue person among the voting population. Voters included the EDG executive committee as well as the review board for the *Journal.* The voters did not know who had designed the logo or where the designer originated.

All in all, I would like to thank all of you who participated or encouraged your students to do so. I would also like to thank Roger Payne and Autodesk for providing prizes for the winners.



First Place
Bill Fletcher



Second Place
Shawn M. Coffing

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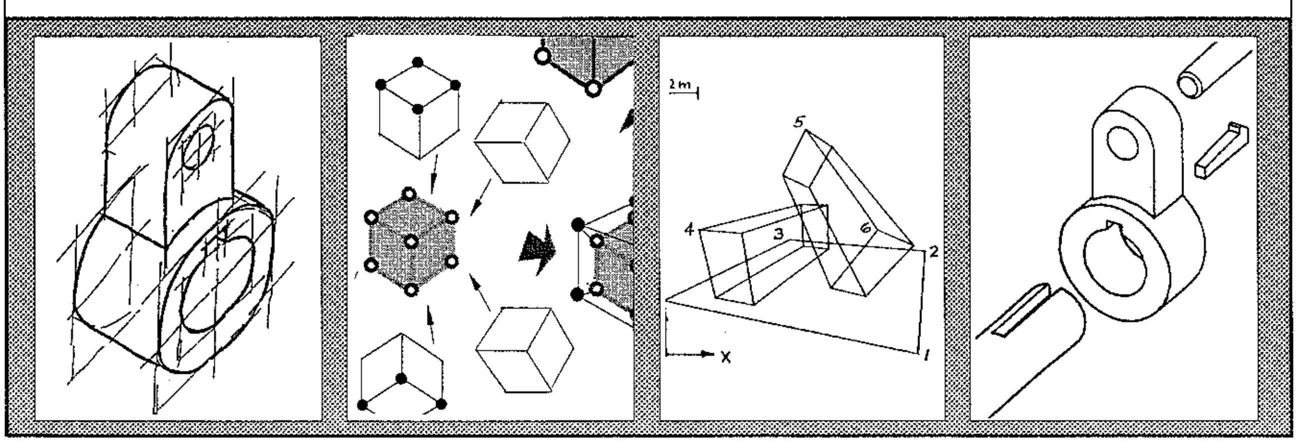

Freshman Engineering Design/Graphics Problem Status: A National Study

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Abstract

Literature dealing with freshman level open-ended design/graphics problems has started to reveal some high interest as well as some concerns. The intent of this national study was to develop a greater understanding about the status of the design process that may or may not exist in United States university/college level freshman engineering/technical graphics classes.

The study attempted to gather, analyze, and disseminate a summary of design/graphics' activities that presently exist across our programs throughout the United States. Study results indicated variations to design/graphics' approaches. Also, faculty opinions about freshman design issues and design/graphics examples were gathered via a comprehensive survey form.

A pilot study population consisted of all 1990-91 members of the Engineering Design Graphics Division of the American Society of Engineering Education. The follow-up study population consisted of all 1992-93 members of the Engineering Design Graphics Division. Participants shared many of their opinions and perceptions dealing with design/graphics activities as well as numerous design/graphics problem examples. It is intended that the findings result in a more in-depth analysis and compilation of freshman level design/graphics' problems.

Introduction

The literature dealing with freshman level open-ended design/graphics' problems is starting to reveal some high interest and some concerns. These concerns were recently discussed extensively and reported in the *Proceedings of the NSF Symposium on Modernization of the Engineering Design Graphics Curriculum* (Barr and Juricic, 1990). McNeill, et al. addressed specific issues in "Beginning Design Education with Freshman" (1990). Rodriguez (1990) spent extensive time in articulating the concepts of design, engineering visualization, and computer graphics' modeling. Regan and Minderman (1993), and Dally and Zhang

(1992) have identified numerous strategies and examples for design problem solving.

A number of issues and concerns addressed by the aforementioned specialists include:

- Engineering and design graphics is a national concern.
- Engineering design graphics curriculums must be modernized.
- The role of descriptive geometry and design graphics in the modernization process must be defined.
- Design visualization is becoming increasingly important in the design process.
- Computer systems' impact on the design process and design visualization is increasing dramatically.
- Engineering design graphics and technical graphics contrasting roles need to be clarified.
- Contemporary approaches to the fundamentals of engineering design graphics–and the four-year curriculum will need to be developed.
- Engineering design ideation and graphics communication methodology for the future must be further developed.
- Solid modeling and other CAD applications in freshman engineering design graphics must be expanded.
- The future role of solid modeling in engineering design graphics must be clarified.

Problem of the Study

The intent of this study was to initiate greater understanding about the status of the design/graphics process that may or may not exist in university/college level freshman engineering/technical graphics' classes. The study attempted to gather, analyze and disseminate a summary of "design activities" that presently exist across our programs throughout the United States. Hopefully, the study findings will result in a more intensive in-depth analysis and compilation of freshman level design problems.

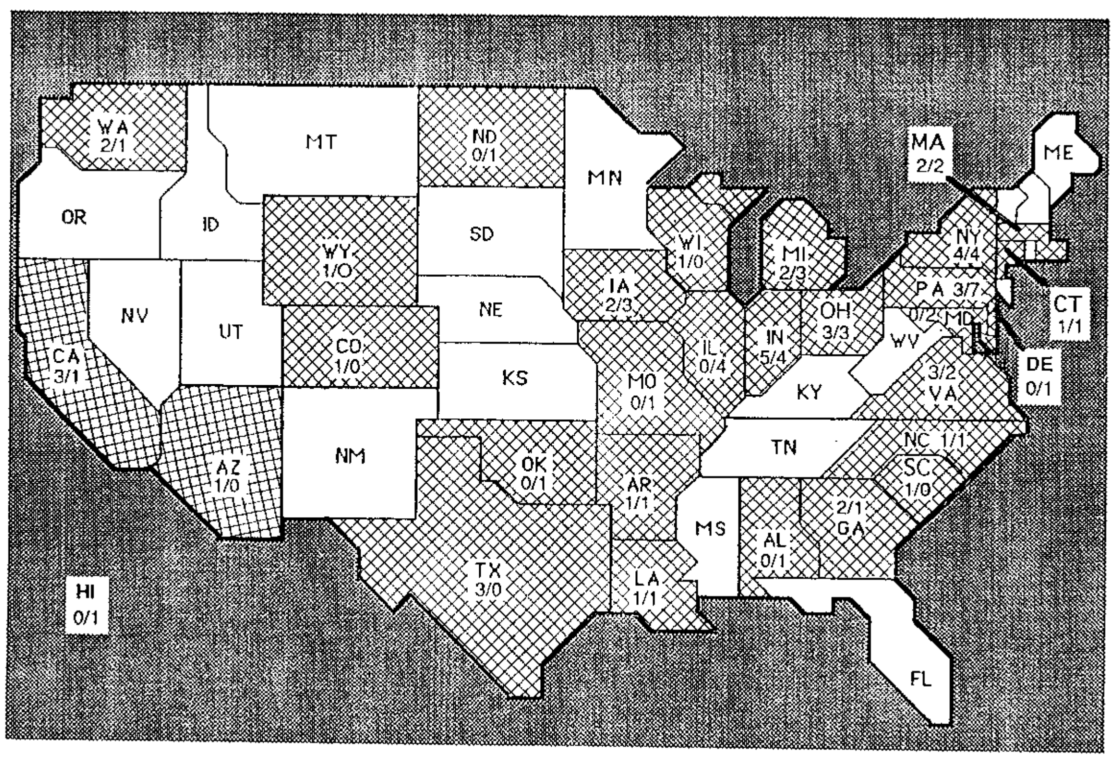

Figure 1. Location of study participants. (Example: WA 2/1 translates to 2 respondents in 1991 and 1 in 1993.

Generally, when freshman students are exposed to the open-ended design process, there is an effort made to work through the following general activities of:

1. problem identification,
2. preliminary ideation,
3. problem refinement,
4. analysis,
5. decision, and
6. implementation.

The study results indicated some variation to this general design approach. The study process gathered freshman design related opinions of faculty and design examples via a survey form.

Method of the Study

The pilot study population consisted of all 1990-1991 members of the Engineering Design Graphics Division of the American Society of Engineering Education (Boyer, 1991). A total of 467 listed members were contacted via a single mailing with no attempted immediate follow-up. The letter of transmittal and survey response form were sent to each member in January, 1991. The follow-up study population consisted of all 1992-93 members. A total of 304 members were contacted again in August, 1993.

A total of 46 (9.8 percent) of the 467 members contacted agreed to participate in the pilot study. A total of 48 (15.8 percent) of the 304 members participated in the follow-up study. Fifteen (15) of the follow-up participants had previously responded to the pilot study. A total of 79 unduplicated participants (25 percent of 304 members) participated in the pilot and follow-up studies. Figure 1. depicts the geographic locations of the 46/48 participants.

The responses given to Questions 2-8 of the survey form follow:

Question 2
Which of the following freshman level graphics classes do you teach or supervise?

Response

(1991/1993)	Number	Percent
Engineering Graphics	33/34	71.7/70.8
Technical Graphics	.4/4	8.7/8.3
Both Courses	.9/8	19.6/16.77
NR	0/2	0/4.2
	46/48	100/100

The greatest percent of graphics courses obviously fell in the engineering graphics category versus technical graphics. Also, the vast majority of participants were at four-year engineering institutions versus four or two-year technology schools.

Question 3
Do you use open-ended design problems in your freshman level graphics classes?

Response

(1991/1993)	Number	Percent
Yes	21/27	45.7/56.3
No	22/19	47.8/39.6
NR	.3/2	6.5/4.1
	46/48	100/100

The participants were nearly equally divided when asked to indicate whether they used open-ended design problems. There was a slight increase in the percentage using open-ended design problems in the 1993 follow-up study.

Question 4
Do you believe that open-ended design problems should be used in freshman level engineering/technical graphics classes?

Response (1991/1993)	Number	Percent
Yes	28/30	60.9/62.4
No	14/15	30.4/31.3
NR	.4/3	8.7/6.3
	46/48	100/100

It was interesting to observe that although the participants were nearly equally divided on Question 3, twice as many felt that open-ended design problems should be used in freshman level classes.

Question 5
Do you offer the freshman level engineering/technical graphics class in one or two quarters or semester class?

Response: 1991/1993	Number	Percent
One-quarter	.6/6	13.0/12.4
Two-quarter	.3/3	6.5/6.3
Three-quarter	.1/1	2.2/2.1
One-semester	28/31	60.9/64.6
Two-semester	.6/4	13.0/8.2
NR	.2.2	4.4/4.2
Other	0/2	2.1
	46/48	100/100

A one-semester offering followed by a one-quarter offering constituted the most prevalent calendar for courses. Two-quarter, three-quarter and two-semester calendars make up 21.7 to 16.7 percent of the offerings. It is obvious that the exposure to engineering/technical graphics for more than one semester or one quarter is rare. Multiple semester and quarter offerings were more prevalent in four and two-year technology programs.

Question 6
If you require a freshman level open-ended design problem how many class weeks or class hours are devoted to the problem?

Response: (1991/1993)

Time Frame	Range	Average	Number
Weeks	1-10/2-11	3.24/5.47	N=19/18
Hours	1-30/2-40	11.60/18.73	N=11/15

Participants were consistent about the amount of total time devoted to freshman level open-ended design problems. For example, 3.24/5.47 weeks could certainly equate to approximately 11.60/18.73 class hours (outside time was not reported). There appeared to be no real time difference between courses offered on a one-semester, one quarter, etc. time frame.

Question 7: (1991/1993)
What rationale do you have for your response to Question 4?

(Do you believe that open-ended design problems should be used in freshman level engineering/technical graphics classes?)

For those participants responding **No** to Question 4, the basic rationales (paraphrased) were:

- The intent of the course is to be an introduction to graphical communication. The wide diversity in technical sophistication and background makes the devising of a suitable open-ended design problem a difficult task. (1991)
- I answer "no" in light of the context of our program. With "open enrollment" (anyone with a high school diploma is acceptable) we get a wide variety of students, often under-prepared for college-level work. They often take a background course in science, math, or creative thinking to be able to handle design projects. We do discuss the process mentioned in your letter in general terms. (1991)

- Very limited time at the entry levels–material is already being eliminated. Open-ended design problems are introduced in the freshman introduction to engineering course. Students are better able to do open-ended design projects at the senior levels – after learning basic skills, etc. Engineering graphics concentrates on 3D visualization skills. (1991)
- We teach only highly structured standards - oriented engineering graphics including traditional drawing, descriptive geometry, 2D Autocad & 3D Intergraph before we start design projects. (1991)
- Graphics is a communication course and so many come so ill-prepared that it is difficult to teach the basics and incorporate a project. Hence projects are not introduced until the second year. (1991)
- It is a useful and worthy experience, but in one course filled with traditional graphics, FORTRAN, and CAD, design went out when computers came into the course. We have to bring back some design in a couple years. (1991)
- We need to get freshman to stop memorizing and start thinking. I don't give this type of problem because of the time it would take to set up good problems and appropriate grading methods. At the moment I'm swamped with completely reworking the course to incorporate CADKEY. (1991)
- I think it is more important for the students to study the fundamentals of descriptive geometry and orthographic projection, sectioning, auxiliary views, etc. (1991)
- No! Too much emphasis has been placed on design without realizing that practical communication via the engineering drawing is what gets things done. (1991)
- We introduce students to design early in the sophomore year (not in the freshman year). One open-ended design project is used, lasting for 4-5 weeks. (1993)
- Students' technical backgrounds are inadequate. Course is "bare bones" now. There is not enough time in a semester to teach graphics and design. (1993)
- Adequate grounding in graphics theory, computer operations, software operation, and computer geometric modeling does not leave time for design problems. (1993)
- I believe that open-ended design problems should be introduced after students have learned at least some methods of engineering analysis–during a statics course at the earliest. (1993)
- To do so would take away time from learning the basics of graphics. With the limited background of freshmen the problems would have to be simplified or contrived to get anything done. (1993)
- Time is better spent at this entry level in getting theory and developing spacial thinking and visualization powers. (1993)

For those participants responding ***Yes*** to **Question 4**, the basic rationales (paraphrased) were:

- It is a great learning experience and affords a close simulation of the industrial experience. (1991)
- Open-ended problems give the students a better feel for engineering practice. They also are a good motivational tool for freshmen. (1991)
- We believe that it is very important to introduce the freshman to engineering design as soon as possible. (1991)
- Familiarization with the design process at the freshman level helps students to confirm that they want to pursue engineering for a career; helps them to think and be creative; learn to work with others; help them learn the organized design process used by engineers. (1991)
- I teach the graphics component for engineering technology programs. Without an open-ended problem, the concept of engineering technology suffers. (1991)
- The main application for engineering and technical graphics is to serve as the communication medium for the design process. A design project shows by example how graphics is used in design from ideation (sketching), clarification (modeling), to documentation (working drawings). (1991)

- It forces students to make a decision independent of his fellow class members. There are no unique solutions and students should be made aware of that. In almost all other classes, students encounter one problem, one solution. (1991)
- 1) Design integrates the students' personal experiences and intuition with the technical information they learn in courses - thus the course material seems more relevant and easier to remember. 2) Design gives students practice in applying course material to realistic situations, which better prepares students for their engineering profession. 3) Students become more accustomed to poorly defined, realistic problems. (1991)
- It takes time to develop creativity and should begin as early in the curriculum as possible. Graphics is the logical place to do that since it is often the only engineering course they get in the first two years. (1991)
- Freshmen need a hook to keep them in engineering. They are probably more creative than the seniors because they are not corrupted with all the analysis classes. (1993)
- The course I am teaching is entitled "Introduction to Engineering and Computer Science." The students learn basic problem solving skills in addition to graphics. An open-ended problem serves to integrate all the materials they learn in the course. (1993)
- Traditional graphics is too dry. We use a semester-long design project as a vehicle for practicing/developing their graphics skills. Although a project is also built (which students find most exciting), most of their grade is from their graphics work. The engineering graphics course is also considered a freshman "gateway" course where students are introduced to the engineering profession. Design projects are fun and are an encouragement to students. Class evaluation surveys cite the design project as one of the best parts of the class. The class is always highly rated. (1993)
- Design is a major function of engineering. Students must begin to think as designers from the start. Freshmen can readily handle the design process as long as the project is one that their analysis tools will solve. Conceptual design works well at this level. (1993)
- We believe the use of open-ended design at the freshman level is an essential learning tool for several reasons. It allows the students to think and brainstorm in an unstructured format while interacting within a small group setting (5-6 students). It demonstrates to the students how to optimize their ideas, and it assists in student retention at the freshman level. The most positive way for students to commit to an engineering career is to have to practice it. (1993)
- We use open-ended design problems as a means to tie our engineering design and graphical communications courses together. We focus on the thought process, organization, team work, written and oral presentations rather than the end product. This decision was made by all engineering faculty at our campus. (1993)

Basically, those responses that were **No** (negative) can be summarized as:

- Design is not the intent of a freshman level class.
- Not enough time to do the design project/process.
- CAD activity has replaced the time spent in design.
- Advanced engineering classes is where design should be covered.
- Students do not have adequate background.
- Course should emphasize communications, visualization, and CAD.

Those responses that were **Yes** (positive) can be summarized as:

- Design should simulate open-ended real world problems.
- Students need to develop creativity early.
- Provides students good career decision making skills.
- Provides students high motivation and favorable impressions about engineering.
- Design needs to be started early.
- Students become accustomed to poorly defined realistic problems versus the one problem and one solution concept.

Recommendations for Further Study

In response to the pilot and follow-up studies the following recommendations/suggestions are submitted for further consideration by various individuals, departments, and professional organizations:

A larger more exhaustive survey should be conducted to determine the total range of successful freshman level design problems. The results should be published and distributed to all engineering design graphics' faculty. Funding should be made available by professional societies, special interest groups, industry, and foundations.

Approximately 3-4 workshops of at least two-days duration each should be conducted over the next 2-3 years to expose present engineering design graphics' faculty and graduate students planning to teach in graphics' programs how to present successful design methods. Funding should be made available by professional societies, special interest groups, industry and foundations.

Specialized studies should be conducted of various industrial, civil, architectural, construction, electronic, computer, chemical industries/organizations to determine what types of problems are available for adaptation as freshman level open-ended design problems. The resulting case studies should be published and distributed to all engineering design graphics faculty.

Selected References/Readings

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Biographical

Currently a professor in the Department of Industrial and Engineering Technology at Central Michigan University, John G. Nee earned his doctorate from the University of Minnesota. His teaching experience includes 30 years at the community college, technical institute, and university levels. Nee has had articles published in more than 100 publications; he has also published four textbooks in engineering technology. A Certified Senior Engineering Technologist and a Certified Manufacturing Engineer, Nee has work experience in machine design at 3M Company, the Beloit Corporation, and various consulting engineering firms.

The Role Of Graphics And Modeling In The Concurrent Engineering Environment*

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Abstract

Concurrent engineering is a new approach to product development in which conceptual design, analysis, manufacturing, marketing, maintenance, and even product disposal are considered simultaneously during the early stages of the design process. A key element in successful implementation of concurrent engineering is the development of an integrated Computer-Aided Design and Manufacturing (CAD/CAM) data base. From this computer data base, a design representation or model of the product is derived for direct application to all phases of design, analysis, manufacturing, and marketing. This paper discusses the fundamental role that design representation plays in concurrent engineering, and illustrates the various graphics and modeling techniques that are appropriate for each aspect of the concurrent engineering design process.

* This paper was presented at the 1994 ASEE Gulf-Southwest Section Annual Meeting in Baton Rouge, Louisiana, and received a First-Place Best Paper Award.

Introduction

The traditional approach to product development could best be described as a serial process. In the past, tasks associated with product specification, design, manufacturing, and maintenance planning were all performed sequentially as separate steps by different teams. As each stage was completed, a team would "throw" their contribution "over-the-wall" to the next group, who would then work on their addition to the design solution. This serial process often required several iterations through the various teams in order to insure correctness of final solution and a high quality end product. These iterations in turn would produce long time-to-market cycles, a situation which is no longer acceptable in today's global business enterprise.

Concurrent engineering is a new approach to developing products and the related support processes concurrently in an effort to improve quality and to reduce design cycle time (DeLorge, 1992). Thus, as opposed to the past design approach, concurrent engineering design can be thought of as a parallel design process. The concurrent product development process involves all task groups from the outset, including conceptual design, analysis, manufacturing, marketing, and maintenance groups. One of the keys to successful implementation of concurrent engineering is the employment of new technologies for efficient communication between task groups and between high-tech development and production tools.

In its broadest sense, concurrent engineering involves many concepts of which some are outside the design realm. It includes new management practices, interpersonnel issues, and wholesale acceptance of a new "business philosophy." According to Carter and Baker (1992), there are four basic dimensions for successful implementation of concurrent engineering. These dimensions can be briefly described as follows.

a. *Organization*
Concurrent engineering organization calls for mixed-discipline teams that are empowered to solve problems and make decisions. It strips away hierarchical management layers, facilitates interdisciplinary communication, and gives team members a sense of ownership of the design solutions.

b. *Communication*
Concurrent engineering requires a sound infrastructure for efficient communication. It includes communication between the various task groups, as well as communication of design solutions between different CAD and CAM tools

c. *Requirements*
It is important from the outset to carefully define the customer requirements as well as requirements imposed on the product from external regulations.

d. *Development Tasks*
Development tasks are defined at the outset of concurrent engineering. Multi-disciplinary team members interact directly during each development task and make decisions by consensus.

The intent of this paper is not to cover all of the above aspects of concurrent engineering. The paper will specifically focus on the communication dimension of the concurrent engineering environment. Within this dimension lies the important development and utilization of an integrated Computer-Aided Design and Manufacturing (CAD/CAM) data base. From this computer data base, a model or design representation of the product is derived for direct application to all phases of design, analysis, manufacturing, and marketing. This product model is truly the key to the widespread, future success of the concurrent engineering design paradigm.

Design Representation in the Evolving Design Paradigm

Design representation is the primary interest of the academic discipline known as Engineering Design Graphics (EDG). The EDG discipline is concerned with the development and conveying of design ideas in its many forms, from freehand conceptual sketches to 3-D computer geometric models. The methodology of choice for Engineering Design Graphics is intimately related to the Evolving Design Paradigm (Wozny, 1989; Barr & Juricic, 1992).

Developments in computer technology have created a new design paradigm based on solid geometric modeling. Design representation based on solid modeling provides a complete and unambiguous description of part geometry that is amenable to an integrated CAD/CAM environment. As illustrated in Figure 1, the data base associated with the 3-D model serves as the central hub for product data communication to all aspects of design, analysis, manufacturing, testing, production, and marketing. The significance of this hub is that all task groups access the same data base, use the data directly in their CAD/CAM tools, make the needed changes or additions to the design, and then share their design contributions immediately with other task groups.

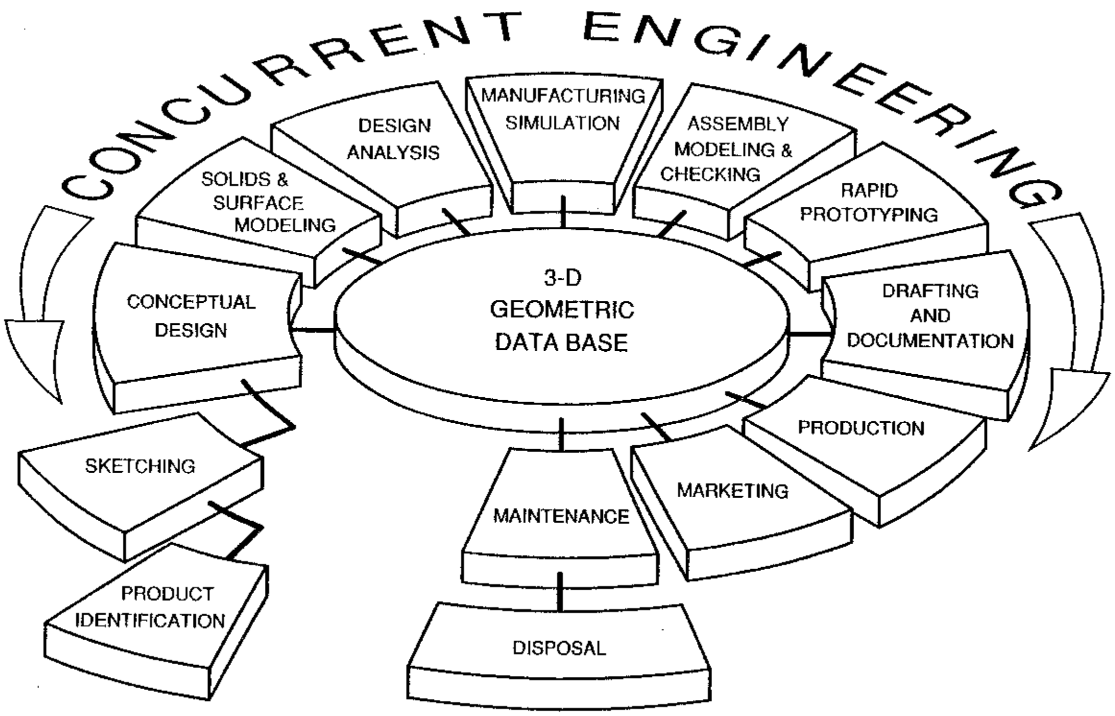


Figure 1. The role of graphics and modeling spans all aspects of the concurrent engineering environment. The 3-D geometric data base serves as the hub for design communication.

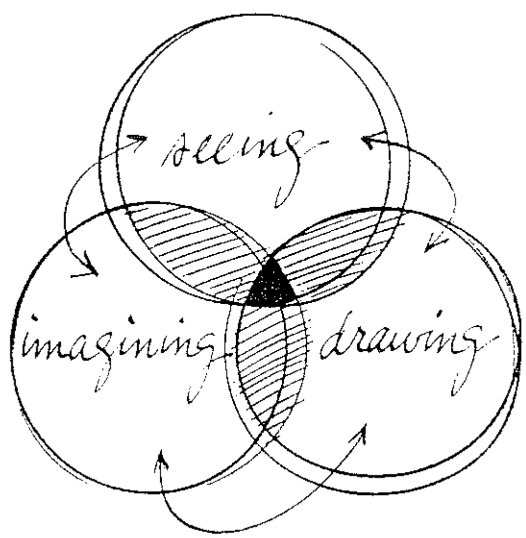


Figure 2. McKim's model of visual thinking includes sketching in a cyclic loop for creative design ideation (McKim, 1980, p. 8). *Figure used with permission of the publisher.*

It should be noted that the 3-D data base for many CAD/CAM applications is still not perfect. Part features, tolerances, material properties, as well as seamless interfaces to tools for analysis and manufacturing, are still fairly deficient. Research efforts continue to develop a product model data base (Dove, 1993) which will improve this information and lead to a more ideal concurrent engineering design paradigm. Nonetheless, the concept depicted in Figure 1 seems attractive, and it is worth visualizing how it may continue to unfold in the near future.

Sketching and Conceptual Design Development

Design ideas and concepts usually originate in the mind of the designer, as he or she imagines physical solutions to a defined problem. This process of design ideation is almost always enhanced if the designer can "see ideas emanating from the mind." McKim (1980) has referred to this ideation process as an imagining-drawing-seeing cyclic loop (Figure 2). Freehand sketching is a way of expressing one's visual thoughts and creative ideas and is, thus, the most appropriate technique used in the creative task of new product conceptualization. For engineering design, the sketching style should be technical, relying on traditional methods such as axonometric pictorials (Figure 3) and multiview orthographic layouts. This sketching style is familiar to all technical team members, and can be used to stimulate and interactively communicate ideas during brainstorming sessions and informal preliminary design meetings.

The designer uses these preliminary sketches to formalize the design representation of the product by creating a 3-D geometric model. This step marks the beginning of the integrated 3-D CAD/CAM data base. There are many approaches to develop and refine this 3-D geometric model, as will be discussed in the next section on solid modeling. The purpose of the conceptual model is for preliminary visualization by all task groups and for early interaction with the customer. It is not expected that the conceptual geometric model will be in any final form, and indeed ease in early modification of the preliminary concept is one of the advantages of using the 3-D computer modeling paradigm. At this stage, team members' experiences, customer preferences, and aesthetic design goals, in addition to requirement specifications, may drive the decision making process.

Solid Modeling

The solid modeling stage develops a formal, unambiguous description of the product geometry to a level of completeness such that the associated 3-D data base can be successfully communicated to high-tech analysis and prototyping tools. This formal, unambiguous description of a solid model surpasses the capabilities of traditional 2-D drawings which are subject to human interpretation and error. Development of this solid model description begins at the conceptual design stage, and refinement of the solid model continues throughout the concurrent engineering design process as results of analysis, simulation, testing, rapid prototyping, and marketing suggest improvements to the 3-D geometry.

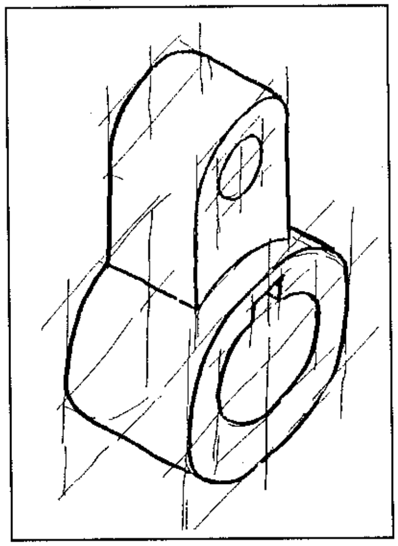


Figure 3

Pictorial sketching facilitates creative ideation and early communication of new design ideas. Shown here is a preliminary axonometric sketch for a proposed rocker arm design.

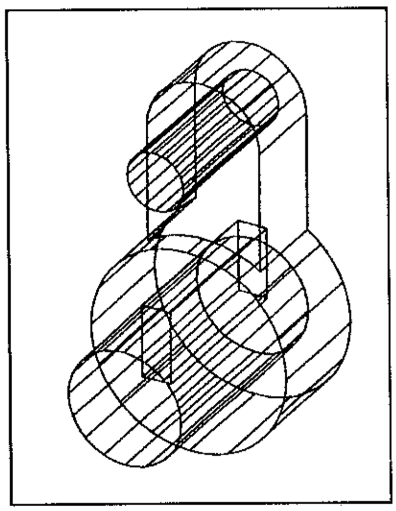


Figure 4

The solid computer model of the rocker arm can be built using a combination of 2-D profile extrusions and Boolean subtractions of base 3-D primitives.

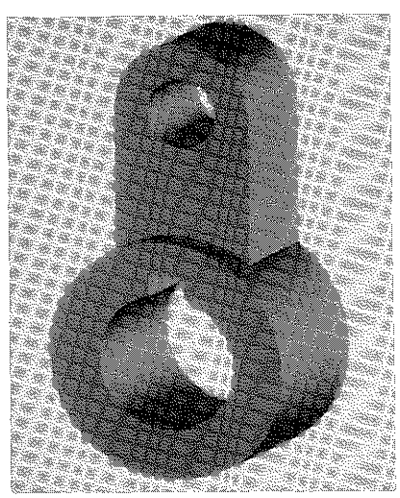


Figure 5

The rocker arm model can be rendered and shaded at this stage of the concurrent engineering design process to facilitate visualization of the design.

```
Ray projection along X axis, level of subdivision: 3.
Mass:            0.6902069 lb
Volume:          2.430644 cu in  (Err: 0.06963354)

Bounding box:          X: -0.875  --  0.875 in
                       Y: -0.875  --  2.25232 in
                       Z: -0.002320288  --  1 in

Centroid:              X: -3.830231e-17  in    (Err: 1.367713e-17)
                       Y: 0.4984632  in    (Err: 0.1051054)
                       Z: 0.4647476  in    (Err: 0.04140455)

Moments of inertia:    X: 0.8381608  lb sq in (Err: 0.08701127)
                       Y: 0.3382647  lb sq in (Err: 0.03201946)
                       Z: 0.772472  lb sq in (Err: 0.07941315)
Products of inertia: XY: -4.953437e-18  lb sq in (Err: 8.429401e-18)
                     YZ: 0.1384659  lb sq in (Err: 0.03800243)
                     ZX: -1.366934e-17  lb sq in (Err: 4.274938e-18)

Radii of gyration:     X: 1.101981  in
                       Y: 0.7000655  in
                       Z: 1.057917  in

Principal moments(lb sq in) and X-Y-Z directions about centroid:
                       I: 0.1880747 along [2.514244e-17 0.9986562 -0.05182396]
                       J: 0.6020913 along [1.130118e-17 0.05182396 0.9986562]
                       K: 0.5175901 along [1 -2.569432e-17 -9.983012e-18]
```

Figure 6. A typical Mass Properties Report (MPR) is shown here for the rocker arm illustrated earlier. Made of mild steel, the design weighs approximately 0.69 pounds. Assuming that the global XYZ-axis is centered at the large through hole on the bottom of the upright, the centroid of the design is at the level of the key-way feature. (Shown is the .MPR file generated with AutoCAD Release 12.)

Approaches to building, editing, and refining solid computer models are varied (Ross & Gabel, 1990; Barr & Juricic, 1994), and the chosen pathway ultimately relies on individual designer preferences. As an example, the rocker arm sketched in Figure 3 was modeled by using a sweeping operation (profile extrusion) to create the main body, and Boolean subtraction operations with base primitives to create the through holes and the key-way (Figure 4). Changes are easily made to the base primitives' size to change the geometry of the holes and the key-way, or the extrusion thickness of the upright feature can be altered, if later analysis dictates these design changes are necessary. For visualization purposes, the solid model can be rendered and shaded at this stage of the concurrent engineering design process (Figure 5).

Design Analysis

One of the advantages of solid modeling is that the geometric data base is directly applicable to engineering analysis software. Some of the types of engineering analysis that stand out in the concurrent engineering design paradigm, and therefore presented in this paper, are mass properties report (MPR), finite element analysis (FEA), machining simulation, and tolerance checking.

Typical mass property values that are calculated from a solid model include: Mass, Volume, Centroid, Moments of Inertia, and Radii of Gyration. For the rocker arm model, a mass properties report is generated and shown in Figure 6. One can note that, for a material assignment of mild steel, the rocker arm weighs approximately 0.69 pounds. Furthermore, assuming that the global XYZ-axis is centered at the back of the large through hole, one can see that the centroid of the proposed rocker arm design is at the level of the key-way feature. Obviously, interpretation of the mass properties report for the proposed design significantly influences refinement decisions in order to meet functionality requirements.

Finite element analysis (FEA) is one of the most useful methods for computer-aided engineering analysis. FEA is used to analyze stresses and deformations in machine parts and structures; it can determine heat flow through and temperature distribution over volumes; and it can be applied to other field problems like electric, magnetic, and fluid flow. The approach starts with the

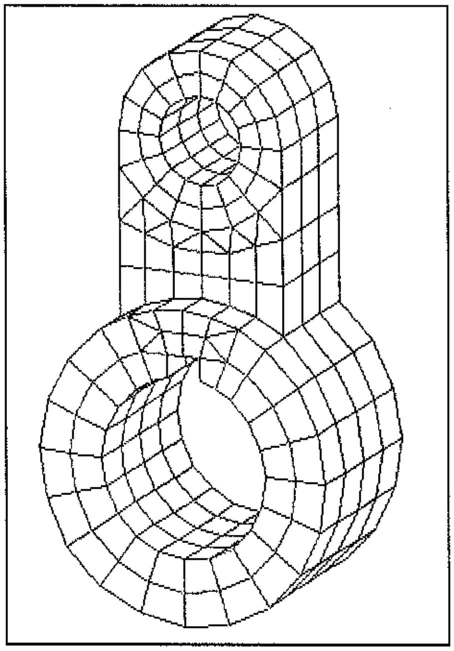


Figure 7.
The solid model data is used to generate the finite element mesh for the rocker arm design. The mesh can be inspected by the engineer and then finite element analysis (FEA) can proceed.

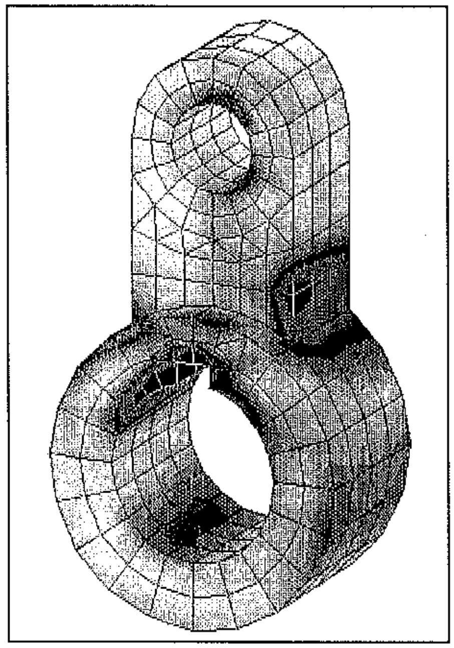


Figure 8.
Results of a finite element analysis are shown here as a contour plot of von Mises stresses that would result when a tangential force is applied at the lug of the rocker arm. *FEA Software PAL2 by the MacNeal-Schwendler Corporation, Los Angeles, CA.*

generation of a finite element mesh which divides the solid geometry into subregions called finite elements. The preprocessors generate this mesh directly from the solid model data. An example of the mesh generation for the rocker arm design is shown in Figure 7. Once the mesh is generated and accepted by the engineer, the FEA software calculates the stresses in the solid body that would result from a given load. For example, Figure 8 shows the FEA results when a given tangential force is applied to the rocker arm lug. In this example, a stress concentration can be noticed at the intersection of the upright lug and the cylindrical body.

Manufacturing Simulation

An important application of solid modeling is the simulation of the machining of a mechanical part. It is possible for software to identify machinable surfaces and to generate the numerically-controlled (NC) tool path from the solid model data base (Figure 9). Dynamic verification of the NC tool path is visualized by animating the motion of the cutting tool on the computer graphics screen. The simulation removes the machined material by applying Boolean differences to the cutting-tool sweep and the solid stock material. In this manner, the designer can check in advance the manufacturability of the proposed design.

Assembly Modeling and Checking

The checking of a mechanical assembly can also be simulated using solid modeling. Components of the assembly can be fit together, and a check for clearance or interference of the fits can be assessed using Boolean operations. Assembly parts that do not meet tolerance requirements can then be re-designed to the correct size using the solid model data base without having to build a physical model. With applicable software, kinematic and dynamic analysis of the assembly can be performed. An example of how assembly modeling and checking can be applied to the rocker arm model is illustrated in Figure 10.

Rapid Prototyping

An exciting new development in the CAD/CAM area is the emergence of rapid prototyping systems that produce a prototype of

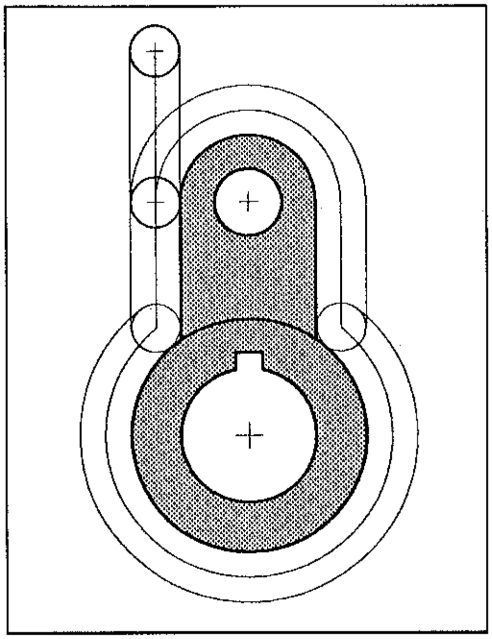


Figure 9.
The CAD/CAM software uses solid model data to identify machinable surfaces and to simulate the tool path necessary to generate them. The Boolean difference between the solid model description of the cutting-tool sweep and the solid stock material is then used to verify the results of the machining operations.

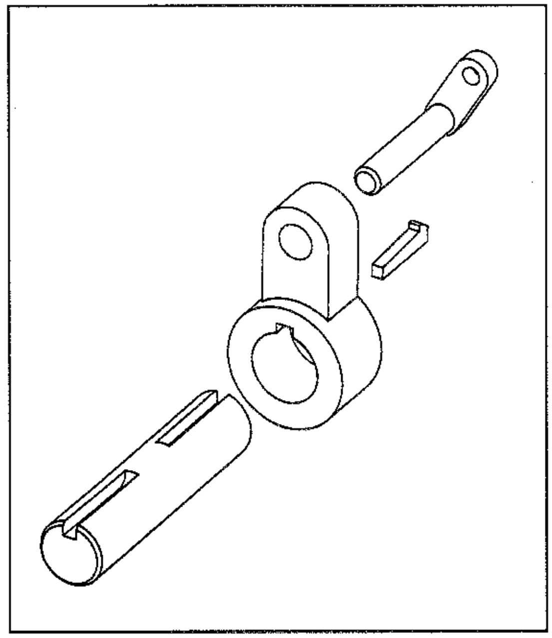


Figure 10.
The solid models are used to check an assembly for correct tolerances (clearance or interference). The analysis uses Boolean operations on the assembly parts. Visual impressions of the assembly can also be obtained, and with the applicable software, kinematic and dynamic analysis can be performed.

the part directly from its solid model data. As opposed to traditional prototyping, rapid prototyping offers the advantage of producing a physical part in much less time and with less expense. The data base generated through solid modeling produces a special file (.STL) that is forwarded to the rapid prototyping system. The prototyping system, based on one of several available technologies, produces the part, its physical model, or its pattern for investment casting. In selective laser sintering systems, a laser beam controlled by an .STL file scans layers of sintering powder and sinters the volume of the part. The rapid prototype of the rocker arm, shown in Figure 11, was obtained by selective laser sintering. Other technologies use fused deposition modeling (ejecting droplets of melted plastic material) or stereo-lithography (a laser beam curing liquid polymers). The rapid prototype model provides first-hand visualization of the proposed design and the designer, as well as the customer, get a tactile sense of the designed geometry.

Product Redesign

The results of analysis, manufacturing simulation, and testing, as well as physical inspection of the rapid prototype, may suggest improvements to the design prior to production. Although the rocker arm is a simple element, one obvious refinement that can be incorporated into its design is the inclusion of filleted surfaces at the intersection of the upper lug and the main body. This will reduce the stress concentration, as indicated by finite element analysis (see Figure 8), and facilitate part manufacturability, as demonstrated by the NC tool path simulation (see Figure 9). This redesign is easily accomplished with editing features available in solid modeling. At this point, the 3-D data base is updated and the concurrent engineering tasks can be repeated as needed.

Drafting and Documentation

While the concept of a paperless design paradigm is attractive, there is still a recognized need for final design documentation in the form of engineering drawings and specification sheets. In cases where CAD/CAM integration is seamless, this documentation may serve primarily as business and legal necessities. Yet, in other cases, the engineering drawings and specification sheets may be the primary communication needed for final production and inspection of the design.

In the concurrent engineering design paradigm, the engineering drawings are generated directly from the 3-D geometric data base. This generation of a multiview engineering drawing from the solid model starts with the creation of multiple viewports with specific views as needed for the planned multiview drawing. Next, the model outline in each viewport is reduced to its 2-D orthographic projection, with hidden lines indicated and overlapping lines eliminated. The projections are then brought to a 2-D drawing plane where they are properly oriented and aligned.

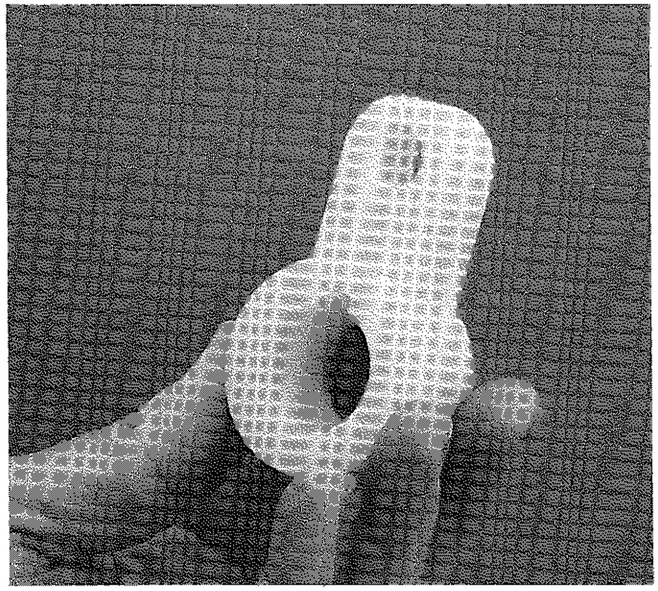


Figure 11.
A rapid prototype of the rocker arm is produced directly from the solid model data using the .STL file sent to a selective laser sintering prototyping station. The designer can visualize the design and receive tactile feeling by holding the prototype in his or her hand. (Model courtesy of DTM, Inc. Austin, TX)

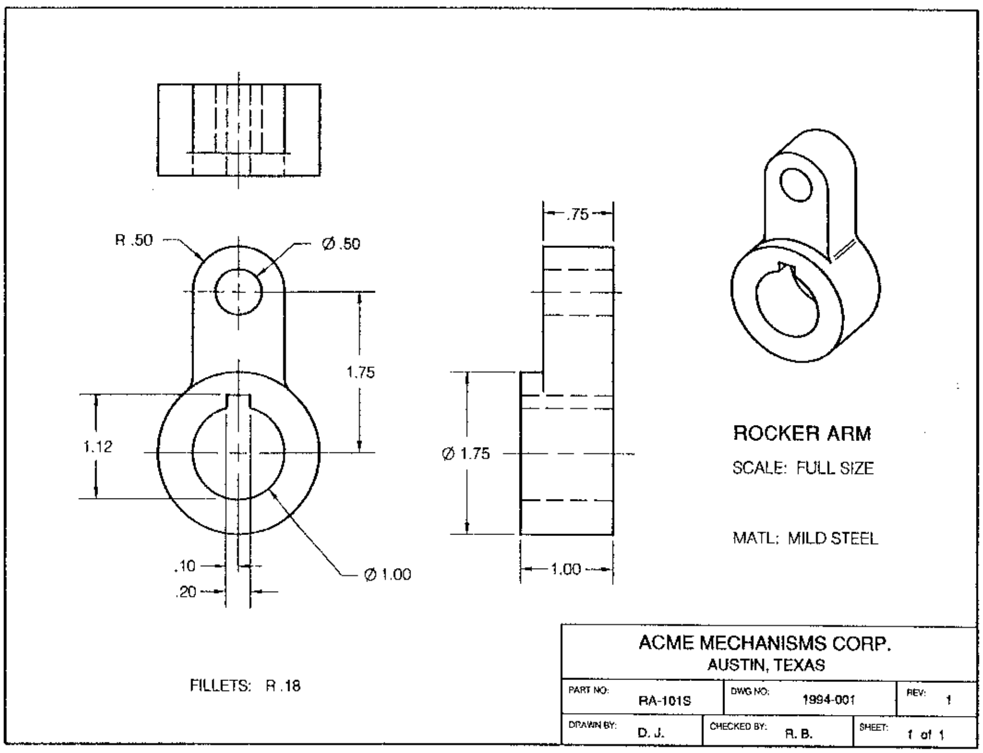
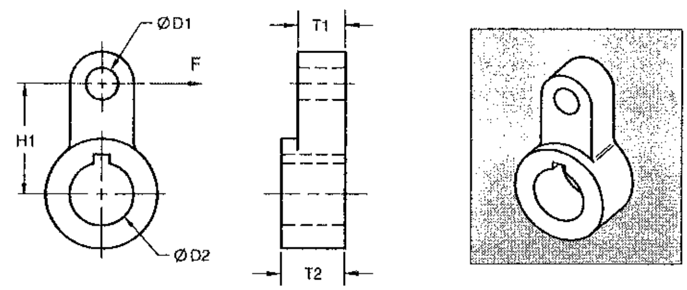


Figure 12. The finished engineering drawing of the rocker arm was generated directly from the solid model and serves as final documentation of the design.

© ACME MECHANISMS CORP. © **ROCKER ARM**



Material	Cat. No.	D1	D2	H1	T1	T2	Limit Load F
Mild Steel (AISI 1030)	RA-101S	0.50	1.00	1.75	0.75	1.00	1,660
	RA-102S	0.55	1.10	1.80	0.80	1.10	2,200
	RA-103S	0.60	1.20	1.85	0.85	1.20	2,930
Aluminum Alloy (3004)	RA-201A	0.50	1.00	1.75	0.75	1.00	900
	RA-202A	0.55	1.10	1.80	0.80	1.10	1,190
	RA-203A	0.60	1.20	1.85	0.85	1.20	1,580
		INCHES					POUNDS

Spec. Sheet No. RA-100

Figure 13. Brochures and other materials for marketing the product can be generated from the CAD/CAM data base developed during solid modeling. Shown here is a customer selection chart for the rocker arm.

Depending upon the sophistication of the orthographic projection routine, the projected lines may need to be edited for correct line type (visible, hidden, or section lines). Centerlines will also need to be added since these will not be generated by the projection routine. Semiautomatic dimensioning routines are used to add linear, circular, and other dimensions according to industry standards. Annotation and title strip information completes the engineering drawing. A hardcopy plot of the drawing can be obtained for communication and archival purposes. The finished engineering drawing for the rocker arm design, obtained using the procedural steps just outlined, is shown in Figure 12.

Production, Marketing, and Maintenance

As mentioned earlier, engineering drawings may still serve as the basis for final production of the design, depending upon the nature of the specific product and the production tools available. Nonetheless, the CAD/CAM data base hub displayed in Figure 1 is still useful for final production. For example, the process planning task group derives the material needed and plans production by using the solid model data base. Factory floor flow and product assembly can be verified early through computer graphics simulations. Proper precision and correct tolerances are assured through the analysis power of solid geometric modeling data.

The solid model data base is also useful in marketing and maintenance. Advertisement brochures and selection charts can be generated using the solid model data base. For example, Figure 13 shows a customer specification selection chart for the rocker arm design. The selection chart allows the customer to select the proper rocker arm dimensions according to the required limit load. In addition, technical illustrations based on computer graphics renderings of the product add visual attraction to the sales pitch. Assembly manuals and maintenance repair instructions are enhanced with illustrated pictorials produced by using the solid model data base.

Conclusion

Graphics and modeling play an important role in the communication dimension of the concurrent engineering environment. The key to this communication is the development of a solid model of the product and the associated data base. This data base can be accessed by all design task groups as they concurrently work on their contributions to the finished product. The various graphical and modeling formats illustrated in this paper aid in definition and visualization of the design at each stage of the concurrent engineering design process, and in the end serve as important archival documentation of the design history.

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Acknowledgements

This research was supported by the National Science Foundation through an NSF Curriculum Development Grant No. USE-8854623, an NSF Laboratory Equipment Grant No. EID-8951732, and in part upon work supported by the Texas Advanced Technology Program under Grant No. 003658-220.

A Perspective On Photogrammetry

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Abstract

This paper presents an overview of the close connections between projective geometry and photogrammetry. Recently developed analytical techniques for close-range photogrammetry are explained. Using appropriate control data and suitable photographs of an object, a 3-D reconstruction can be achieved by an inversion of the well-known perspective transformation. An example is presented in which the geometry of an object is reconstructed from two perspective drawings

Introduction

In the last two or three decades the major trend in engineering design and photogrammetry has been the revolutionary increase in the use of digital computers for the generation of graphics. CAD packages are now able to do solid modeling, draw perspective pictorial views, and prepare contour maps. Powerful programs are available to automatically digitize, reduce and analyze data obtained from existing maps, photographs or drawings. Significant advances have simultaneously been made in the associated analytical techniques. These developments have had a dramatic effect on the way in which engineers and photogrammetrists do their work.

Close-range photogrammetry has benefited immensely from these developments. The expense and limited availability of specialized stereometric camera systems and stereoplotters has made the use of the non-metric, off-the-shelf variety of camera a common occurrence in investigative engineering

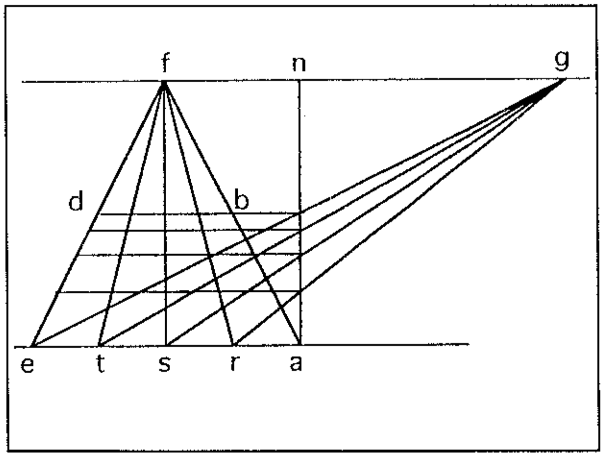

Figure 1a. Perspective Square
Leonardo da Vinci

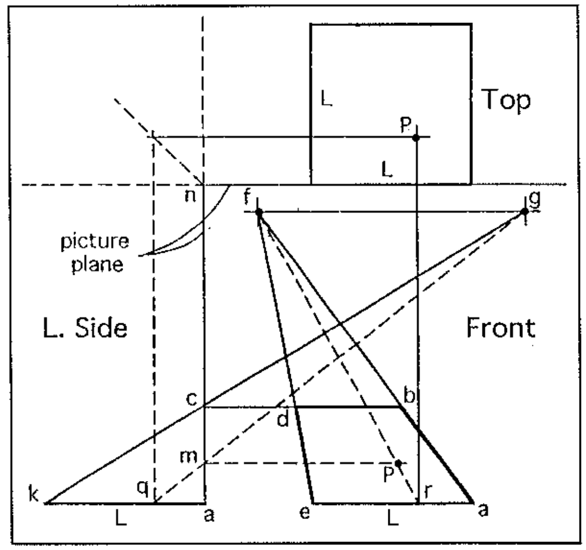

Figure 1b. Leonardo's Procedure

work. This is especially the case in forensic science, in accident reconstruction and in architectural photogrammetry. For example, if suitable photographs are taken of an accident scene with the vehicles still in their positions of rest, there are analytical techniques for extracting the needed information from the photographs to arrive at a credible three-dimensional reconstruction of the scene.

The most desirable end product of a photogrammetric or engineering design data reduction process is a list of coordinates which define the spatial positions of a finite number of discrete points of an object. Such a list represents a digital 3-D model of the object, and is very flexible in the ways it can be used. Areas, volumes, true lengths, centers of gravity and changes in position, size and shape can easily be computed from the digital model with the aid of a computer.

This paper addresses these data reduction techniques, and explores the common analytical basis of projective geometry and photogrammetry in a simple way.

Selected Background

Engineers require true lengths, shapes and sizes, that are generally obtained by direct measurement or deduced from plans, elevations or other orthographic projections of a construction or object. The aim in photogrammetry is to elucidate true information (in the form of 3-D coordinates) from photographs, i.e., perspective projections. The fundamental task of photogrammetrists is therefore to 'work perspective backwards' (Booker, 1963).

This idea is, in principle, nearly as old as perspective itself. Leonardo da Vinci (1452 - 1519) showed how to deduce true information from a perspective drawing, given certain information. With respect to Figure 1a, taken from the work of Leonardo (see Booker, 1963), he wrote

> "If you draw the plan of a square (in perspective) and tell me the length of the near side, and if you mark within it a point at random, I shall be able to tell you how far is your sight from that square and what is the position of the selected point. You must proceed as follows: Produce *ab* and *de* to intersect in *f*. This point *f* gives you the height of the eye. If you wish to know the distance, draw the division *an* and the line *eg*. Its intersection with *gf* gives the distance point. Then join the marks *a, r, s, t, e*, to the point *f* and to the point *g*. Scale your drawing and you will see the position of your point marked at random in the square."

This is a very early example of the science of photogrammetry, albeit on the basis of a drawn projection, not a photograph. An interpretation of Leonardo's procedure is shown in Figure 1b, where the top, front and left side views of a one-point perspective projection scenario are shown. A square of known side length L, lying in the horizontal

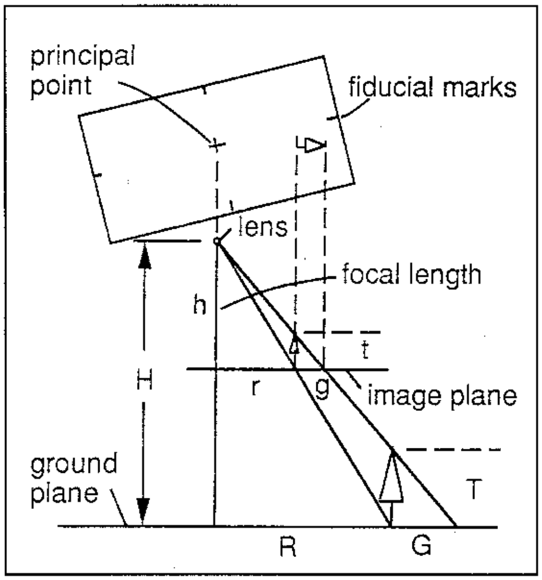

Figure 2. Geometry of Classical Photogrammetry

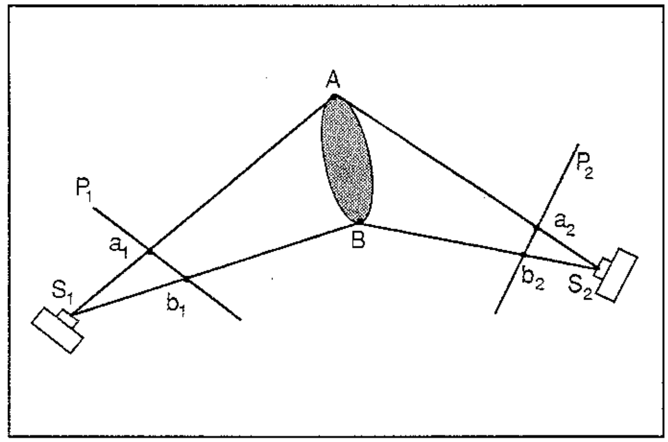

Figure 3. Schematic of Close-Range Photogrammetry

plane, is observed from the point of sight (*f,g*) through a vertical picture plane containing one side of the square. The resulting perspective projection *aedb* of the square and an arbitrary point P on it are given. Working backwards from the perspective projection, *ed* and *ab* intersect at the vanishing point point *f*, and *bd* produced establishes point *c* on picture plane *an*. The intersection of *kc* with the horizon line through *f* yields point g. The two points *f* and *g* fully define the point of observation. The perspective projection of the random point P lies at elevation *m* on the picture plane *an*. Then *gm*, produced, yields *q* and *fp*, produced, yields *r*. These two points together establish the exact coordinates of the arbitrary point P, in the top view.

The classical application of photogrammetry is in the field of topographic mapping. Vertical photographs from airborne metric cameras are analyzed with specialized measuring and plotting devices in the laboratory for map making purposes. The size, height, position and elevation of an object can be determined by very simple measurements on the photographs when the altitude and focal length of the camera are known and when fiducial marks define the principal point on the photograph. Figure 2 shows the essential geometry of a single vertical photograph.

Photogrammetric measurements in close-range applications have characteristics that are distinctly different from aerial applications. Among these are the measurement objectives, the control requirements and the configuration of the photographs. Figure 3 gives a schematic overview of a close-range photogrammetry situation, showing photographs P_1 and P_2 of an object AB from two independent camera positions S_1 and S_2. The objective is to reconstruct the object geometry from the photographs, knowing sufficient control information. In the most general case of close-range photogrammetry the photographs are taken from arbitrary camera stations, whose coordinates are unknown, and at arbitrary and unknown orientations. The cameras are non-metric so that neither the focal distances nor the principal points on the photographs are given. All that is available are the perspective images of the object on the photographs, plus sufficient 'ground control' to permit a 3-D reconstruction.

The spatial position of a point A on the object, which appears in at least two photographs as a1 and a2 , can be determined by the intersection of two lines Aa_1S_1 and Aa_2S_2 (see Figure 3). This requires such data as the camera focal lengths, camera orientation and location with respect to the object and the photographic coordinates of the image points a_1 and a_2. Much of this data is unknown a *priori*, but can be deduced from appropriate control data of known points on each photograph. With reference to the simpler case of Leonardo's problem (Figure 1), knowing that the object is a square and knowing the length of its side is sufficient 'ground control' information to reconstruct the square with its arbitrary point P.

In the following sections the basic projective transformations and analytical processes for perspective projection, photography and photogrammetry are reviewed. Photogrammetric measurements taken from a pair of perspective images of an object are processed to exemplify the analytical techniques involved in reconstructing the actual space coordinates of the object.

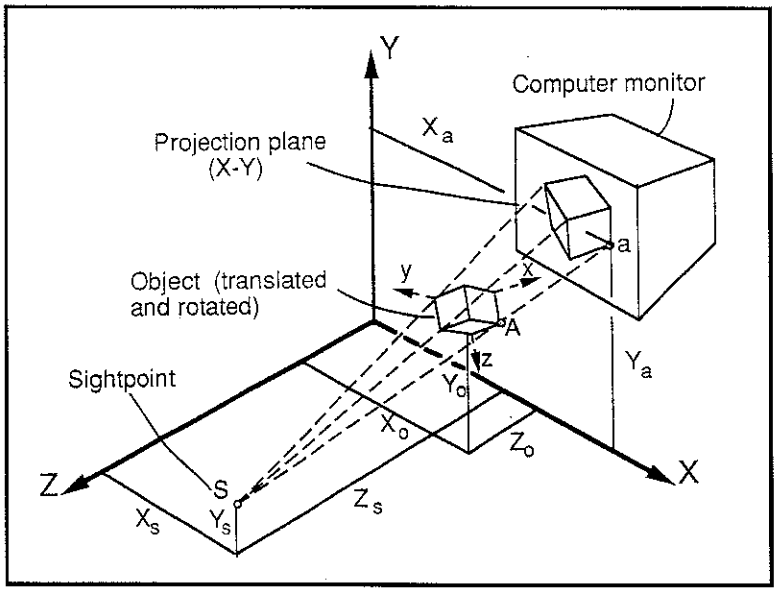

Figure 4. Coordinate System

Projective Theory

Any projection of a three-dimensional object onto a plane viewing surface involves a process of finding which point on the viewing surface corresponds to a point (or line) on the object. The viewing surface can be represented by the paper on a drawing board, by the display screen of a computer system, by the film in a camera or by the enlarged photograph prepared from this film. Referring to Figure 4, the two-dimensional image on a computer display screen, for example, corresponds to a particular view of the three-dimensional object. To produce this image requires knowledge of the location of the sight point, and the location and orientation of the object to be imaged, with respect to the projection plane.

The mapping of object point 'A' (object coordinates x, y, z) onto the image point 'a' (global coordinates X, Y, Z) in the viewing plane is given by a linear projective transformation of coordinates in space, namely:

$$\begin{Bmatrix} vX \\ vY \\ vZ \\ v \end{Bmatrix} = \begin{bmatrix} c_{11} & c_{12} & c_{13} & c_{14} \\ c_{21} & c_{22} & c_{23} & c_{24} \\ c_{31} & c_{32} & c_{33} & c_{34} \\ c_{41} & c_{42} & c_{43} & c_{44} \end{bmatrix} \begin{Bmatrix} x \\ y \\ z \\ 1 \end{Bmatrix} \qquad \text{Equation 1}$$

A dummy variable 'v' is associated with the coordinates (X, Y, Z) of the image point to give a convenient 4x4 transformation matrix operating on homogeneous coordinates. This is a singular transformation because the projections of all points (x, y, z) on the three-dimensional object lie in one, and only one, image plane, i.e., plane Z=0 in Figure 4. Such a transformation cannot be uniquely inverted because every image point corresponds to an infinity of space points (Thompson, 1971).

For the specific coordinate system of Figure 4 the matrix $[c_{ij}]$ in equation (1) is the product of three separate matrices as follows:

$$[c_{ij}] = \begin{bmatrix} -Z_s & 0 & X_s & 0 \\ 0 & -Z_s & Y_s & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -Z_s \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 & X_0 \\ 0 & 1 & 0 & Y_0 \\ 0 & 0 & 1 & Z_0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} m_{11} & m_{12} & m_{13} & 0 \\ m_{21} & m_{22} & m_{23} & 0 \\ m_{31} & m_{32} & m_{33} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Equation 2

where (X_s, Y_s, Z_s) are the coordinates of the sight (focal) point, (X_0, Y_0, Z_0) are the translations of the object, and m_{ij} are trigonometric functions of the rotations θ_X, θ_Y, θ_Z of the object about the global axes.

Conversion from homogeneous to Cartesian coordinates leads to the so-called collinearity equations represented by the linear fractional functions (Wong, 1975).

Equation 3

$$X = \frac{L_1 x + L_2 y + L_3 z + L_4}{L_9 x + L_{10} y + L_{11} z + 1}$$

$$Y = \frac{L_5 x + L_6 y + L_7 z + L_8}{L_9 x + L_{10} y + L_{11} z + 1}$$

These equations arise from the requirement that the sight point S, the object point 'A' and the projection 'a' lie in a straight line. The nine independent parameters X_S, Y_S, Z_S, X_0, Y_0, Z_0, θ_X, θ_Y, θ_Z which define the transformation are embedded in the 11 coefficients L_1 to L_{11}. The latter are therefore not truly independent.

The development of a perspective image (X, Y) from known object coordinates (x, y, z) involves the straightforward task of first evaluating the coefficients L1 to L11 on the basis of given X_S, Y_S, Z_S, X_0, Y_0, Z_0, θ_X, θ_Y, θ_Z and then repeatedly applying equations (3) to find the image points.

Photography is, in a sense, the optical/chemical automation of this process. For a given camera the relationship, or the interior orientation, of the focal point S with respect to the plane of projection (the film) is essentially a fixed one. All that can be varied is the exterior orientation of the object with respect to the camera.

Photogrammetry Theory

The more difficult problem is the inverse of perspective projection, i.e. 'working perspective backwards.' This is the problem of photogrammetry. It involves an analytical method for determining object space coordinates from measured photo or other projected coordinates. Additionally, it is sometimes required to determine the position and attitude of the camera at the time of photography.

For a given perspective drawing or photographic image the coefficients L_i (i = 1, 2, ..., 11) in equations (3), used for the projection, are unknowns and must first be found. Evidently 6 control points (x_k, y_k, z_k; k = 1, 2, ..., 6) in object space must be known and must also be visible in the projected image. Each control point gives rise to two measured image coordinates (X_k, Y_k ; k = 1, 2, . . ., 6) for a total of 12, of which only 11 need to be used to determine L_i. The collinearity equation (3), for a typical control point k, can be re-written as (Bopp and Krauss, 1978)

$$\begin{bmatrix} x_k & y_k & z_k & 1 & 0 & 0 & 0 & 0 & -X_k x_k & -X_k y_k & -X_k z_k \\ 0 & 0 & 0 & 0 & x_k & y_k & z_k & 1 & -Y_k x_k & -Y_k y_k & -Y_k z_k \end{bmatrix} \{L\} = \begin{Bmatrix} X_k \\ Y_k \end{Bmatrix}$$

Equation 4

in which $\{L\} = [\ L_1\ L_2\ L_3 \ldots\ldots\ldots L_{11}\ ]^T$. For five of the six control points both the first and second row of equation (4) need to be written. For the sixth control point only the first row of equation (4) is required. This procedure finally yields 11 linear equations in L_i, $i = 1, 2, \ldots\ldots, 11$, i.e.

$$[A]\ \{L\} = \{X\} \qquad \text{Equation 5}$$

where $\{X\} = [X_1\ X_2 \ldots\ldots\ldots X_6\ Y_1\ \ Y_2 \ldots\ldots\ldots Y_5]^T$. Note that (X_k, Y_k) can be measured relative to any convenient Cartesian coordinate system in the image plane. Similarly, the Cartesian coordinate system x, y, z for the object space control points is quite arbitrary also. With all the elements of matrix [A] and vector{X} known the direct linear solution for the coefficient vector {L} is found by inversion and multiplication, i.e.

$$\{L\} = [A]^{-1}\ \{X\} \qquad \text{Equation 6}$$

In this calculation the coefficients L_i, $i = 1, 2, \ldots\ldots, 11$ are treated as 11 independent variables. This is redundant since they are actually related by way of the 9 truly independent projection parameters X_S, Y_S, Z_S, X_0, Y_0, Z_0, θ_X, θ_Y, θ_Z. While it is certainly possible to solve for these 9 parameters, this is a highly nonlinear problem. They are not required for reconstructing object space coordinates and are therefore not further dealt with here.

Having found the coefficients L_i for two photographs, it becomes possible to determine the space coordinates of an arbitrary point on the object, provided this point is visible in both photographs. Formally, the problem is to solve for coordinates x_p, y_p, z_p given the image coordinates X_{1p}, Y_{1p}, X_{2p}, Y_{2p} of the point in two photographs. Once again, using the collinearity equations, three linear equations in the three unknowns x_p, y_p, z_p can be written as (Wong,1975)

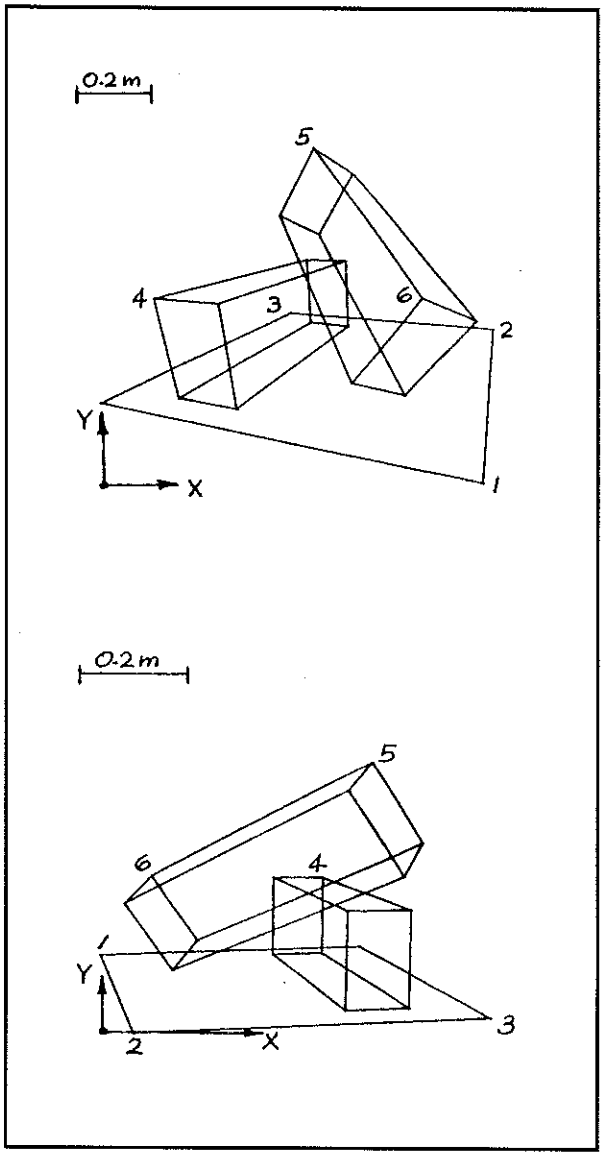

Figure 5. Two Perspective Views of an "Accident Scene"

Only three of the four available image coordinates are used to solve for the three unknown object coordinates. The first two define the line of projection from (x_p, y_p, z_p) to (X_{1p}, Y_{1p}). The last equation defines a plane containing the projection line from (x_p, y_p, z_p) to (X_{2p}, Y_{2p}). The coordinates (x_p, y_p, z_p) are fully determined by the intersection of these two elements.

$$\begin{aligned}
(L_{1,1}-L_{1,9}X_{1,p})\,x_p+(L_{1,2}-L_{1,10}X_{1,p})\,y_p+(L_{1,3}-L_{1,11}X_{1,p})\,z_p &= X_{1,p}-L_{1,4}\\
(L_{1,5}-L_{1,9}Y_{1,p})\,x_p+(L_{1,6}-L_{1,10}Y_{1,p})\,y_p+(L_{1,7}-L_{1,11}Y_{1,p})\,z_p &= Y_{1,p}-L_{1,8}\\
(L_{2,1}-L_{2,9}X_{2,p})\,x_p+(L_{2,2}-L_{2,10}X_{2,p})\,y_p+(L_{2,3}-L_{2,11}X_{2,p})\,z_p &= X_{2,p}-L_{2,4}
\end{aligned}$$

Equation 7

	x	y	z	X_1	Y_1	X_2	Y_2
1	0.000	0.000	0.000	1.016	0.000	0.000	0.144
2	11.500	0.000	0.000	1.049	0.416	0.061	0.000
3	11.500	10.500	0.000	0.510	0.466	0.725	0.031
4	1.000	8.595	3.000	0.148	0.506	0.415	0.291
5	9.071	7.541	7.349	0.577	0.912	0.507	0.505
6	2.000	1.768	3.266	0.865	0.504	0.095	*0.292
* not used in calculations							

Table 1. Control Point Coordinates (m)

i	$L_{1,i}$ (x 10^{-3})	$L_{2,i}$ (x 10^{-3})
1	121.25800	3.77422
2	-96.74950	47.91080
3	-37.72570	-0.86709
4	1016.00000	0.00000
5	83.12290	-12.52180
6	30.32020	2.22535
7	104.82700	46.32290
8	0.00000	144.00000
9	112.85800	-25.08420
10	41.58360	4.02051
11	-56.48980	-4.79089

Table 2. Collinearity Coefficients

Control Points

Six control points, giving a minimum of eleven image coordinates, are required to find the transformation coefficients L_i. In order to achieve a stable solution which is relatively insensitive to measurement errors, control points should be selected to avoid extrapolation. Control points should as much as is possible surround the object of interest, or at least should be well distributed throughout object space. No more than four of the six space control points should be coplanar and it is prudent to achieve as much deviation from the planar condition as can be allowed by 'depth of field' considerations in photography (Atkinson,1980).

Refinements in the computation procedure for the space coordinates of an object may become necessary when small errors are present in measured space or image coordinates of the control points, or when lens and film distortions invariably associated with non-metric cameras affect the images. Additional image refinement parameters are then included in the collinearity equations. These, along with the transformation coefficients L_i, are determined by means of an iterative least squares approach. Cartesian image coordinates are then corrected for lens and film distortion. Extra control points may also be used to improve the solution by means of a similar least squares adjustment process (Abdel-Aziz and Karara, 1971; Wong, 1975; Bopp and Krauss, 1978).

An Example

Two different perspective drawings of a situation representative of a railway accident - a pair of wire frame 'box cars' placed on a wireframe 'ground plane'- are shown in Figure 5. Six known controls are indicated by the numbered points in Figure 5. Their space coordinates, measured with respect to a Cartesian reference frame with origin at point 1, are given in Table 1. Image reference frames (X,Y) are selected as shown in the given drawings. Digitized image coordinates of the known control points, measured in accordance with the given scales, are also listed in Table 1 for both drawings. With these inputs, equations (4), (5) and (6) yield a set of 11 collinearity coefficients L_i for each drawing, as listed in Table 2.

Digitization of the coordinates of the remaining points in the given perspective drawings and repeated solution of equations (7) allows the determination of the complete geometry of the situation. The three orthographic drawings shown in Figure 6 - top, front and side views- are based on this reconstructed geometry. The thick lines appearing here and there in these drawings are evidence of small errors in the numerical

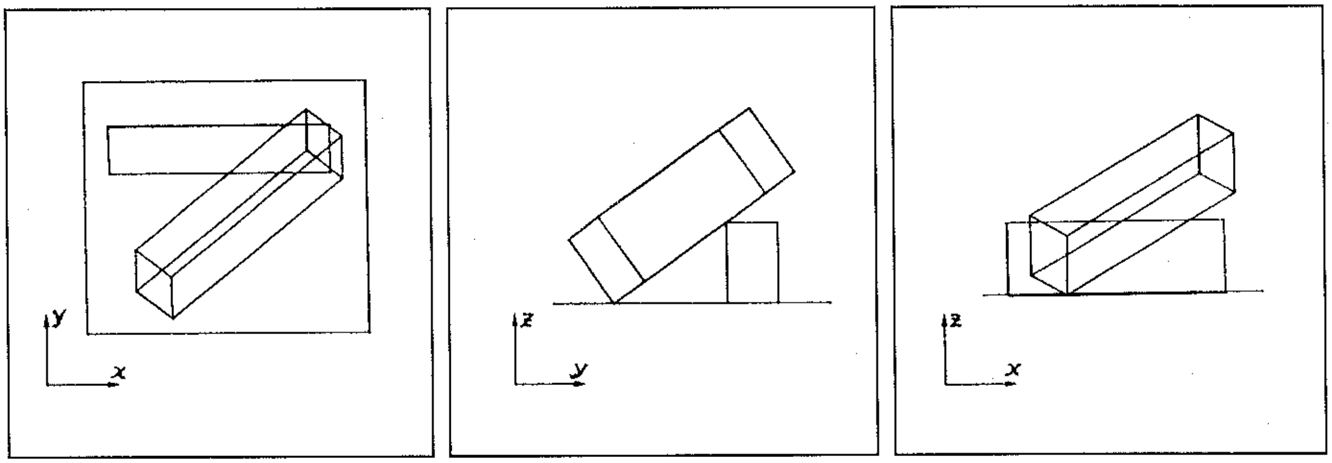

Figure 6. Top, Front and Side Views of the Reconstructed "Accident Scene"

results, giving rise to a slight shift of points and lines where these should be exactly coincident.

A comparison of the reconstructed numerical values of the coordinates with their actual values shows the largest discrepancy to be approximately 0.05 m, less than one-half percent of the overall size of the object being portrayed.

Given the sensitive nature of the inverse transformation involved here, these are indeed not large errors. They can be reduced by applying the refinement procedures mentioned in the previous section.

Concluding Remarks

The use of the fundamental relationship between sight point, object and photographic image to analyze the most general case of close-range photogrammetry, in which all orientation elements are unknown, has been reviewed in this paper. The reconstruction of object geometry from image coordinate readings has opened many possibilities for close-range applications of photogrammetry, particularly for engineers and architects who generally rely on graphical outputs for the presentation of information and results. Any type of camera, metric or non-metric, can be used. Corrections and refinements can be introduced to improve accuracy. Almost any kind of object can be measured by close-range photogrammetry provided it is possible to obtain images of the area of interest.

The accent in the analytical technique is on numerical output and the creation of a digital model of the object under consideration. In its simplest form this model can be a sequence of space coordinates of significant points on the object, which can readily be converted into graphical form on a visual display unit, plotter or other graphing device. With the software and computer power now available the continuing development of close-range photogrammetric measurements in industry and engineering is assured.

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Hypersolid Modeling Fundamentals

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Abstract

Hypersolid modeling is defined and fundamental concepts are presented. The use of Euler's formula in boundary representation solid modeling is reviewed. The extension of boundary representation modeling from three to four dimensions is described. The paradigm for boundary representation of hypersolids is formulated. The methods developed for boundary representation are used to model the 5-cell, 8-cell and 16-cell four-dimensional regular polytopes.

Introduction

Hypersolid modeling is the extension of solid modeling into 4-space where the highest order entity in the space is a hypersolid. Hypersolid modeling represents hypersolids in terms of vertices, edges, faces, and bodies analogous to the way solid modeling represents solids in terms of vertices, edges, and faces.

Solid modeling in 3-space has become an essential part of the application of numerical methods to the solution of equations governing objects in 3-space. The finite element method has been applied to a great variety of problems including heat transfer, metal forming, and structural analysis. Without geometrically accurate and topologically valid models of the entities being analyzed, the finite element method is limited in its application. The true strength of the finite element method has been the solution of problems involving complex geometry and boundary conditions that were previously unsolvable by other approximation methods and analytic solution of governing equations.

Numerical methods have not been as extensively applied to problems in 4-space as they have been in 3-space. One area of interest in 4-space is the relativistic space-time continuum. Typically problems in space-time are formulated in terms of simple geometric entities such as points and lines that can be solved analytically. However, just as in 3-space many problems of interest in space-time cannot be formulated in terms of simple geometric entities that are amenable to closed form solution. Methods of representing geometrically and topologically complex entities in 4-space are required for successful application of numerical methods to problems in the space-time continuum.

Another application of numerical methods to 4-space is solution of problems with four independent variables. Time is typically the fourth variable. For example, time dependent boundary conditions are applied to many problems, such as, radiative heat transfer, moving coordinate systems, and LaGrangian motion. It other cases the element functions themselves are time dependent as is the case in models of extrusion and other forming processes. Formulation of the problem in four-dimensional space permits the fourth variable to become part of the descretized space, thus simplifying the solution of the problem. The trade-off for simplified solution of governing equations is more complex model formulation in hyperspace using hypersolid modeling.

Euler's Formula

In the sixteenth century, Leonhart Euler, an eminent Swiss mathematician and scientist, developed many of the basic relationships of topology. Euler's formula (Grunbaum, 1967) has been used extensively in developing boundary representation solid modelers in 3-space. Incorporating Euler's formula in the algorithms for construction of solids ensures that the resultant models are valid representations of solids. In simple terms, valid solids are solids that could be built physically. They have no self intersecting surfaces such as those found in a Klein bottle or non-orientable surfaces such as the surface of a Mobius strip.

Each space, whether it be one, two, three, four or N dimensional, is defined by the geometric and topological elements comprising the space. Euler's formula defines the topology of entities in space, thus topological elements are used to define these entities. Topological elements for spaces of dimension one through four are as follows: one-dimensional space (vertex and edge), two-dimensional space (vertex, edge and face), three-dimensional space (vertex, edge, face and body), and four-dimensional space (vertex, edge, face, body and hyperbody).

Euler's formula provides us with a way of defining the meaning of a valid solid in topological terms. In 3-space Euler's formula is given by:

$$K_0^3 - K_1^3 + K_2^3 - K_3^3 = 1 \qquad \text{(Equation 1)}$$

where K_n^m represents the number of entities in the model, its subscript represents the order of the entity and its superscript represents the order of the space. In 3-space K_0^3 is the number of vertices, K_1^3 is the number of edges, K_2^3 is the number of faces, K_3^3 is the number of bodies. Euler's formula applies to all spaces and ensures the topological validity of the entities being modeled in any given space. In 4-space Euler's formula is given by:

$$K_4^4 - K_1^4 + K_2^4 - K_3^4 + K_4^4 = 1 \qquad \text{(Equation 2)}$$

where K_4^4 is the number of hyperbodies in the entity being modeled.

Euler's formula in n-dimensional space (Grunbaum, 1967) is given by Equation 3.

$$\sum_{m=0}^{n} (-1)^{m} K_m^n = 1 \qquad \text{(Equation 3)}$$

Representation of Hypersolids

In topological models entities in space are represented in terms of the elements comprising them. For example a pentagon is represented by five vertices, five edges and one face. Each vertex has two edges adjacent to it. Each edge is terminated at a vertex on each end. The face is surrounded by five edges and five vertices. Each vertex and each edge is in contact with the face. The set of edges and the union of the edges are equivalent and form the boundary of the face.

In general any entity can be represented topologically by an orderly scheme that enumerates the number of different types of elements comprising the entity and the adjacencies of each of the elements. Referring to the pentagon, we see that enumerating the number of vertices, edges and faces gives:

$$K_0^3 - K_1^3 + K_2^3 = 5 - 5 + 1$$

Furthermore, when considering adjacencies, we find that two sets of adjacency information apply. The first set considers the adjacency of elements of the entity:

1. Each edge is adjacent to two vertices (i.e., each edge is terminated by a vertex on each end);
2. Each vertex is adjacent to two edges;
3. Each vertex is adjacent to two other vertices; and
4. Each edge is adjacent to two other edges.

When considering adjacency of the entity itself (i.e., a pentagon is represented topologically by a face) the second set of adjacencies apply:

1. The face is adjacent to five vertices meaning that the face is surrounded by five vertices;
2. The face is adjacent to five edges meaning that the face is surrounded by five edges;
3. Each vertex is adjacent to the face meaning that each vertex is in contact with the face;
4. Each edge is adjacent to the face meaning that each edge is in contact with the face; and
5. The face is not adjacent to any other faces; in other words there is only one face.

Element Adjacencies

In this section we consider a subset of the adjacencies relevant to an overview of hypersolid modeling fundamentals. (A description of the details of all the element adjacencies is beyond the scope of this

Symbol	Definition	Value 1-space	 2-space	 3-space	 4-space
v_e	number of vertices bounding an edge	**2**	**2**	**2**	**2**
v_f	number of vertices bounding a face	NA[2]	δ[3]	δ	δ
v_b	number of vertices bounding a body	NA	NA	δ	δ
e_v	number of edges adjacent to a vertex	**1**	**2**	δ	δ
e_f	number of edges bounding a face	NA	δ	δ	δ
e_b	number of edges bounding a body	NA	NA	δ	δ
f_v	number of faces adjacent to a vertex	NA	**1**	δ	δ
f_e	number of faces adjacent to an edge	NA	**1**	**2**	δ
f_b	number of faces bounding a body	NA	NA	δ	δ
b_v	number of bodies adjacent to a vertex	NA	NA	**1**	δ
b_e	number of bodies adjacent to an edge	NA	NA	**1**	δ
b_f	number of bodies adjacent to a face	NA	NA	**1**	**2**

Table 1. Element adjacencies for a single instance of the highest order entity1 in the space.

[1] The highest order entity in 1-space is a line; in 2-space it is a face; in 3-space it is a body, and in 4-space it is a hyperbody.

[2] NA=Not Applicable

[3] δ = the quantity is not constant and depends on the topology (connectivity) of the entity being represented.

paper). See (Weiler, 1985) for details of some 3-space adjacencies). The number of different element adjacencies in each space is equal to the square of the number of different kinds of elements in the space. For example in 2-space there are 3 elements (vertex, edge and face) and nine element adjacencies as listed above.

In this section we will make use of the element cross adjacencies listed in Table 1 to define the fundamental precepts of hypersolid modeling. Cross adjacencies are adjacencies of elements to other dissimilar elements. For example, the number of edges adjacent to a face is a cross adjacency but the number of faces adjacent to a face is not.

The combination of Euler's formula and the element adjacencies defined in Table 1 form the foundation for hypersolid modeling and for modeling in 1-, 2-, 3-, and 4-space. Certain element adjacencies have fixed values arising from the following conditions: (*Note: The conditions on the boundary arise from the boundary set being equivalent to the union of all the elements of the boundary set.*)

1-space

An edge must be completely bounded by vertices. The condition of a complete boundary requires $v_e = 2$. The condition $v_e = 2$ holds for all spaces.

2-space

A face (1) must be completely surrounded by a continuous set of edges that is everywhere in contact with the face and (2) edges exist only on the boundary of the face. The condition of a continuous boundary requires $e_v = 2$. If e_v were to equal 1, then there could be holes in the boundary. If e_v were to be greater than 2, then the boundary could be self-intersecting. The condition that the boundary surface not extend into the interior to the surface requires that $f_e = 1$. If f_e were to become greater than 1 then an "edge" could exist inside the surface because it could have faces on both sides of it. If f_e were to be equal to 0, then part of the boundary could extend away from the solid and not be in contact with the surface creating a lamina edge.

3-space

A solid body (1) must be completely surrounded by a continuous surface (set of faces) that is everywhere in contact with the solid and (2) the surface exists only on the boundary of the solid. The condition of a continuous boundary requires $f_e = 2$. If fe were to equal 1, then there could be holes in the boundary. If f_e were to be greater than 2 then the surface could be self-intersecting. The condition that the boundary surface not extend into the interior of the solid requires that bf = 1. If b_f were to become greater than 1 then a "surface" could exist inside the solid because it could have bodies on both of its sides. If b_f were to be equal to 0, then part of the boundary could extend away from the solid and not be in contact with the solid creating a lamina face.

4-space

A hypersolid (1) must be completely in contact with a continuous set of bodies that is everywhere in contact with the hypersolid. The condition of a continuous boundary requires $b_f = 2$. If b_f were to equal 1, then there could be passages through the boundary. If b_f were to be greater than 2, then the boundary could be self-intersecting and two bodies could occupy the same space. The condition that the boundary solid not extend into the interior to the solid requires that number of hyperbodies adjacent to a body be exactly one (i. e., $h_b = 1$). If h_b were to become greater than 1 then a "solid" could divide the hypersolid because it could have hyperbodies surrounding it. If h_b were to be equal to 0, then part of the bounding body could extend away from the hypersolid and not be in contact with the hypersolid. For a more detailed explanation of hyperbody adjacencies see (Duane, 1994).

The symbol δ is used in Table 1 to indicate that the element adjacency is dependent on the topology of the entity being modeled.

The Paradigm for Hypersolid Modeling

The methods for hypersolid modeling outlined in this paper are based on an extension of boundary representation modeling from 3- to 4-dimensional space. Boundary representation solid models are formed by joining faces together to model the boundary

Operator		K_0^3	$-K_1^3$	$+K_2^3$
MBFV	Make a Body, Face and Vertex	1	0	1
MEV	Make an Edge and a Vertex	1	-1	0
MFE	Make a Face and an Edge	0	-1	1
KBFV	Kill a Body, Face and a Vertex	-1	0	-1
KEV	Kill an Edge and a Vertex	-1	1	0
KFE	Kill an Edge and a Face	0	1	-1

Table 2. Euler Operators in 3-Space

of a solid. The surface boundary of the solid is represented topologically by faces and characterized geometrically by surfaces and patches. *(Surfaces and patches are geometric elements. A complete model of an object requires both a topological representation and a geometric representation).* The solid must be constructed in such a way that:

1. The adjacency relationships given in Table 1 are not violated; and
2. When construction is complete Euler's Formula is balanced.

Computer implementation of the boundary representation method in 3-space entails the use of data structures such as the winged edge data structure (Mantyla, 1989) to insure that condition (1) is met and the use of Euler operators to ensure that condition (2) is met. Table 2 gives an elementary set of Euler operators used for boundary representation modeling in 3-space. The set of Euler operators given in Table 2 is representative of many different sets of Euler operators that have been developed for boundary representation (Eastman, 1979) and is not intended to be all inclusive.

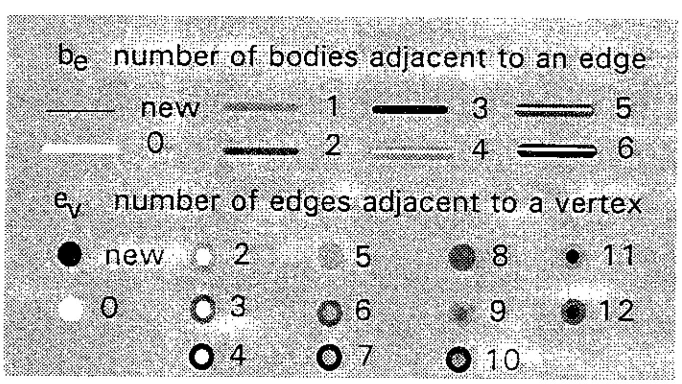


Figure 1. Element adjacency symbols and symbols for new elements added to the polytope under construction.

The paradigm for hypersolid modeling follows the paradigm for boundary representation modeling of solids. Boundary representation hypersolid models are formed by joining bodies together to model the boundary of a hypersolid. The boundary of the hypersolid is represented topologically by bodies and geometrically by solids and hyperpatches. The hypersolid must be constructed in such a way that:

1. The adjacency relationships given in Table 1 are not violated; and
2. When construction is complete Euler's Formula is balanced.

In implementation of the hypersolid modeling paradigm presented here, we use the symbols presented in Figure 1 to ensure that the above condition (1) on adjacency relationships is met. To ensure that the above condition (2) is met, we construct hypersolids from bodies and tabulate the number of entities at each stage of construction (see the tables inserted in Figures 2, 3 and 4).

Boundary Representation Modeling of 3- and 4- Polytopes

As the spatial dimension increases so does the number and complexity of entities in the space increase. Polytope is the general term that applies to the sequence of entities, point, line, polygon, polyhedron. Polytopes are modeled by the highest order elements in the space. For example, a 2-polytope (polygon) is two-dimensional and modeled topologically by the elements: face, edge and vertex. A 3-polytope (polyhedron) is three-dimensional and modeled by the elements: body, face, edge and vertex. Likewise, a 4-polytope is

Regular 3-Polytope (polyhedron)	v_e	v_f	e_v	e_f	f_v	f_e
Tetrahedron	2	3	3	3	3	2
Octahedron	2	3	4	3	4	2
Rhombic hexahedron (cube)	2	4	3	4	3	2
Dodecahedron	2	5	3	5	3	2
Icosahedron	2	3	5	3	5	2

Table 3. Element adjacencies for regular 3-polytopes (polyhedrons) in Euclidean 3-space.

four-dimensional and modeled by the elements: hyperbody, body, face, edge and vertex.

A set of regular polytopes is defined in each order of Euclidean space. In two-dimensional Euclidean space regular 2-polytopes are polygons with equal length edges and equal size interior angles. Examples of regular 2-polytopes are the equilateral triangle, regular quadrilateral (square), regular pentagon, regular hexagon, regular heptagon and so forth producing an infinite number of such polytopes in 2-space. However, the number of regular polytopes in all spaces of order higher than 2 is finite. In Euclidean 3-space there are five regular polyhedra, the regular tetrahedron, regular hexahedron (cube), regular octahedron, regular dodecahedron and regular icosahedron. In each of these regular 3-polytopes all edges are of equal length, all edges meet at equal interior angles and all faces meet at equal dihedral angles.

Polytopes in 4-space (4-polytopes) are built from polyhedra. Of the six regular 4-polytopes, three are built from regular tetrahedrons (5-cell or simplex, 16-cell and 600-cell), one is built from regular hexahedrons (8-cell or tesseract), one is built from regular dodecahedrons (120-cell) and one is built from regular octahedrons (24-cell). In this paper we model three of the six regular polytopes existing in four-dimensional Euclidean space, the 5-, 8- and 24-cell 4-polytopes.

Regular 3-polytopes

Before modeling the 4-polytopes we will use the element adjacencies and Euler's formula to visualize the familiar 3-polytopes. Applying the conditions on the element adjacencies given in Table 1 to Euler's formula for 3-space, Equation 1, gives the solution for the remaining element adjacencies (Duane, 1994). Results are given in Table 3.

If you spend a few moments visualizing polyhedra, it becomes clear that the only regular polyhedron that can be constructed with $v_f = 3$ and $e_v = 3$, is a tetrahedron. (The choice of visualization aid is left to the reader. Suggestions include paper, scissors and paste; a sketch pad; or a CAD system.) Likewise if $v_f = 3$ and $e_v = 5$ the outcome is an icosahedron. The polyhedra are uniquely and completely determined by the element adjacencies obtained from the solution to Euler's formula. The polyhedra resulting from modeling solids as defined by the element adjacencies in Table 3 are given in Table 4.

Regular 3-Polytope (polyhedron)	K_0^3	K_1^3	K_2^3	K_3^3
Tetrahedron	4	6	4	1
Octahedron	6	12	8	1
Rhombic hexahedron (cube)	8	12	6	1
Dodecahedron	20	30	12	1
Icosahedron	12	20	30	1

Table 4. Regular 3-polytopes (polyhedrons) in Euclidean 3-space.

Regular 4-Polytope	v_e	v_f	v_b	e_v	e_f	e_b	f_v	f_e	f_b	b_v	b_e	b_f
5-cell (simplex)	2	3	4	4	3	6	6	3	4	4	3	2
8-cell (hypercube or tesseract)	2	4	8	4	4	12	6	3	6	4	3	2
16-cell	2	3	4	6	3	6	12	4	4	8	4	2
24-cell	2	3	6	8	3	12	12	3	8	6	3	2
120-cell	2	5	20	4	5	30	6	3	12	4	3	2
600-cell	2	3	4	12	3	6	30	5	4	20	5	2

Table 5. Element adjacencies for the six regular polytopes in Euclidean 4-space.

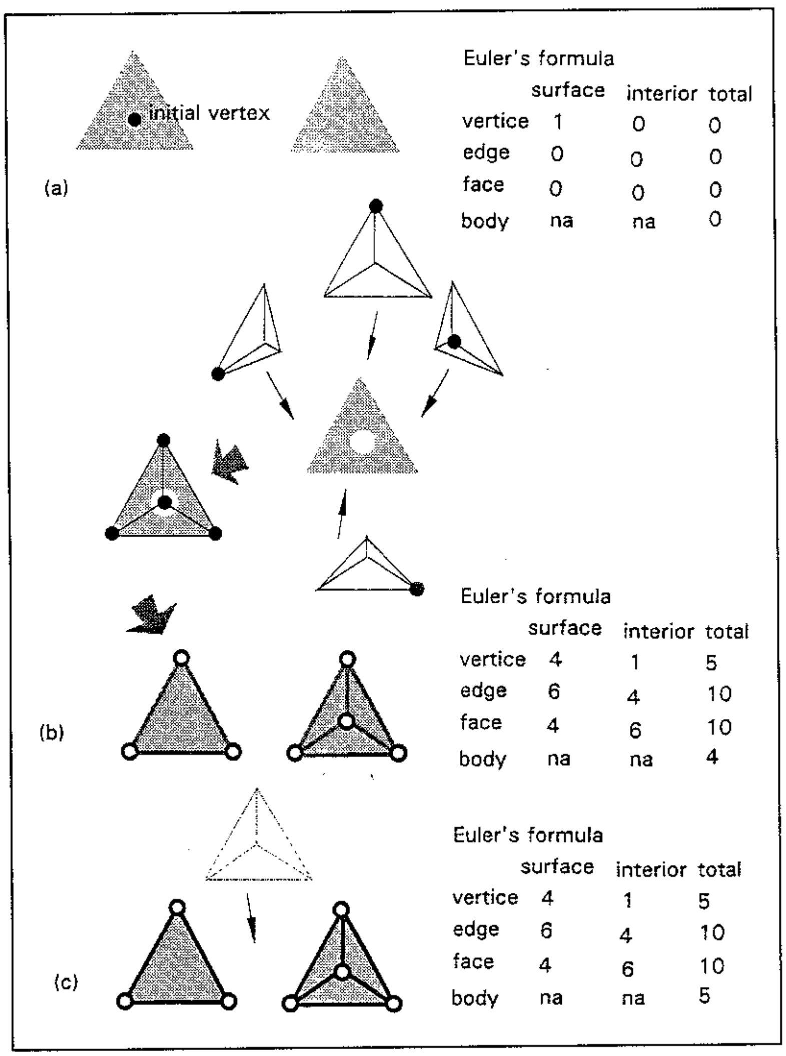


Figure 2a, 2b and 2c.
Modeling of the 5-cell 4-polytope, a member of the simplex group.

In this section we will apply the same methods used to find the element adjacencies for 3-polytopes to 4-polytopes. Using the element adjacencies we will model the 4-polytopes. Applying the conditions on the element adjacencies given in Table 1 to Euler's formula for 4-space, Equation 1, gives the solution for the remaining element adjacencies (Duane, 1994). Results are given in Table 5.

Three of the six regular 4-polytopes are modeled in the next three sections. The three polytopes selected for modeling are the three that have analogous polytopes in all the different dimension spaces. The remaining three polytopes (24-cell, 120-cell, and 600-cell) exist only in 4-space.

Figure 1 gives the symbols for the element adjacencies used in the modeling of the 5-cell, 8-cell, and 16-cell regular 4-polytopes. The symbols for the element adjacencies are used to illustrate the connectivity of the elements used to model the polytopes. In addition to the symbols used in representing polytopes in this paper, the table also serves to define symbols for modeling the remaining polytopes as well as other hyperbodies.

The models presented in the next three sections are topological models. Geometric properties of the polytopes are not incorporated into the models. The basis for incorporating geometric properties in the models exists in the paradigm presented in this paper, but is not implemented. Implementation is planned using methods developed by the author and a group of Chinese researchers (Wan 1989a, 1989b, and 1994a). The polytopes are represented in Figures 2 through 4 by a series of graphs showing only that portion of the polytope surface 6 under construction. *(Note that some of the surfaces under construction are represented by an edge. The edge representation of* *the graph is equivalent to the edge of a suface.)* Previously constructed portions of the polytope surface are hidden.

Topological Model of the 5-Cell 4-Polytope

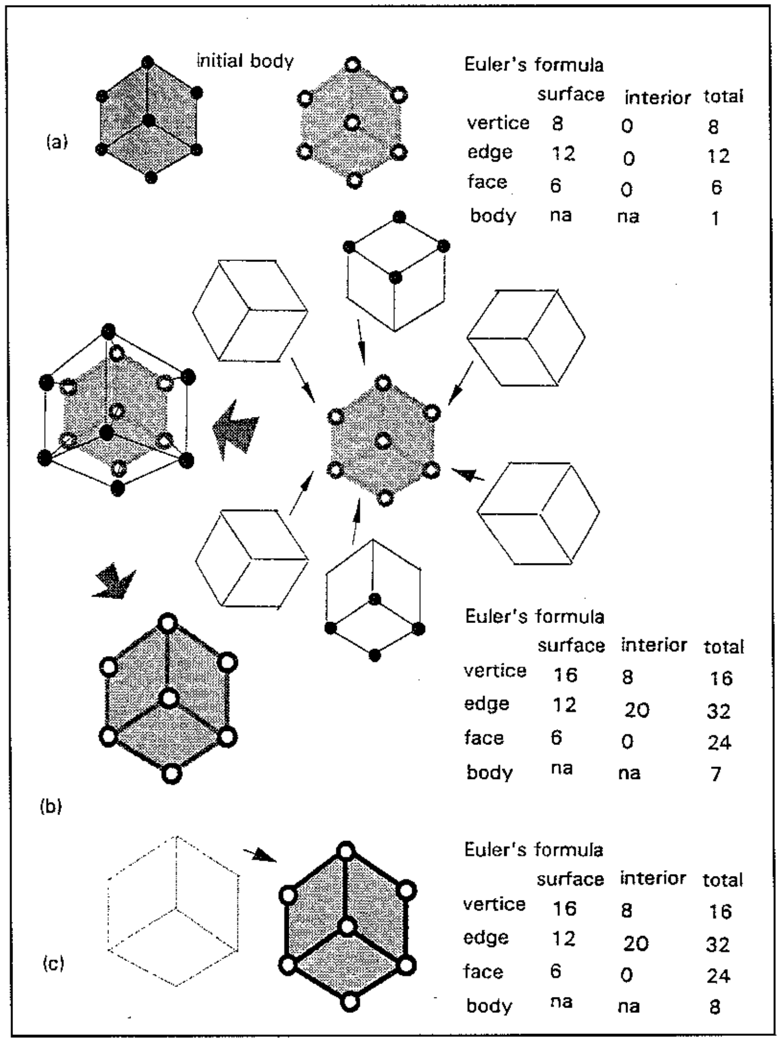
Figure 2 shows the construction of the 5-cell or four-dimensional simplex that is constructed from tetrahedrons. There exists a series of different dimension simplexes one in each order space. The simplexes are the series of the most elementary forms that can be constructed from linear elements in each space. The 1-space simplex is a line; the 2-space simplex is a triangle, the 3-space simplex is a tetrahedron; and in 4-space the simplex is the 5-cell.

Construction of the 5-cell begins with the initial vertex shown in Figure 2a. In Figure 2b four tetrahedral bodies are attached to the initial vertex. From Table 5, we see that e_v and b_e both are equal to 4 and 3 respectively. As a result only four edges can be connected to the initial vertex. Three bodies must share each edge. All five bodies must share five vertices. At the completion of the construction step represented by Figure 2b, all the element adjacencies for the 5-cell are satisfied except b_e, b_v and b_f.

Adding another body that is formed from the outer vertices, edges and faces of the 5-cell graph completes construction of the 5-cell. The number of vertices, edges, faces, and bodies for the complete 5-cell 4-polytope is shown in Figure 2c. Note that Euler's formula for 4-space is balanced at the completion of construction.

Topological Model of the 8-Cell 4-Polytope

Figure 3 shows the construction of the 8-cell or four-dimensional tesseract. The four-dimensional tesseract is constructed from hexahedrons (cubes). There exists a series of different dimension tesseracts, one in each order space. All tesseracts are constructed from four edged faces. The word tesseract comes from the Latin word *tessera* meaning small four-sided tablet.



Euler's formula (a)

	surface	interior	total
vertice	8	0	8
edge	12	0	12
face	6	0	6
body	na	na	1

Euler's formula (b)

	surface	interior	total
vertice	16	8	16
edge	12	20	32
face	6	0	24
body	na	na	7

Euler's formula (c)

	surface	interior	total
vertice	16	8	16
edge	12	20	32
face	6	0	24
body	na	na	8

Figure 3a, 3b and 3c.
Modeling of the 8-cell 4-polytope, a member of the tesseract group.

Construction of the 8-cell begins with the hexahedron shown in Figure 4a. In Figure 2b, six hexahedrons are attached, one to each face of the initial hexahedron. From Table 5, we see that e_v and b_v are 4 and 3 respectively. For the initial cube, e_v is 3. As a result only one edge can be added to each vertex and each added edge must be shared by three of the added bodies. At the completion of the construction step represented by Figure 3b, all the element adjacencies for the 8-cell are satisfied except b_e, b_v, and b_f.

Adding another body that is formed from the outer vertices, edges and faces of the 8-cell graph completes construction of the 8-

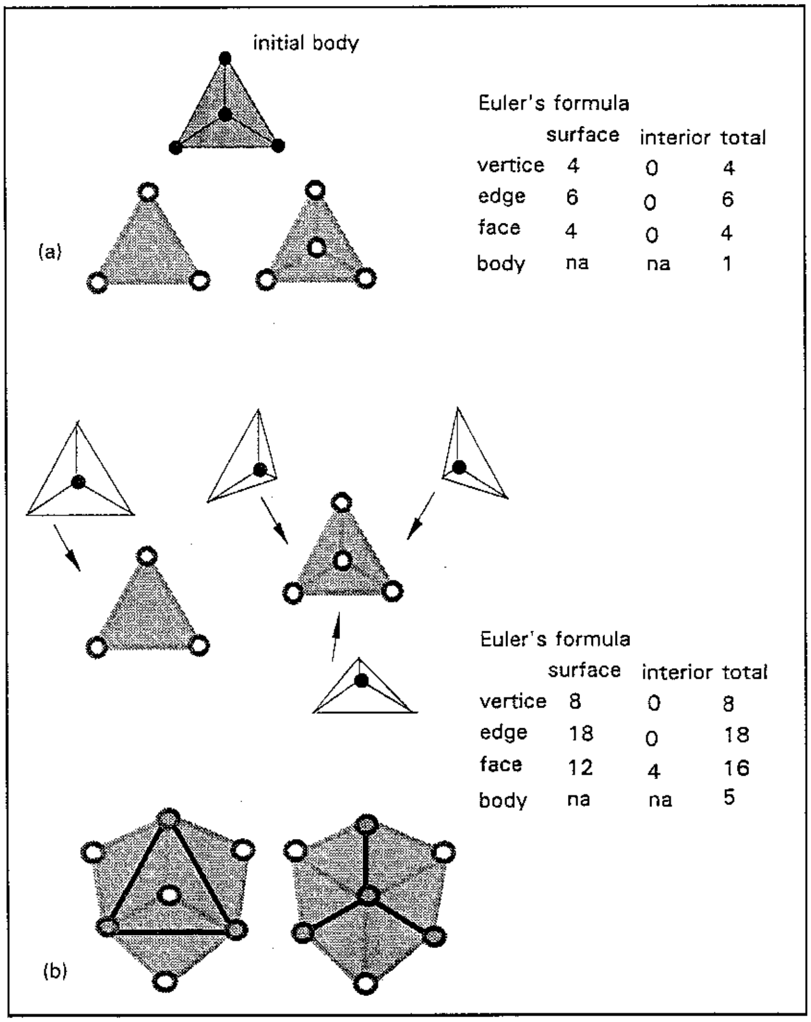


Figure 4a and 4b.
Initial steps in modeling of the 16-cell 4-polytope, a member of the cross

cell. The number of vertices, edges, faces, and bodies for the completed 8-cell 4-polytope is shown in Figure 3c. Note that again, Euler's formula for 4-space is balanced at the completion of construction.

Topological Model of the 16-Cell 4-Polytope

Figure 4 shows the construction of the 16-cell or four-dimensional cross polytope. The four-dimensional cross polytope is constructed from tetrahedrons. There exists a series of different dimension cross polytopes, one in each order space. All cross polytopes are constructed from three edged faces.

Construction of the 16-cell begins with a tetrahedron shown in Figure 4a. In Figure 4b, four tetrahedrons are attached, one to each face of the initial tetrahedron. From Table 5, we see that e_v and b_e are 6 and 4, respectively. For the initial tetrahedron, e_v is 3. Unlike the 8-cell each added edge need not be shared by three of the added bodies. Hence adding a body to each face adds three additional edges to each vertex, making $e_v = 6$. Figure 4c shows six bodies being added one over each edge of the initial body. Note that all that is required to add a body over an edge is to add one edge and two faces. All vertices and all other faces and edges are already in place. Next, in Figure 4d, four bodies are added, one over each vertex or the initial body. All elements of the added bodies are in place except one face per body. Thus, all that is required to add four bodies it to add four faces.

At the completion of the construction step represented by Figure 4d, all the element adjacencies for the 16-cell are satisfied except b_e, b_v and b_f. Adding another body that is formed from the outer vertices, edges and faces of the 16-cell graph completes construction of the 16-cell. The number of vertices, edges, faces, and bodies for the completed 16-cell 4-polytope is shown in Figure 4e. Again we find that Euler's formula for 4-space is balanced at the completion of construction.

Discussion

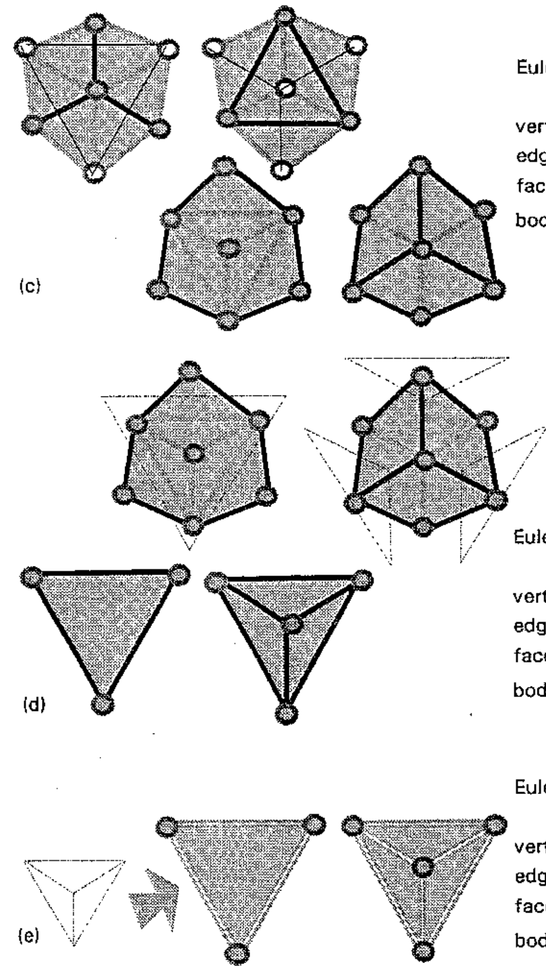
The topological models of the polytopes shown in Figures 2, 3 and 4 are based solely on the element adjacencies given in Table 1 and Euler's formula. The models agree with the description of the polytopes given by Coxeter (1963) based on algebraic solutions. Coxeter describes the connectivity of the polytopes and lists the number of vertices, edges, faces and bodies for each as given in Table 6. The values given in Table 6 agree with the number of vertices, edges, faces and bodies shown in Figures 2c, 3c, and 4e. The polytope models shown in Figures 2, 3 and 4 are also consistent with the topology of the physical models build by the Japanese artist Miyazaki (1982).

Conclusions

This paper builds a foundation for development of hypersolid modeling. We define hypersolid modeling in terms of quantities and operations used for boundary representation solid modeling in 3-space. The basis for boundary representation solid modelers in 3-space is Euler's formula and adjacency relationships. We have formulated the basic paradigm for hypersolid modeling by:

1. Developing methods for boundary representation of hypersolids in 4-space; and
2. Demonstrating the method by modeling three of the six 4-polytopes and verifying that, for each of the three polytopes modeled, the element adjacencies together with Euler's formula uniquely and completely determine the topology of the polytope.

Finally, this paper demonstrates how hypersolid modeling can aid in the visualization of entities in 4-space by enabling us to visualize the construction of hypersolids from solids. The hypersolids modeled in this paper are relatively simple. The author plans to demonstrate the visualization potential of the hypersolid modeling method



Euler's formula (c)

	surface	interior	total
vertice	8	0	8
edge	18	6	24
face	12	16	28
body	na	na	11

Euler's formula (d)

	surface	interior	total
vertice	4	4	8
edge	6	18	24
face	4	28	32
body	na	na	15

Euler's formula (e)

	surface	interior	total
vertice	4	4	8
edge	6	18	24
face	4	28	32
body	na	na	16

Figure 4c, 4d and 4e.
Final steps in modeling of the 16-cell 4-polytope, a member of the cross polytope group.

Regular 4-Polytope	K_0^4 (vertices)	K_1^4 (edges)	K_2^4 (faces)	K_3^4 (bodies)	K_4^4 (hyper-bodies)
5-cell (simplex)	5	10	10	5	1
8-cell (hypercube or tesseract)	16	32	24	8	1
16-cell	8	24	32	16	1
24-cell	24	96	96	24	1
120-cell	600	1200	720	120	1
600-cell	120	720	1200	600	1

Table 6. Regular 4-Polytopes in Euclidean 4-space (Coxeter, 1963).

presented in this paper by modeling the 24-cell, 120-cell and 600-cell 4-polytopes.

The models shown in Figures 2, 3 and 4 aid in visualization of entities in 4-space. The approach taken to understanding four-dimensional space depends on experience and expertise. Many mathematicians realize 4-space through the algebraic and topological relationships governing operations in 4-space. However, most designers and many engineers are more visually oriented than mathematicians, and benefit from model construction relationships.

Descriptive geometry has been extended into the fourth dimension (Ernesto, 1968) and has proven to be a useful tool for engineers in understanding the fourth dimension. Descriptive geometry permits objects to be constructed and manipulated in four-dimensional space according to rules governing their projection onto two-dimensional space. As a result, engineers can work with objects in four-dimensional space in a way that is familiar to them in working with objects in three-dimensional space.

Another method for visualizing 4-space is through rotation matrices and successive projection of entities in 4-space onto a 2-dimensional picture plane developed by the author and a group of Chinese researchers (Wan, 1989a and 1989b) and (Wan, 1994a and 1994b). This rotation/projection method is complementary to the modeling method presented in this paper. The author plans further collaboration with the Chinese group to add dynamic visualization capability to the modeling method.

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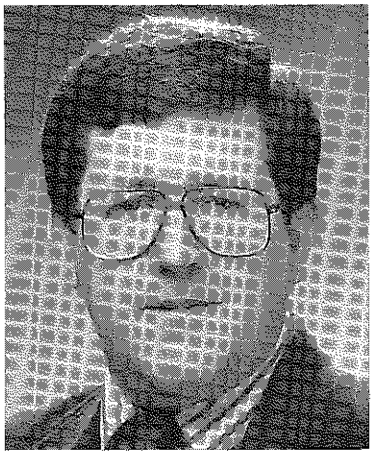
Division News and Notes



Chair's Message
William A. Ross

As I look back to January 1984, my first midyear meeting in Pittsburgh, it is easy to see why I'm such a loyal and longtime fan of the Division. That first meeting made an indelible and wonderful impression. Colorful and 'legendary' figures like Larry Goss and Bob Larue made me feel welcome and valued. No pretenses and no airs. It was a great feeling to suddenly discover a professional identity and home. If memory serves me correctly, Thom Jefferson and some guy named Mongé each sat next to me during the technical sessions. Although they spoke with strange accents and had trouble understanding the concept of accreditation, both were long time supporters of the Division; neither seemed to like our haircuts or neckties. I can't tell you exactly how I knew it at the time, but I'd definitely found a home.

With this as a true confession from a loyal member, I would like to address a critical issue. One of the biggest concerns of the Division in the last few years, and a priority long-range goal, is to develop and implement a systematic means of increasing membership. Although retirement explains some of the normal attrition, where are the new members? Like many of you, I have pondered this and a number of related questions. How will we recruit and retain members in our division? What type of background will a new member of the engineering design graphics division have in the year 2000? What will these future professionals be teaching in the classroom and laboratory? Where will they come from?

There is one very encouraging trend which appears to be on the increase over the last few years. That is the involvement of graduate students in the engineering design graphics educational process. Although far flung and diversified in effort, Iowa State, Texas, Ohio State, North Carolina State, Georgia Tech, Penn State, Purdue and other institutions are involved in cultivating professional interest in engineering graphics education through their graduate students. This is a critically important development and should be encouraged and supported as fully as possible. It allows for both the development of teaching skills and creates opportunities for much needed research in our field.

A second important source of professional members is from technology and engineering technology programs at four- and two-year post secondary schools. Many of our members are already from programs of this type. However, with technology programs on the rise, there is still a vast untapped population of highly qualified professionals out there looking for a professional identity and home. The *NSF EDG Curriculum Development* project created by Ron Barr and Davor Juricic at the University of Texas is exemplary of the type of effort essential for attracting and retaining new professionals. There is much work yet to be done.

Thinking back to conversations with colleagues during the last 15 to 20 conferences, there's one fascinating observation about our members: diversity. We are highly eclectic in terms of our backgrounds; both educationally and experientially. Except for some limited formal education in graphics, there is no typical pedigree or professional preparation to become an EDG educator. I recall formal educational backgrounds in mechanical engineering, civil engineering, physics, mathematics, industrial technology, architecture, industrial design, computer science, fine art, art education, education, psychology, and yes, even chemistry, to name a few. In fact, our diversity appears to be on the increase. Might it not also be our strength? I am not aware of a single formal discipline, including any modern engineering curriculum, which claims to formally prepare professionals for careers as engineering design graphics educators. We have all arrived in our graphics arena through different gates. Perhaps we should perceive ourselves as an evolving but interdisciplinary field with graphics at the core.

Although we are highly diversified, it is hard to imagine a more loyal or dedicated professional group all committed to a mission dear to us all: the education of young minds striving to acquire the essential graphical and problem solving skills necessary to progress onward into engineering and related technology careers. Imparting this mission to new or aspiring professionals is just as important as the students we teach. It is the life's blood and future of our evolving interdisciplinary profession.

edgd 1994 Distinguished Service Award

Presented to:
Garland K. Hilliard

June 28, 1994
Edmonton, Alberta, Canada
ASEE Annual Conference

Introduction by William A. Ross

It is a distinct honor to be called upon to present this year's recipient of the Engineering Design Graphics Division Distinguished Service Award. When the recipient also happens to be a long-time personal friend, mentor, and former colleague, the honor is even more cherished. It is a great pleasure to announce and to present to you, this year's recipient of the Distinquished Service Award, from North Carolina State University, Garland K. Hilliard.

Before Garland comes up to received this award, I would like to share some of the highlights of his career and life with you. Garland's long association with and contributions to the division and especially the *Engineering Design Graphics Journal* are noteworthy. He joined ASEE and the division in 1968 while working as an engineering graphics instructor with Bob Hammond at N. C. State.

Possessing a life-long background in the printing and publishing business, his editorial talents and organizational skills were soon recognized. In 1969 he began assisting with the editorial layout and publication of the *Engineering Design Graphics Journal.* In the Spring of 1973, he was officially appointed as Assistant Editor to the *Journal* working with Editor, Al Romeo. For over 17 years, Garland contributed his expertise to the *Journal* in a variety of capacities: As an editorial assistant between 1969 and 1973; as an appointed Assistant Editor in1973-74; as creator and editor of the Teaching Techniques column first appearing in the *Journal* in the Winter of 1974; as Associate Editor from 1974 to 1977; as Circulation Manager from 1977 to 1980; again as Associate Editor from 1981 through 1984; and as a member of the Editorial Review Board from 1983 through 1986.

As an example of his craftsmanship and ability as a publisher and editor, Garland, assisted by Bill Vanderwall of N. C. State, published and distributed the handsome and glossy bound *Proceedings of the (First) International Conference on Descriptive Geometry*, held in Vancouver, British Columbia, in June 1978. At that time, Garland might have described desktop publishing as 'basement publishing'.

Recognized by the membership of the division for his leadership and quiet administrative skills, Garland was elected and served as Vice Chair in 1983-84 and Chairman of the division in 1984-85. Throughout his long association with the division, Garland demonstrated a quiet but competent leadership style, a wonderful sense of stewardship, and served as a mentor and friend to many.

Garland began his teaching career as an engineering graphics instructor in the Freshmen Engineering Division at North Carolina State University in 1964. An advocate of self-paced instruction and individualized learning, he wrote and published the first Self-Paced Instruction Manual for Engineering Graphics in 1971. Garland is also recognized at N. C. State for his leadership as Co-Director of the university's Living and Learning Program; a program designed to help incoming freshmen make a successful transition to university life.

In 1979 when the engineering graphics program and its faculty were transferred from the College of Engineering over to the College of Education and Psychology, Garland was appointed as Program Coordinator (Department Head) and took on the leadership role of helping the program to redefine its mission. Soon after the move, the engineering graphics group officially changed the name to the Graphic Communications Program. When the future of the entire engineering graphics program at N. C. State seemed in doubt in 1979, Garland tirelessly and skillfully rebuilt and rejuvenated the program. Having served as a member of Garland's faculty group between 1980 and 1988, I can personally attest to his administrative savvy and effort. As a direct result of Garland's leadership, the program has grown from a declining service program with 3 courses in 1979 to a much respected and sought after interdisciplinary degree program in Graphic Communications with more than 13 different courses. Additionally, the program is supported by modern well equipped workstation and microcomputer CAD laboratories. The success and growth of the Graphic Communications Program at N. C. State is a living landmark to Garland's skill as an engineering graphics educator, leader, and administrator.

Garland recently retired from N. C. State, in December 1993, after a long and successful 30-year career. Garland and Marie, his wife and high-school sweetheart, are currently enjoying a long and well-earned retirement in their new home at the coast near Topsail Beach, North Carolina. And oh yes, being very family oriented folks along the way, Garland and Marie raised and educated four children. Their new home at the beach is already a pretty popular spot for children and grandchildren.

As an example of the great respect and warmth shown to Garland upon his retirement from N. C. State, it is my pleasure to read a personally revealing poem penned by a mutual colleague, a great friend, and an aspiring bard, John Crow; written especially in isometric pentameter.

Going to the Beach

A Retirement Tribute to Garland K. Hilliard

by John L. Crow
North Carolina State University
April, 1994

Garland, you are truly a vital part of the history and success of the Engineering Design Graphics Division of ASEE. You are indeed our favorite old salt! It is with a great deal of pride that I am allowed to present the Distinguished Service Award to you.

The inscription reads:

Distinguished Service Award
Garland K. Hilliard

Garland K. Hilliard is hereby recognized by the Engineering Design Graphics Division of The American Society For Engineering Education for his outstanding contributions to the division and to engineering education. He has served the division in many capacities including chairman, editor of the Engineering Design Graphics Journal, circulation manager, and editor-publisher for The Proceedings of the First International Conference On Descriptive Geometry. His skillful but selfless leadership has been an invaluable asset to the division and its members! This award is the highest that can be presented by the division to one of its members. Garland K. Hilliard has been selected for this honor by his colleagues for his outstanding career at North Carolina State University as an educator, scholar, and administrator. Presented this day June 28, 1994, at the ASEE annual conference Edmonton, Alberta, Canada.

[Signed by] J. Barry Crittenden

Allow me to share a few verses of prose,
Of a fellow we hold dear, he's one of those.
A man who's a leader and born to teach,
Who had a desire to reside at the beach.

The son of a master printer, a talented young lad was he,
He began learning the art of printing sitting on his father's knee.
Even before the back of a horse he could reach,
Garland had an inborn love for the beach.

A native of Orange County, early childhood spent in Chapel Hill,
Can we forgive him of that, well, I think we will.
Garland married Marie when they were in high school,
They're still married today, thats got to set some kind of rule.

First as a teacher at N. C. State,
Garland rose quickly to lead and administrate.
One of the best graphics programs in the nation,
So named by many in the field on more than one occasion.

Clean shaven, mustached, or even full bearded more,
Garland all through the years had his heart set on the North Carolina shore.

As a teacher of the industrial trades, he knew a chamfer from a saw kerf,
But always in the back of his mind was a desire to enjoy the surf.
Teaching engineering geometry, dimensions, and visualizing orthographic views,
We knew one day he would leave for the coast, because the man just has sand in his shoes.

You've heard it said 'time waits for no one', nor do the tides,
Garland Hilliard has served us well and now at the ocean resides.
As he works in his rose garden with colors of red, yellow, and peach,
We can rejoice with him because we know he's happy at the beach.

For some men it's brand new automotive machines,
For others trips, fine foods, and pralines.
But for Garland it's fish and swimming, boating, seagulls, shells, and tan.
Oysters, spot, shrimp, scallops, flounder, pelicans, and sand.

This I can say with absolution,
Garland, I do believe your blood is 90% saline solution.
Dear friend we now wish you well, all of us whom you have loved and lead and taught,
For in all honesty you are truly our favorite old salt!

And as for us, who are here left behind,
Fret not, for I know we have a map and are able to find.
Something truly wonderful and grand,
And of course I'm referring to Garland and Marie's home on the strand.

So allow me to end with this verse,
Before Garland his reply can rehearse.
For fear that if I go further I might start to preach,
Garland and Marie, we're all coming to see you at the beach!

1994 Distinguished Service Award

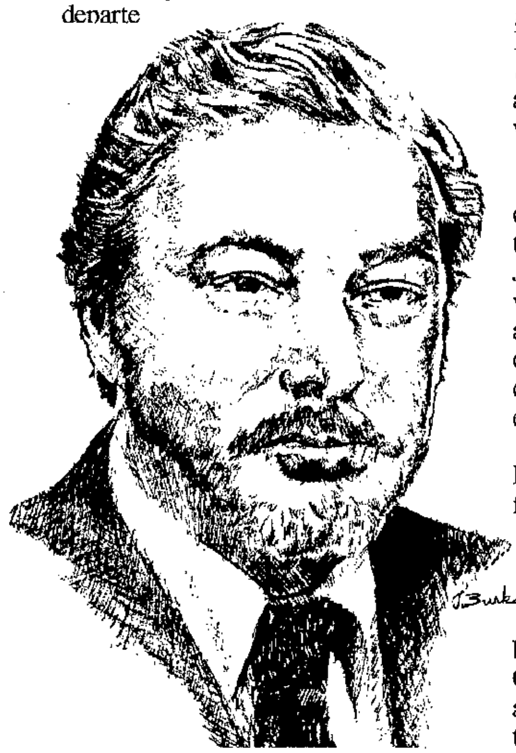
Acceptance Speech
Garland K. Hilliard

Thank each and every one of you, my colleagues and friends, for the great honor you have bestowed upon me.

Thank you, Bill, for making the presentation of the award and your most kind and gracious descriptive summary of my career achievements. I am extremely proud to have worked with you (Bill) over the years, and to now have you, as chair-elect of the Engineering Design Graphics Division, to personally bestow this highest and most cherished award upon me.

Bill, your remarks about me have been most refreshing and heartwarming... so much so that I am hesitant to say anything at all for fear that what I say might jeopardize my qualifications, and the award might be retracted. But, I realize, too, that I am as far North as I have ever been, and that I should at least bless this part of Canada with a taste of my Southern Accent!

One of my good friends in North Carolina gave me a book to read as I departe



m the airport in Raleigh on my way here, to Edmonton. Knowing that I was a little nervous, she offered assurance as she wished Marie and I a pleasant and safe trip. This is that book. The title of it is, *Live and Learn and Pass It On.* It is a collection of thoughts from many persons of all ages and backgrounds on what they have learned about life in their years so far. One of these sayings was written by a 45 year old who says, "I've learned that you can get by on charm for about 15 minutes. After that you had better know something." A 33-year-old writes that he has "learned that he doesn't make many mistakes with his mouth shut." With these two quotes in mind, I am going to try to limit what I have to say to less than 10 minutes.

In all seriousness, though, and as I have heard other Distinguished Service Award recipients express on this occasion in the past, "I would not have thought 30 years ago that I would ever have been worthy of joining the ranks of those who have received this award in the past." When I began my Graphics teaching career, I was awed by the likes of the greats such as Giesecke, French, Luzadder, Hill, McNeary, Paré, Earle, Slaby, Spencer... and what they had accomp-lished. Thirty years ago I was a new instructor at North Carolina State University. I knew of the Engineering (Design) Graphics Division of ASEE, as it was called then, through occasional copies of the *Journal* that I came upon. Though I was most impressed with what I read and the greats I read about, thoughts of myself ever belonging to this elitist organization of the greats were foreign, far-off visions.

Twenty-eight (28) years ago, Robert H. (Bob) Hammond joined our faculty as the Director of the Freshman Engineering Program which included engineering graphics instruction. Professor Hammond, I might add, would himself later become a recipient of this very award. One of his strong suggestions (if, not a mandate) to all his new faculty was to join ASEE and the Engineering Design Graphics Division. Later this mandate would become a tradition that I, too, would perpetuate as head of Graphic Communications at North Carolina State.

I did join ASEE, as you might expect, and in the summer of 1969 I attended my very first Annual Conference. It was held at Penn State on the State College, Pennsylvania campus. For the entire conference I remained in a state of reverence, respect, wonder and utmost pride as I began to actually meet the greats in this Division that I had read and heard so much about.

Contrary to my previous perceptions, I learned that, for the most part, Division members were much like myself. They had the same desires, the same dreams, the same problems as I had. They were instructors, like myself, who were on the firing line and in the classroom trenches. They were people who had to slug it out to maintain their positions in the engineering curricula; people who experienced similar frustrations of defeat and joys of success; people who cared for each other and for their students.

Unlike other groups I had been witness to, this group (EDGD) overflowed with a genuine feeling of compatriotism and closeness. The Engineering Design Graphics Division still does! I knew in 1969 and have not since doubted, that I had discovered my place. Although I was not a joiner of anything, I was attracted by the magnetism of this group and its ideals. I had found home. This was what it was all about. There was new meaning and fresh inspiration for what I was doing.

At that first meeting at Penn State our Division was undergoing change–just as it is now. At that time considerable debate and controversy centered around the concept of "design" in engineering graphics, and the changing of the Division name, Engineering Graphics, to include the word, "Design." I can remember the Divisions oldtimers, the stalwarts, the greats of the time, and the sometimes heated discussions at our business meeting at that little Dutch restaurant in the hills of Pennsylvania. There was Earle Blace, Jim Earle, Steve Slaby, Gene Paré, Clyde Kearns, Percy Hill, Bob Hammond, Bill Rogers, Claude Westfall and other greats. This Division had spirit then – as it does now, and has come a long way in the past 25 years.

And yes, I too, have been a part of those last 25 years. But, I could not have achieved what you are honoring me for tonight without the encouragement, support, teamwork and talent of many others including you who are here tonight. To quote an 82 year old in *Live and Learn and Pass It On*, "I've learned that it is impossible to accomplish anything worthwhile without the help of other people."

I am truly honored and grateful to have been singled out this year to receive the Division's highest honor, the Distinguished Service Aware.

In closing, I would like to quote a few other "I've learneds" that seen appropriate for this occasion:

I've learned that...

...every great achievement was once considered impossible.
...nothing of value comes without effort.
...success is more often the result of hard work than of talent.
...you must fight for what you believe in.
...if you keep on doing what you've always done, you'll keep getting what you've always gotten.
...you can't be a hero without taking chances.
...life challenges us with the fact that everything can be done better.
...that it is OK to enjoy success, but you should never quite believe it.
...the best thing about growing older is that now I don't have to impress anyone.
...nothing tastes as good as vegetables from your own garden.
...after age 50 you get the furniture disease. That's when your chest falls into your drawers.

Thank you, Bill, and thank you all...those present tonight and those unable to attend for this treasured milestone in my life.

Garland Hilliard
1994 EDGD
Distinguished Service
Award Winner

Call For Posters

1995 ASEE/EDGD

49 th Annual Mid-year Meeting

January 15, 16, & 17

University of Houston, Houston, Texas.

Theme: *What's Graphics Got To Do With It?*

A late decision has recently been made to have a poster session at this Mid-Year. If you missed the deadline for presentation abstracts, but would like to participate, you may submit a poster proposal until November 22, 1994.

Send a on- page maximum, double spaced abstract to:

Charles W. White
Department of Technical Graphics
School of Technology
Purdue University
West Lafayette, IN 47907-1419

Phone- 317-494-8738
Fax- 317-494-0486
E-mail: cwwhite@vm.cc.purdue.edu

Suggested Topics:

- Evolving graphics standards.
- The interaction of graphics and changing production procedures now and in the future.
- Electronic graphics- revolution or evolution?
- Are we losing the core of knowledge to learning the machine?
- Where is that "paperless" society?
- Effect of reduced military budgets on engineering and technology.
- Innovative teaching: catch phrase or fact?
- Technical graphics is more than engineering.
- Unusual applications for graphics.
- What is in the near or far future for graphics?
- Co-operation between industry and education, both good or bad experiences.
- Graphics curriculum issues.
- Graphic science: Fact or Fiction.

NATIONAL DESIGN GRAPHICS COMPETITION

Date: 1 August, 1994

Dear Colleague,

On behalf of the sponsoring divisions of the American Society for Engineering Education (ASEE), I want to invite you to submit student design projects for the National Design Graphics Competition (NDGC). This event will be held in conjunction with the 1995 ASEE Convention, June 25-28, 1995, at Anaheim, California.

Please find the enclosed guidelines and registration forms for this event. These documents should answer most of your questions. The project this year is both interesting and challenging. For anyone who has been the person to get out of a warm vehicle into a cold rain to open a gate, this project has great significance.

Students involved in the design teams need not be freshmen but only be enrolled a freshman level class where this project is introduced. Also, the number of students in any one team is five (5). It is hoped that these two factors will allow more students and schools to participate in the design process at the freshman level.

The graphic part of the project is a major component of the competition. Although the graphics are separate from the written report, they should augment the written report and represent a chronological graphic record of the project.

In addition to the competition there will be a display of student projects. The display is <u>not</u> a part of the competition.

Even though I look forward to many interesting design solutions, please realize the main reason for this competition is for the students to gain a good understanding of the design process. I hope to see you in Anaheim.

Sincerely,

Patrick J. McCuistion, NDGC Chairman

P.S. Addison-Wesley and Autodesk will support the competition this year with funding and software prizes. For the competition in Edmonton, Autodesk provided the 1st place student winners and all winning sponsor schools with Autocad Release 12, Designer, Auto Vision, and 3D Studio.

AMERICAN SOCIETY FOR ENGINEERING EDUCATION — SPONSORING DIVISIONS — ENGINEERING DESIGN GRAPHICS; FRESHMAN PROGRAMS; DESIGN IN ENGINEERING EDUCATION

1994 COMPETITION GUIDELINES

The National Design Graphics Competition (NDGC) will be held June 25-28, 1995, in Anaheim, California, in conjunction with the American Society for Engineering Education (ASEE) Annual Conference. In addition to the competition, a display of the entries will also be held.

I. Design Project:

The project is to design an automatic opening and closing gate. The gate may be located in remote locations, so it's operation must be solely mechanical: the use of electricy for any part of the design is not allowed. The device must open and close from either direction but only for a specific vehicle modified for this purpose. The driver of the vehicle must remain completely inside the vehicle during opening and closing. The specific vehicle may range from a small car to a large truck with a long trailer. Installation must be adaptable to existing fencing.

II. Project Contents:

Each project entry should contain the following listed items. The possible point value for each part of the entry is noted after the description. The highest number of total points accumulated will be used to determine the winners. One copy of the abstract, written report, and all graphics must be submitted for each entry.

A. Title and Abstract Page: An 8.5" X 11" title and abstract page on white paper shall accompany each report. It must include the project title, school name, names of participating students, date completed, estimated time to complete, and an abstract of no more than 250 words. The type font should be no less than 12 point size. 10 points

B. Written Report: The written report shall be type written on no more than 10 - 8.5" X 11" white paper pages. The print must be double spaced, on one side only, be 10-12 point font size, and not encroach on 1" borders on all four sides of each page. The report shall be a segmented narrative that completely describes the activities of the team members in the following areas: 1) Problem Statement, 2) Preliminary Ideas, 3) Refinement, 4) Analysis, and 5) Final Solution. No graphics are permitted in the written report. Each section is worth 15 points. (75 points total)

C. Graphics: A chronological graphic record is an integral part of this competition. The graphics must be in a separate portfolio from the written report. Pertinent graphics are required for each phase of the design project, except for the Problem Statement (see part B). The graphics should range from concept sketches to final detail and assembly drawings and arranged in that order. Each graphic must include a minimum of a title, date, and name of the person who created it. The graphics must be on white paper. The total points for all graphics is 100.

D. Additional Scoring: Creativity and the Presentation Quality of the entry are worth 20 points each.

III. Project Team/Entry Limitations:

A. The maximum number of students per project is 5. Each team member must be enrolled in the same Freshmen level class where this design project is introduced.

B. The maximum number of entries per school or branch campus is 3.

AMERICAN SOCIETY FOR ENGINEERING EDUCATION — SPONSORING DIVISIONS — ENGINEERING DESIGN GRAPHICS, FRESHMAN PROGRAMS, DESIGN IN ENGINEERING EDUCATION

IV. Project Interest and Registration Forms

Please find the entry forms on the back of this page. The Project Interest Form must be received no later than March 1, 1995. The Registration Form and entry fee for each design team must be received no later than June 1, 1995.

V. Entry Fee:

An entry fee of $10.00, in U.S. currency, must accompany each Registration Form. Entry fees are not refundable.

VI. Entry Submission Date and Time:

All project entries must be submitted at the ASEE registration area before 8:30 a.m. (Pacific Time Zone), June 25, 1995. Representatives of the sponsoring divisions of the ASEE or NDGC will not be responsible for transporting the project to Anaheim.

VII. Judging:

Judging will be based solely on the items listed in sections I - VI. Each project will be judged by at least three judges. Judging will start on Sunday morning at 9:00 a.m. and be completed prior to the start of the conference.

VIII. Display Location and Schedule:

Location:	Anaheim Convention Center
Set-up:	June 25, between 2:00 p.m. and 4:00 p.m.
Display hours:	9:00 a.m. - 5:00 p.m. June 26 - 27 Project security is the responsibility of the entering schools.
Removal:	June 28 between 8:00 a.m. and 10:00 a.m. Removal and return of projects is the responsibility of the entering schools. Projects not removed will not be returned.

IX. Display contents:

The displays must include the written report and the graphics. A small placard with the school name will be provided for each entry. The displays may utilize any additional medium of communication but must fit on table space no larger than 36" wide X 30" deep.

VII. Awards/Prizes:

First, Second, and Third place awards will be given. Each student on an award wining team will receive an appropriate certificate. All other students will receive certificates of participation. The award winning schools will receive plaques. Prizes will be announced at a later date.

Please direct questions to:
Patrick J. McCuistion
FAX # 614-593-4684
e-mail mccuistion@dolphins.ent.ohiou.edu

AMERICAN SOCIETY FOR ENGINEERING EDUCATION — SPONSORING DIVISIONS — ENGINEERING DESIGN GRAPHICS, FRESHMAN PROGRAMS, DESIGN IN ENGINEERING EDUCATION

1995 ASEE NATIONAL DESIGN GRAPHICS COMPETITION
PROJECT INTEREST FORM
Anaheim, California

Our institution is considering submission of student design projects:

Number of Freshman projects ____ (3 permitted)

Contact person at your institution:

Full Name: ______________________________

Address: ______________________________

____

Phone #: ______________________ Fax #: ______________________

Please mail to: Patrick J. McCuistion
124D Stocker Center
Ohio University
Athens, OH 45701-2979

This form due by March 1, 1995

-- CUT ALONG THIS LINE --

1995 ASEE NATIONAL DESIGN GRAPHICS COMPETITION
REGISTRATION FORM
Anaheim, California

All the information on this form should be the same as you wish it to appear on any award.

School: ______________________________

Advisor(s): ______________________________

Address: ______________________________

____

Phone #: ______________________ Fax #: ______________________

Team Members: ______________________ ______________________
(limit of five)
______________________ ______________________

____

Please mail to: Patrick J. McCuistion
124D Stocker Center
Ohio University
Athens, OH 45701-2979

This form due by June 1, 1995

NATIONAL DESIGN GRAPHICS COMPETITION

Date: 1 August, 1994

Dear Colleague,

On behalf of the sponsoring divisions of the American Society for Engineering Education, I want to invite you to judge the National Design Graphics Competition. This event will be held in conjunction with the 1995 ASEE Convention, June 25-28, 1995, at Anaheim, California.

We will start on Sunday June 25, at 9:00 a.m. and finish with lunch about noon. We will first cover the judging criteria and then the judging sheets and projects will be assigned. When you complete the judging, you will hand in your score sheets for tabulation. The scores will be compiled and the results will be announced at the sponsoring division lunches and banquets.

If you will be in attendance and would like to help judge, please fill in the enclosed Judging Interest form and mail to the printed address.

Sincerely,

Patrick J. McCuistion, NDGC Chairman

- - - - - - - - - - CUT ALONG THIS LINE - - - - - - - - - -

JUDGING INTEREST FORM
1995 ASEE NATIONAL DESIGN GRAPHICS COMPETITION
Anaheim, California

I am interested in judging the 1995 competition. Please contact me in March 1995 to confirm my availability. Please use single stroke gothic capitals.

Name: ____________________

Address: ____________________

____

____

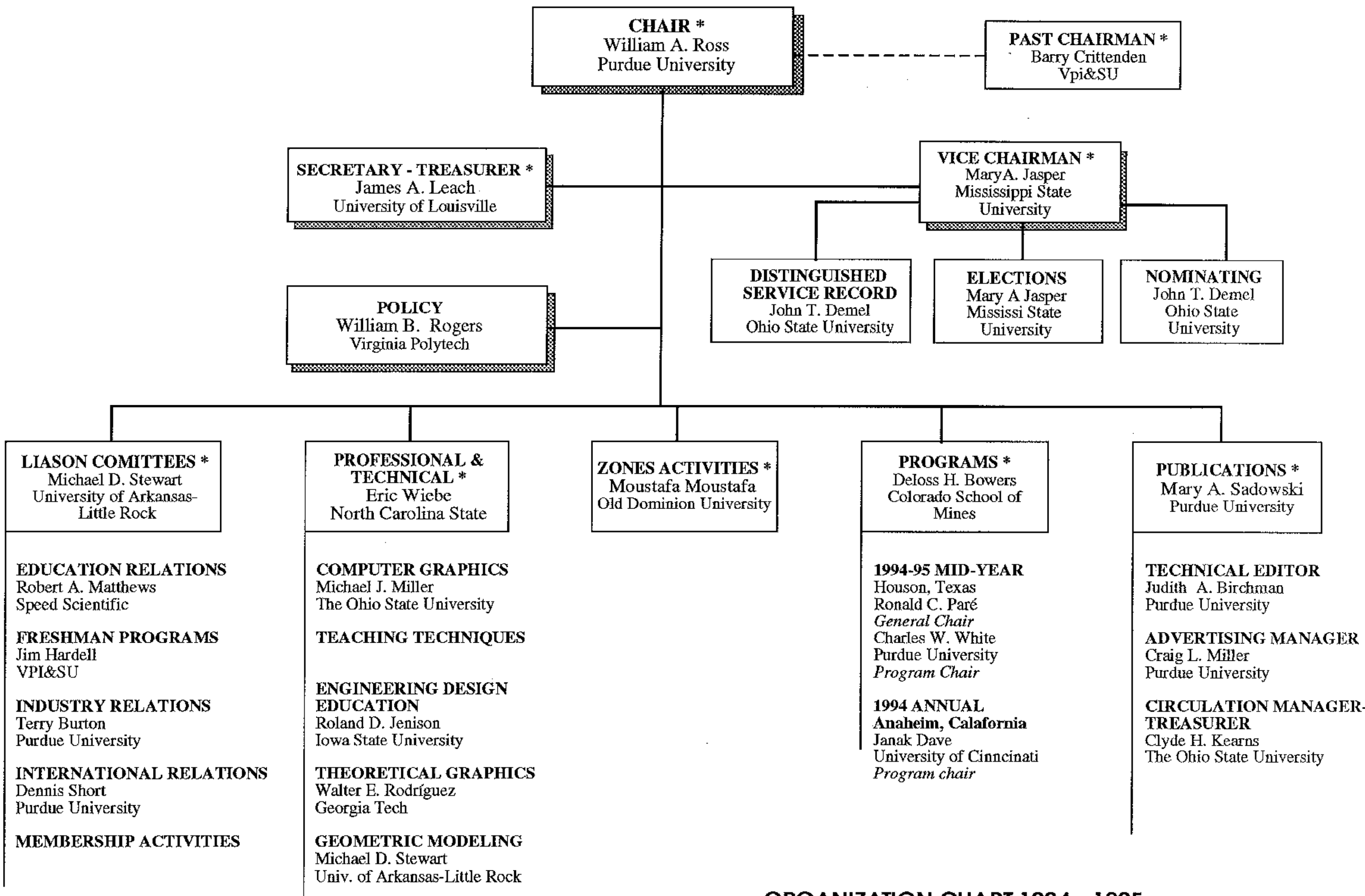
Phone #: ____________________

FAX #: ____________________

Please mail to: Patrick J. McCuistion, 124D Stocker Center, Ohio University, Athens, OH 45701-2979

AMERICAN SOCIETY FOR ENGINEERING EDUCATION	SPONSORING DIVISIONS	ENGINEERING DESIGN GRAPHICS FRESHMAN PROGRAMS DESIGN IN ENGINEERING EDUCATION

ENGINEERING DESIGN GRAPHICS DIVISION of ASEE



ORGANIZATION CHART 1994 - 1995

* **Executive Committee member**

Submission Guidelines

The *Engineering Design Graphics Journal* is published by the Engineering Design Graphics (EDG) Division of the American Society for Engineering Education (ASEE). Papers submitted are reviewed by an Editorial Review Board for their contribution to Engineering Graphics, Graphics Education and appeal to the readership of the graphics educators. By submitting a manuscript, the authors agree that the copyright for their article is transferred to the publisher if and when their article is accepted for publication. The author retains rights to the fair use of the paper, such as in teaching and other nonprofit uses. Membership in EDGD-ASEE does not influence acceptance of papers.

Material submitted should not have been published elsewhere and not be under consideration by another publication. Submit papers, including an abstract as well as figures, tables, etc., in quadruplicate (original plus three copies) with a cover letter to

Mary A. Sadowski, Editor
Engineering Design Graphics Journal
1419 Knoy Hall / Technical Graphics
Purdue University
West Lafayette, IN 47907-1419
FAX: 317-494-0486 PH: 317-494-8206

Cover letter should include your complete mailing address, phone and fax numbers. A complete address should be provided for each co-author. Use standard 8-1/2 x 11 inch paper, 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. All line work must be black and sharply drawn and all text must be large enough to be legible if reduced. The editorial staff may edit manuscripts for publication after return from the Board of Review. Upon acceptance, the author or authors will be asked to review comments, make necessary changes and submit both a paper copy and a text file on a 3.5" disk.

Page Charges

A page charge will apply for all papers printed in the *EDG Journal*. The rate is determined by the status of the first author listed on the paper at the time the paper is received by the Editor. The rates are as follows:

$5 per page for EDGD members
$10 per page for ASEE, but not EDGD members
$25 per page for non-ASEE members

This charge is necessitated solely to help offset the increasing costs of publication. Page charges are due upon notification by the Editor and are payable to the Engineering Design Graphics Division.

The *EDG Journal* is entered into the ERIC (Educational Resources Information Center), Science, Mathematics, and Environmental Education/SE at:

The Ohio State University
1200 Chambers Road, 3rd Floor
Columbus, OH 43212.

Article copies and 16, 35, and 105 mm microfiche are available from:

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300 Zeeb Road
Ann Arbor, MI 48106

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The Ohio State University
2070 Neil Avenue
Columbus, OH 43210

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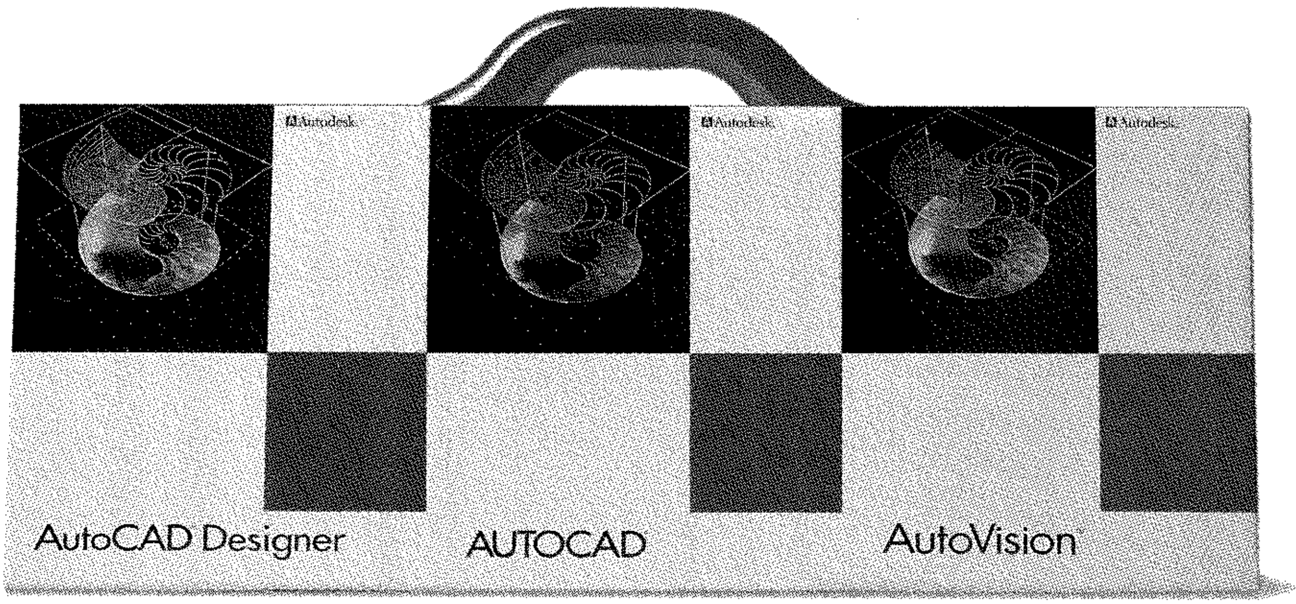

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Circulation Manager
The Engineering Design Graphics Journal
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2070 Neil Avenue
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