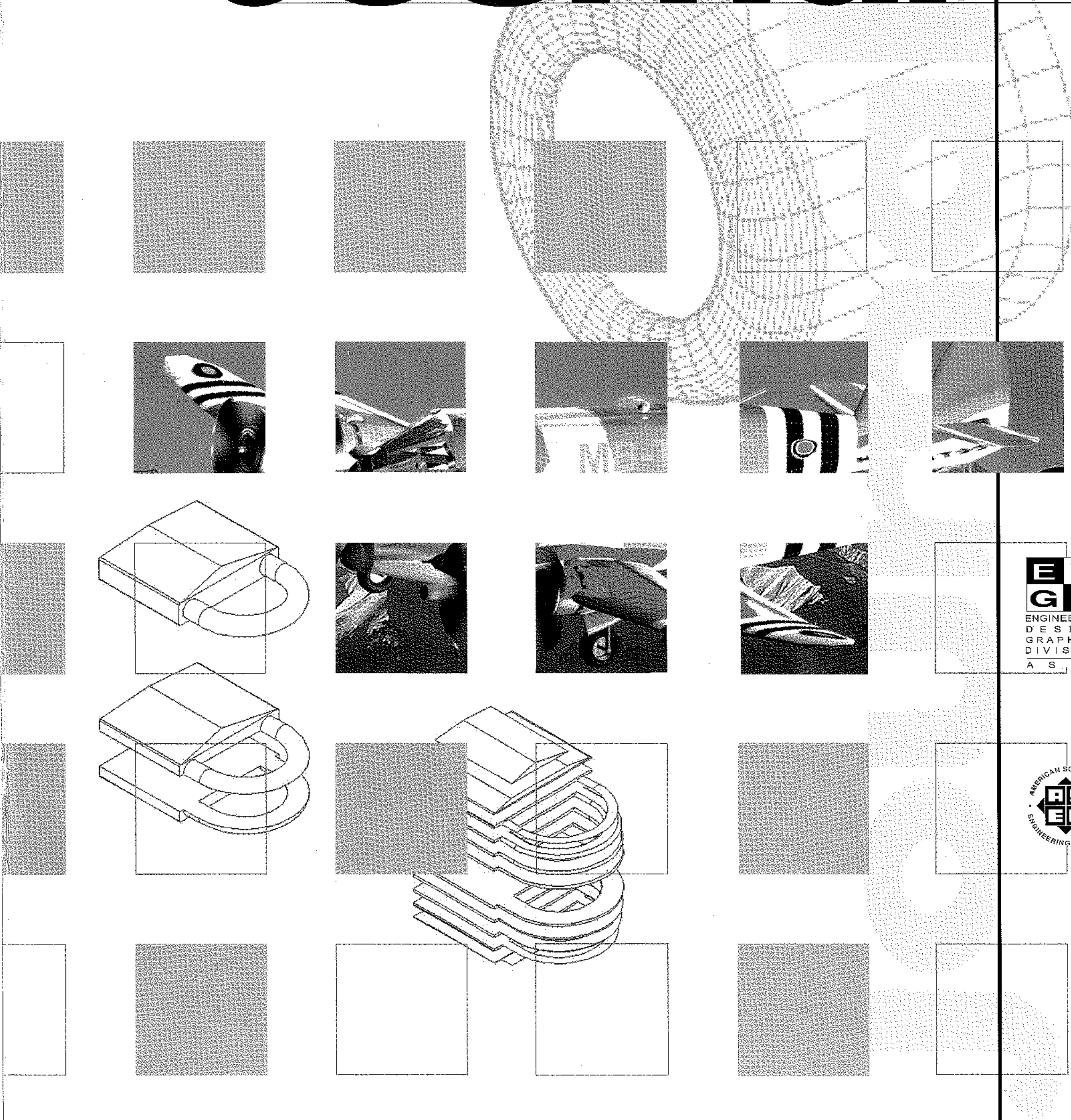
SPRING 2001

volume 65 number 2

THE ENGINEERING DESIGN GRAPHICS Journal



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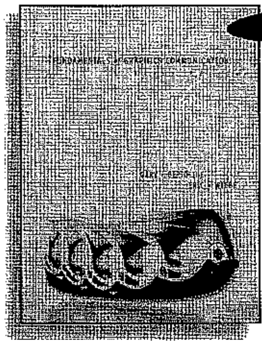

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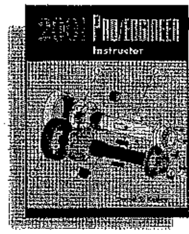

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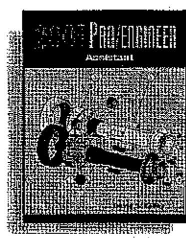

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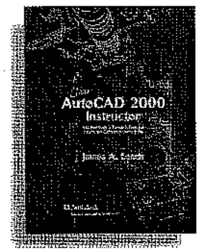

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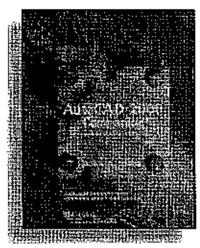

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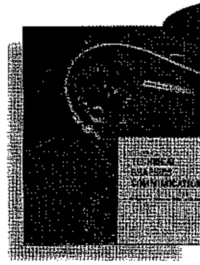

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THE ENGINEERING DESIGN GRAPHICS
Journal

SPRING 2001

volume 65 number 2

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.

Cover graphics from articles by Duff, Tennyson, and Krueger.

ISSN 0046 - 2012

[From the Editor]

Dear Members:

As hard as it seems this is the end of my first year as editor of the *Engineering Design Graphics Journal*. Time does fly. Last year at this time I was pregnant with my third child who just turned nine months old! I have learned many things about the Division and the *Journal*. There are many people who have helped me get started as editor who I need to thank. First is Judy Birchman who provided me with the important logistical information that is needed to keep the *Journal* in production and who acted as technical editor. Also Jim Leach who helped me with questions concerning the *Journal* and made my transition into this position much easier. David Kelley for securing advertisements for the continued financial support of the *Journal*. And Clyde Kearns for his services as circulation manager. And finally Mary Sadowski for all of her insights, suggestions, and humor that has helped keep things in perspective.

Congratulations are in order for Ted Branoff of North Carolina State University who won the 2001 editor's award for the most outstanding paper published in Volume 64 of the *Engineering Design Graphics Journal*. The following individuals should also be congratulated for election as officers of the Engineering Design Graphics Division: Sheryl Sorby who was elected as Vice Chair, Pat Devens as Director of Liaison, and Ron Pare as Director of Programs.

Jim Leach must also be commended and thanked for his service as Chair of the Engineering Design Graphics Division. His efforts allow this division to continue to function in a professional manner. In this same tone I want to welcome Mike Stewart as the incoming Chair of the Division.

I hope that all of you have a safe and relaxing summer and I look forward to seeing you at the MidYear in Berkeley, California.

Susan G. Miller

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[Message from the Chair]

James Leach
University of Louisville

EDGD R US

The Engineering Graphics Design Division is people. EDGD is you. EDGD is us.

You may think of EDGD as an organization with bylaws, officers, an Executive Committee, meetings, a refereed journal, traditions—an institution in itself. These things are not the EDGD—these things make up the structure of EDGD, a framework to work in, guidelines to operate.

Instead, the EDGD is people. You, me, all of us. We are the Division.

It takes all of us to be the Engineering Design Graphics Division. Thanks for all your efforts and support. Thanks for a good year.

Beginning my year as Chair of the Division, I thought, "I would like to introduce some positive change to the Division." Guess what? I've discovered that we do not control changes that occur to the Division. Change occurs naturally to the Division because change occurs naturally to us. We change individually and collectively because of changes that occur in the world, in industry, in technology, and in academia. As teachers of engineering graphics, we change the technologies we use; we change the methods we use for teaching; we change the way students learn and perceive Engineering Graphics.

On the other hand, the EDGD structure, bylaws, traditions, meetings, etc. pretty much stay the same in spite of the change that occurs with us. In fact, the meetings, presentations, and *Journal* articles are instruments of change—they allow us to communicate new ideas, technologies, philosophies and teaching methods.

The fact that the structure of the EDGD has been in use for about 73 years now proves that it was well designed and is somewhat flexible. Keep in mind: there have been modifications to the EDGD structure over the years as a result of our change. Because we are the Division, and because we change, it is up to us to maintain a structure for the EDGD that is flexible enough for us to operate most effectively and efficiently.

The EDGD is people. We are the Division. We have accomplished a lot this year. We had an excellent Midyear Meeting in San Antonio. We have instituted several new membership recruitment initiatives such as the new member mentor program and free one-year memberships. We have established the Schroff Graduate Student Participation Grant. We will begin the tradition of a two-year school technical session and a keynote address at the 56th Midyear Meeting in Berkeley.

The EDGD is people. People such as Clyde Kearns who continues his relentless pursuit of the *Journal* circulation and financial accounts. Tim Sexton, our Secretary/Treasurer, who has established new responsibilities for the position. Sue Miller, serving in the "best job" of the Division (Director of Publications), who has created a great new look for the *Journal*. You, because you attend meetings, give presentations, submit articles, and because you are reading this *Journal*. Mike Stewart, who has taken on several new duties as Vice Chair and helped us realize the new programs mentioned previously. Stephen Schroff, who has displayed fresh ideas and generosity. Frank Croft, who is always there for consultation and to offer assistance on any Division issue. Larry Goss, who is glad to give an opinion and offer information on Division history. Mary Jasper who mails out all the membership packets and who has established other new membership recruitment ideas. Arron Clark, who has provided us with several great ideas on membership. Ron Barr and Ron Pare, who provided us with a great Midyear Meeting. Jerry Vinson and Matt Whiteacre, who have taken over for Pat McQuistion to continue the Engineering Graphics Design Competition. Mary Sadowski and Jon Duff, who have worked behind the scenes, who filled in for me on short notice, and who offered their consultation and assistance on about everything. People such as all the other Directors and Committee Chairs who gave their efforts to the division.

You get the idea. It takes all of us to be the Engineering Design Graphics Division. Thanks for all your efforts and support. Thanks for a good year. Let's get behind Mike Stewart and continue to have another good year.

announcement

Schroff Graduate Student Participation Grant

Dear EDGD Members:

The Schroff Graduate Student Participation Grant is being offered again this year. This grant provides a maximum of $500 for graduate students to attend the EDGD Midyear Meeting at Berkeley, California, January 6-8, 2002.

The Schroff Graduate Student Participation Grant is intended as a developmental program to encourage potential graphics instructors to participate in the activities of the Engineering Design Graphics Division (EDGD) of ASEE. It is also anticipated that the grant recipients will make the EDGD one of their professional affiliations and activities on an ongoing basis throughout their professional career.

The grant is provided by Schroff Development Corporation and must be used to pay for travel, accommodations, and/or conference registration. The grant is open to all graduate students in graphics related programs (for example, Engineering Graphics, Technical Graphics, and Computer Graphics). Application forms and guidelines for the grant are available on the EDGD Web site at http://www.east.asu.edu/edgj/edgd/awards/awards.htm

The schedule for the application and selection process is:

October 15	Deadline for applications submitted to the Selection Committee
October 30	Selection Committee notifies potential grant recipients
November 15	Deadline for notice of commitment of recipients submitted to Selection Committee
November 20	Grant checks sent to recipients

Details about the Schroff Graduate Student Participation Grant are available on the EDGD Web site at http://www.east.asu.edu/edgj/edgd/awards/awards.htm

Mike Stewart
Vice Chair, EDGD

Using CADKEY to Solve Shortest Connector Problems

Frank M. Croft, Jr.
The Ohio State University

Abstract

A three-dimensional CAD package such as CADKEY can be a powerful tool in the solution of descriptive geometry problems. CADKEY offers the user a tool that allows solutions similar to traditional solutions using projection techniques without constructions or procedures that are unique to the software. Solutions regarding the shortest connector, the shortest level connector, and the shortest connector at a given grade are examined and explained in detail. Researchers in this area are encouraged to duplicate the solutions using other software packages.

Introduction

CAD systems have been shown to be very effective in the solution of descriptive geometry problems. Most recently, Branoff (2000), demonstrated solutions to descriptive geometry problems using AutoCAD, SolidWorks, and Pro/Engineer. His solutions showed that frequently, one must use commands and construction methods that are unique to the software. Duplication of the solution using other software such as CADKEY or IDEAS may be cumbersome because the construction technique may not be as straight forward using other software. Chen (2000), in studying concurrent coplanar and non-coplanar structures, used the work-plane concept in IDEAS to solve 3-D vector problems. The work-plane concept is basic to IDEAS and works very well; however, it is not easy to incorporate it when using other software such as CADKEY. Croft (1998) demonstrates that 3-D CAD is a very useful tool for descriptive geometry and offers that there is a need for descriptive geometry in the evolving world of three-dimensional modeling.

The purpose of this paper is to demonstrate the use of CAD software (CADKEY) in the solution of shortest connector problems. A single problem will be defined with requirements to determine the shortest possible connector, the shortest level connector, and the shortest connector at a given grade. Furthermore, the 3-D power of the CAD system will be used in the solutions while an effort will be made to not establish construction methods that are unique to CADKEY, hopefully making duplication of the solutions by others easier.

The Problem and Layout in CADKEY

The selected problem was taken from Hawk (1962). The problem states that two pipelines are determined by their centerlines AB and CD. Point A is at coordinates 0,0,0. Point B is located 50' west, 10' north, and 35' above A. Similarly, point C is located 5' west, 20' south, and 60' above A and point D is located 30' west, 40' north and 25' above *A*. The scale of the drawing is 1" = 20'-0". You are required to find the true length and bearing of the shortest possible connector between the pipelines, the true length and bearing of the shortest level connector between the pipelines, and the true length and bearing of the shortest connector at -25% grade between the pipelines.

In CADKEY, the solution begins by simply entering the X, Y, and Z coordinates of each point using the three dimensions expressed in the problem statement. In CADKEY, the east/west bearing is measured along the X axis, the north/south bearing is measured along the Y axis, and elevation (above or below) is measured along the Z axis. In order to enter the data, the system must initially be set up in 3-D construction and World Coordinates. This is accomplished in the Settings Window by setting the construction toggle to 3D, and the coordinates toggle to World Coordinates. CADKEY enables one to display the database in as many as four viewports at one time. This is done by pressing the Viewport button in the Menu Bar and selecting the 4 viewport icon. The four viewports with the problem layout is shown in Figure 1. The frontal view is displayed in the lower left viewport, the horizontal view in the upper left viewport, and the right profile view in the lower right viewport. The upper right viewport shows an isometric view of the problem and is used for construction of auxiliary views in the various solutions. Line AB is represented as the solid line while line CD is represented as a dashed line. A horizontal construction plane is shown as a broken triangle in the horizontal view and as one would expect, this horizontal plane is an edge in the frontal and right profile viewports. The purpose of this horizontal construction plane is to aid in the selection of the proper viewing direction for the second auxiliary view. The viewing direction determines which solution (shortest distance, shortest level distance, shortest distance at given grade) is obtained.

Problem Solution - Shortest Connector

The solution that yields the shortest connector between lines AB and CD can be achieved by using either the Line Method or the Plane Method (Hawk 1962). The plane method is a general solution that can be used to determine other solutions such as the shortest level connector and the shortest connector at a given grade between the skew lines. The line method can only be used to determine the shortest connector. Therefore, the plane method will be used in the solution of the shortest connector.

The plane method incorporates construction of a plane containing one of the skew lines such that it is parallel to the other skew line. Using the Application Menu and the Line Submenu, CADKEY enables one to construct

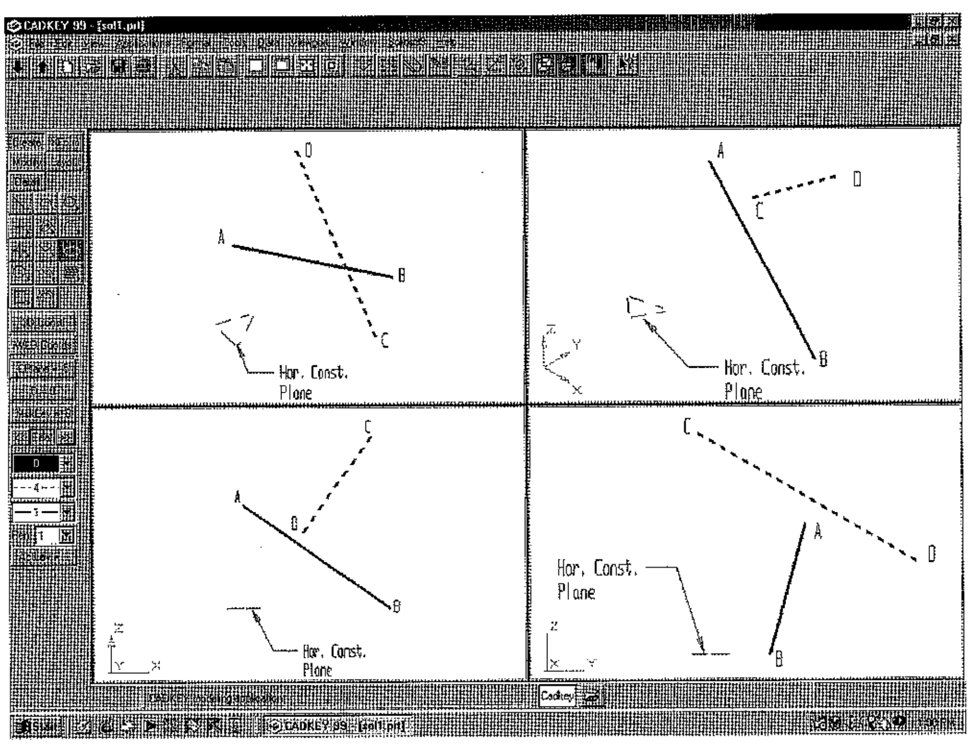

***Figure 1** Four Viewport Display of the Problem Layout*

a line parallel to another line through a specific point. The solution to this problem begins by constructing a line EF parallel to CD (dashed line) through one of the ends of AB (solid line). The plane (line AB intersecting EF) resulting from this construction is a plane that is parallel to line CD. Line FG is constructed in the lower left viewport as a horizontal line contained in this parallel plane and it connects the end of the parallel line (F) with the given solid line (AB) at point G. This horizontal line (FG), by definition, is true length in the horizontal view. Figure 2 shows this parallel construction and the creation of a plane EAFG that is parallel to line CD (dashed line). Furthermore, it shows a new view in the upper right viewport that was created by getting a point view of the true length line FG in the upper left viewport. In this view the skew lines appear parallel. CADKEY allows one to create new views and display them in any viewport. Notice that the horizontal construction plane is an edge in this view. This view is saved and is added to the view list.

The next step requires that one construct a line in the upper right viewport that is true length and perpendicular to the skew lines shown parallel in the view. The purpose of this line is simply to determine the direction of the next orthogonal view so that a point view of the shortest connector can be displayed. This true length line is drawn by first changing the system from 3-D construction to 2-D construction. When the system is in 2-D construction, any line drawn in any viewport will be true length in that viewport. Therefore, it is relatively simple to construct a true length line perpendicular to the parallel view of the skew lines. Figure 3 shows this construction in the upper right viewport. The view in the lower right viewport is constructed by getting a point view of the true length line constructed in the upper right viewport. Notice that line AB (solid line) and line CD (dashed line) cross in the lower right viewport. In this view, line AB (solid line) and line CD (dashed line) are true length and are located in different planes. In this view, one of the lines is considered to be in front of the other. The shortest connector is

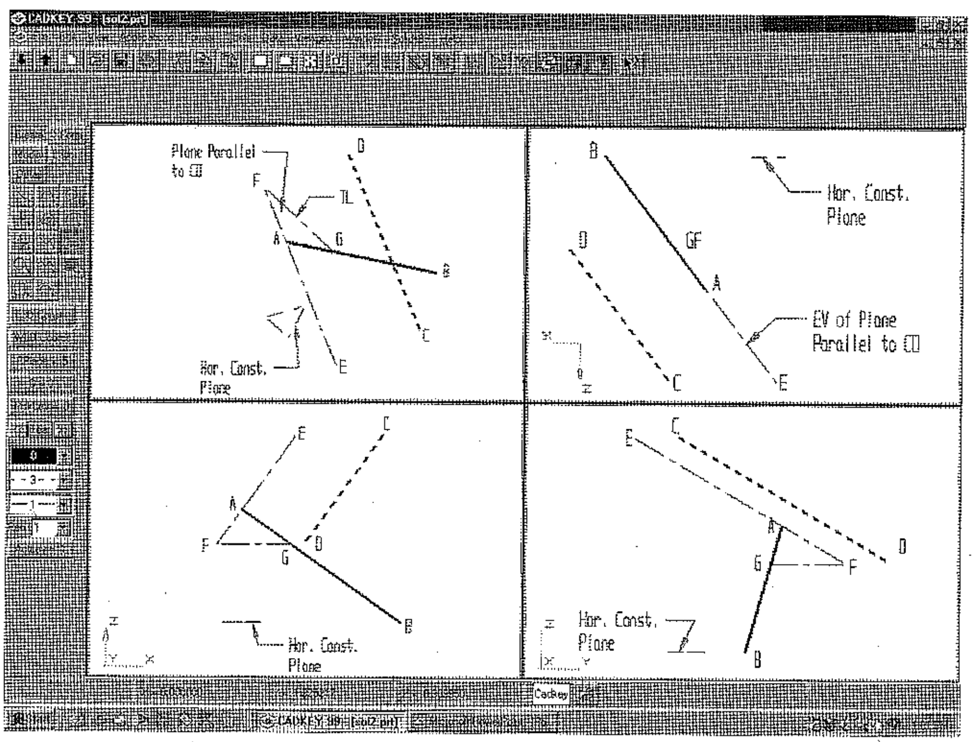

Figure 2 Plane Method Solution - Shortest Connector

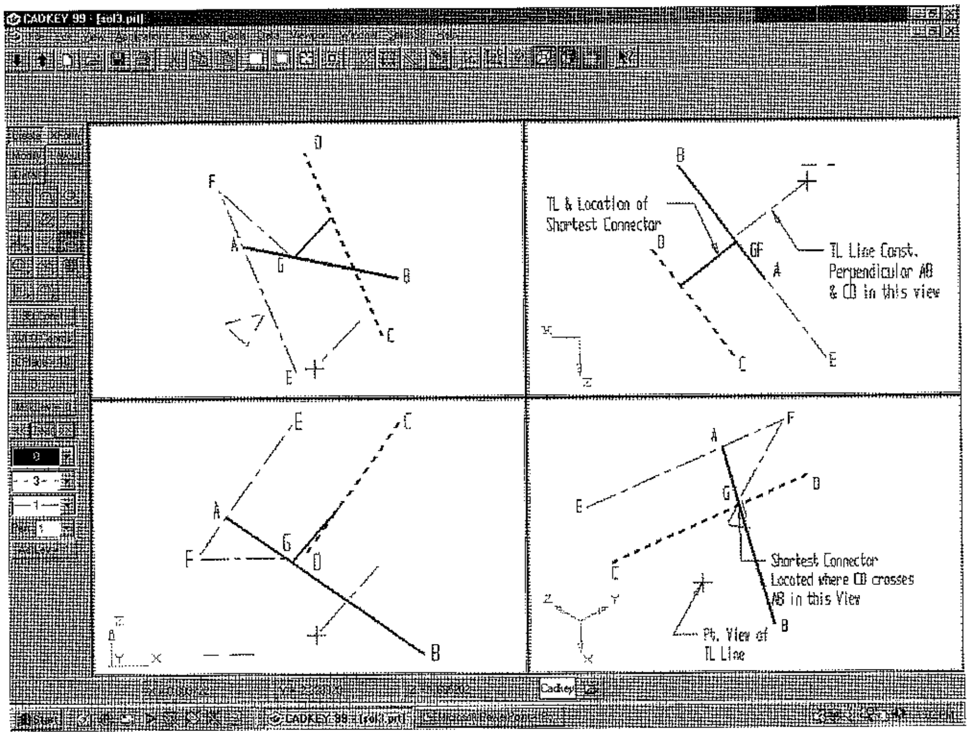

Figure 3 *CADKEY 3-D Model of Shortest Connector Solution*

constructed in this viewport at the apparent intersection. After constructing the shortest connector at this location, CADKEY displays the connector in all views.

The last step in the solution is to determine the true length and bearing of the shortest connector. This is achieved by simply querying the system regarding the length of the connector. The bearing is determined by measuring the angle between the connector and a North-South line that passes through one end of the connector. Figure 4 shows an orthographic layout of the solution. It shows a front view, horizontal view, and two auxiliary views. All of these views are in projection with one another with reference lines shown and labeled.

Problem Solution - Shortest Level Connector

The shortest level connector is determined in a similar manner as the shortest connector except the last auxiliary view where the point view of the connector is determined is achieved using a different line of sight. In the plane method of solution, all solutions whether you are interested in the shortest connector, shortest level connector, or the shortest connector at a given grade are achieved by first getting a view showing one skew line parallel to a plane containing the other skew line (Figure 2 upper right viewport). For the shortest level connector, a true length line that is parallel to the horizontal plane is required to determine the direction of sight for the next auxiliary view. In the upper right viewport of Figure 5, a true length line is drawn parallel to the edge view of the horizontal construction plane. This is achieved by setting the system to 2-D construction as explained in the shortest connector solution. A new view in the direction of this true length line is generated and shown in the lower right viewport. Again, the point view of the shortest level connector is located at the apparent intersection between line AB (solid line) and CD (dashed line) in the lower right viewport and when constructed in this view, it will be displayed in all views. Figure 6 shows an orthographic layout of the solution. It shows a front view, horizontal view, and two auxiliary views. All of these

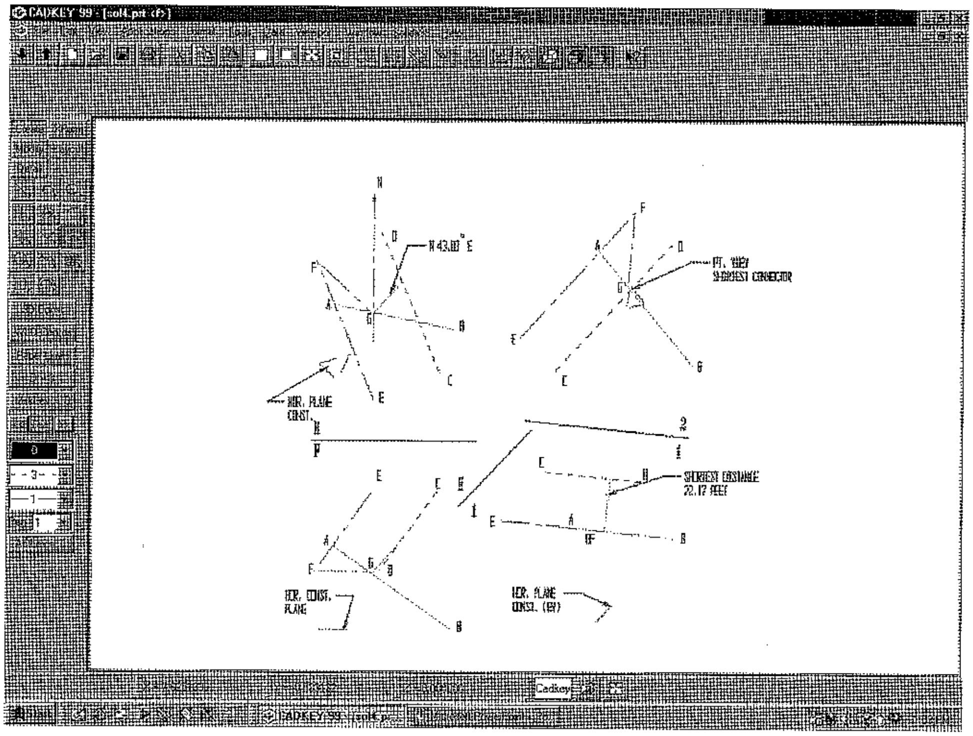

Figure 4 *Orthographic Layout of Shortest Connector Solution*

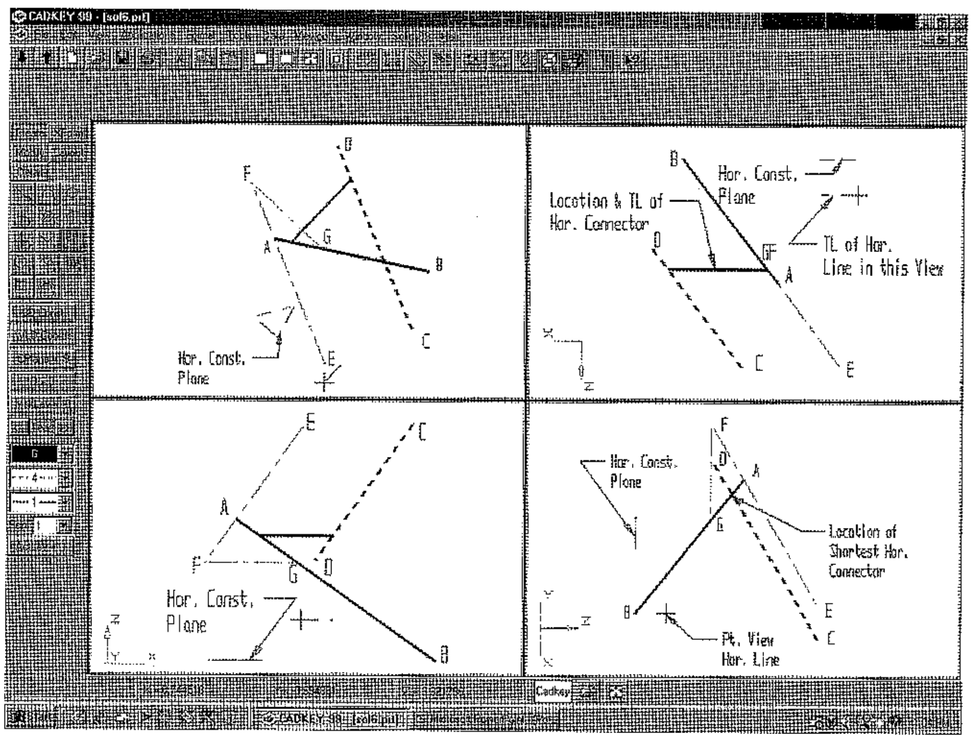

Figure 5 *CADKEY 3-D Model of Shortest Level Connector Solution*

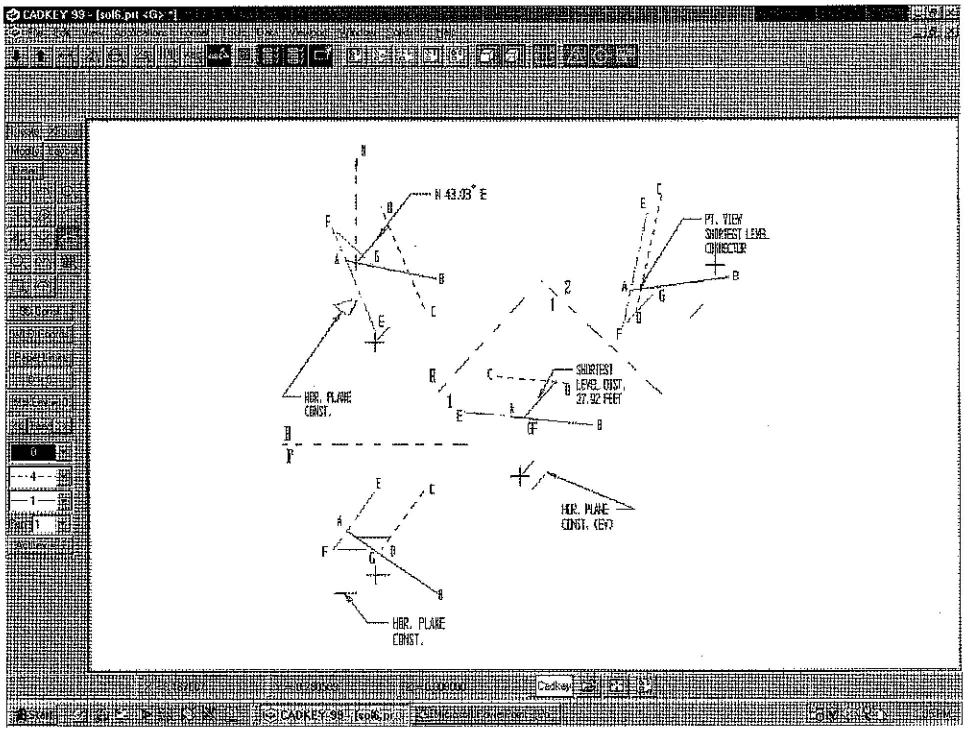

Figure 6 Orthographic Layout of Shortest Level Connector Solution

views are in projection with one another with reference lines shown and labeled.

Problem Solution - Shortest Connector at a Given Grade

The shortest connector at a given grade is determined in a similar manner as the shortest connector and the shortest level connector. Again, the last auxiliary view where the point view of the connector is determined is achieved using a different line of sight. This solution begins by referring to Figure 2 (upper right viewport) since, as previously stated, all solutions whether you are interested in the shortest connector, shortest level connector, or the shortest connector at a given grade are achieved by first getting a view showing one skew line parallel to a plane containing the other skew line. For the shortest given grade connector, a true length line that is at the given angle to the horizontal plane is required to determine the direction of sight for the next auxiliary view. In the upper right viewport of Figure 7, a true length line is drawn at -25% grade (-14.4 degrees) to the edge view of the horizontal construction plane. This is achieved by setting the system to 2-D construction as explained in previous solutions. A new view in the direction of this true length line is generated and shown in the lower right viewport. Again, the point view of the shortest given grade connector is located at the apparent intersection between line AB (solid line) and CD (dashed line) in the lower right viewport and when constructed in this view, it will be displayed in all views. Figure 8 shows an orthographic layout of the solution. It shows a front view, horizontal view, and two auxiliary views. All of these views are in projection with one another with reference lines shown and labeled.

Conclusion

In solving most descriptive geometry problems and specifically shortest connector problems, CADKEY offers an easy to learn format that is similar to traditional projection methods of solution. The complicating factor, if it can be stated as such, is the user must be aware that he/she is working in a 3-D environment and that creating views are done so in 3-D. Constructions used in the solutions that are

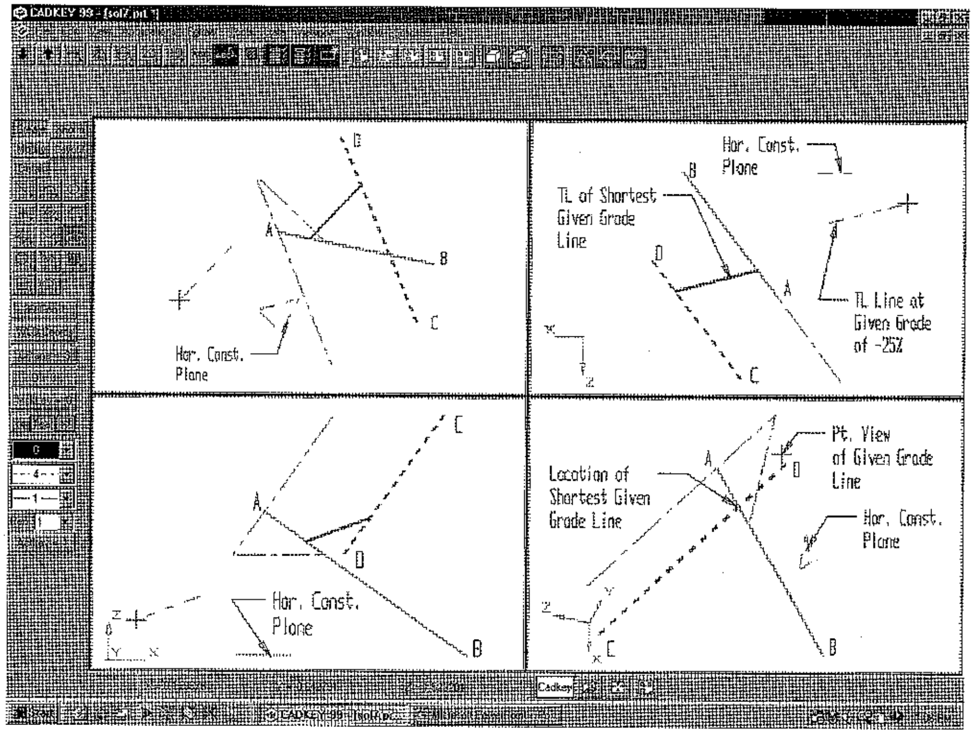

Figure 7 *CADKEY 3-D Model of Shortest Connector at a Given Grade Solution*

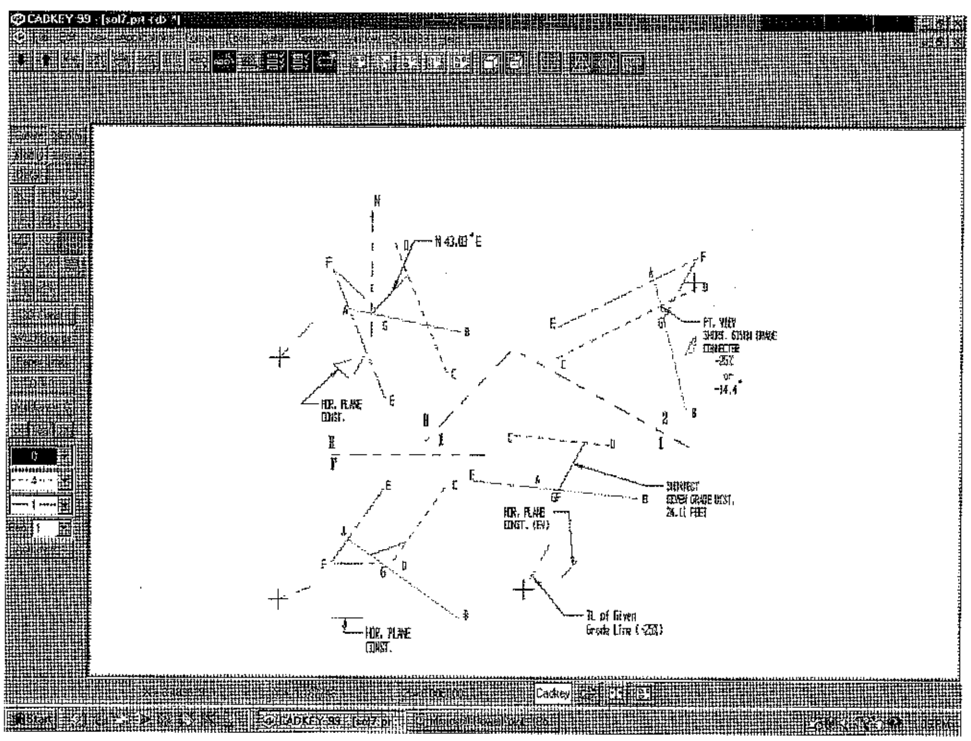

Figure 8 *Orthographic Layout of Shortest Connector at a Given Grade Solution*

unique to the software are minimal which result in fairly easy duplication using other software; however, this conclusion remains to be tested by others and the author encourages other professionals to solve the problem using a variety of 3-D CAD software packages.

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Computer Modeling from Models: Jumping the Engineering Drawing Hurdle in Technical Illustration

Jon M. Duff
Arizona State University-East

Abstract

Technical illustrations have evolved from strictly two-dimensional constructions made from engineering drawings into static, dynamic, and even interactive presentations based on exacting three-dimensional geometry. As has been done in the past, these models can be constructed from "reading" traditional engineering drawings. However, current students receive insufficient preparation in traditional engineering drawing to be able to create commercially viable technical illustrations by reading two-dimensional views and constructing axonometric pictorials; translating those views into 3D models that can be viewed in axonometric position is equally ineffective. This paper presents an approach to teaching technical illustration based on using small, inexpensive plastic models as the source of dimensional and visual information. By using these models, students are able to sketch and measure physical parts and make use of scanning and digital cameras to produce realistic, dimensionally accurate, and professional technical illustrations.

Introduction

Technical illustrations continue to be valuable tools in design, marketing, and training among architectural, engineering, and construction industries. But as engineering designers increasingly rely on digital tools, traditional technical illustrations—those produced by reading engineering drawings and producing 2D axonometric pictorials—simply lack the flexibility needed to justify the cost of production. Two-dimensional technical illustrations cannot be easily used for other purposes such as web, multimedia training, video, or derivative product development.

Technical publication and training departments are in a quandary: continue to produce limited two-dimensional technical illustrations or adopt digital modeling, rendering, and animation techniques. The PortSort Web site (2001) displays examples of digital technical illustration that reinforce the adaptability of digital illustration to differing media.

Because technical illustrations are created from a variety of source data (paper views, CAD views, CAD models, photographs, verbal descriptions) it is to a student's advantage to develop a full range of geometric construction skills. This certainly includes an ability to create technical illustrations from existing model geometry that they themselves have not created. But beyond this, illustrators should be experienced in creating visuals from sketches, photographs, engineering drawings, and physical parts.

Technical illustrators seek out existing model geometry whenever it is available and existing data, including clip model libraries available from such sources as Model Vision's *ModelWorks* (2001) visualization library, should be utilized. There is, however, limited pedagogical benefit from assembling existing geometry into an illustration.

Left to their own designs, students might use clip libraries exclusively. There is little educational benefit in using pre-existing model geometry to learn technical illustration. Without the ability to create geometry, an illustrator simply becomes an assembler of pre-existing parts. One way to assure that students create their own models and materials maps is to require all profile splines, paths, sweeps, lofts, and raster maps be documented in developmental screen captures, and submitted with the final illustration in the form of a report. In this way, the developmental process (as opposed to software skills) is emphasized.

The Overhead of Reading Drawings

In the past, curricula have been designed to develop the engineering drawing reading ability necessary to produce technical illustrations by traditional 2D construction methods. This normally meant a minimum of two courses—the first, traditional engineering projections, and the second, descriptive geometry. Unfortunately, few programs now have the luxury of devoting six credit hours to engineering drawing as a precursor to technical illustration. If a technical illustration experience is desired, several approaches appear available. Each option, however, exhibits serious, if not fatal, limitations that must be considered if implemented.

- Teach a reduced version of technical illustration based on traditional construction methods (axonometric projections and scale constructions). Use digital tools such as Illustrator, FreeHand, or CorelDRAW and 2D engineering drawings as source data.

  Downside: students fail to develop an understanding of illustration from modeling. This is a serious limitation because modeling is accepted as the paradigm for engineering design.

- Teach technical illustration by assembling and editing existing 3D geometry, applying materials, and viewing that geometry from desired positions.

  Downside: students fail to develop either construction or modeling abilities. This is a serious limitation because in the absence of existing model geometry, illustration becomes impossible.

- Teach technical illustration as a modeling activity, however not from engineering drawings. Provide objects that students can hold in their hands, analyze, and then model.

  Downside: students fail to develop engineering drawing reading skills. This is the least limiting approach because reading skills are already a casualty of reduced engineering drawing experience.

Using Physical Models

Historically, manipulating physical objects has been used to foster visualization skills. Wooden blocks were often issued in an EG 1XX course, blocks that were held, rotated, and pondered over as orthographic, isometric, and oblique representations were sketched. Computer graphics provides the mechanism for the same activity—without actually handling the part. The tactile benefits of actually being able to handle parts as they are being modeled parallels the benefits of using 3D computer models to promote visualization (Sexton, 1992).

Additionally, it has been shown that previous non-academic exercises (such as building models) may contribute to greater spatial visualization abilities (Deno, 1995). Tactile manipulation of actual parts should prepare students to visualize geometry, propose possible modeling strategies, and implement the strategies to create effective technical illustrations. Gender differences reviewed in the literature by Miller (1991) have not been witnessed while using hobby models. Male and female students choose equally difficult models and produce equally sophisticated illustrations.

Hobby models, like that shown in Figure 1, pose a possible solution to the problem of constructing technical illustration models from traditional engineering drawings. By starting with a tactile model, some of the overhead of learning to read 2D engineering drawings is bypassed. The parts don't have to be visualized; they can be handled and viewed. The model can be test assembled, further strengthening an understanding of part relationships. Students may discover creative strategies such as sawing a fuselage into cross sections, tracing

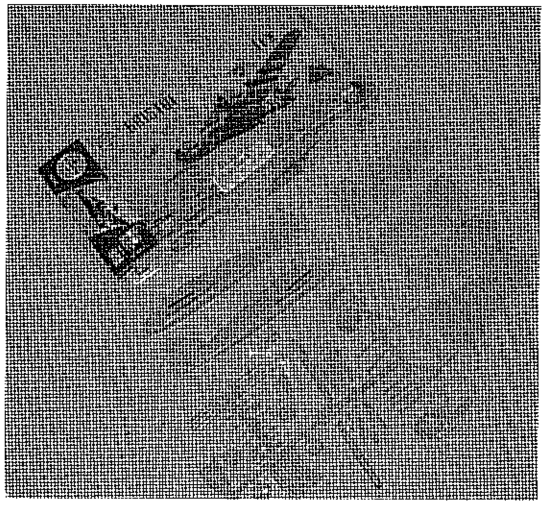

Figure 1 A typical aircraft model that students might choose for a technical illustration assignment.

those sections, scanning, and then over drawing for creating nubs profiles. Sketching can be promoted as a way of understanding part geometry and modeling strategies.

By de-emphasizing engineering drawing reading skills, how modeling strategies are executed becomes a significant intellectual activity in technical illustration. Additionally, using hobby models yields the following additional benefits:

- Students choose the subject of their modeling and illustration activity. This may give them a greater investment in a successful outcome over being assigned a part.

- Model kits are available in a range of complexity and at a cost of less than $5.00. Kits include cars, trucks, planes, trains, military hardware, ships, and buildings so the range of possible subjects is almost limitless. If a "theme" is chosen (such as a construction site) students can work as team members on components of a larger illustration.

- The kits give students professional illustrations to emulate. Descriptive illustrations on the package can be used to guide both modeling and materials mapping.

- Many kits include pictorial assembly instructions that can be used to further understand model geometry.

Modeling Strategies

Using hobby models promotes learning varied modeling approaches. A variety of modeling strategies must be entertained because aircraft, ships, construction equipment, automobiles, and military equipment are comprised of varied and complex parts. Where simple industrial parts (often the typical technical illustration assignment) can be modeled using extrusions, sweeps, and lofts, hobby model subjects may require complex nurbs surfaces and compound shapes formed by multiple Boolean operations.

A Typical Part

Choosing an appropriate kit may pose a problem for some students and it may be beneficial for the teacher to have an example to show the class before students select their own subject.

Models are available at a number of scales (1:24, 1:32, 1:72). Of course the larger the scale, the greater the detail captured in the parts. However, larger scale models are often cost-prohibitive. Though at an acceptable price, some smaller parts at 1:72 scale may be diffi-

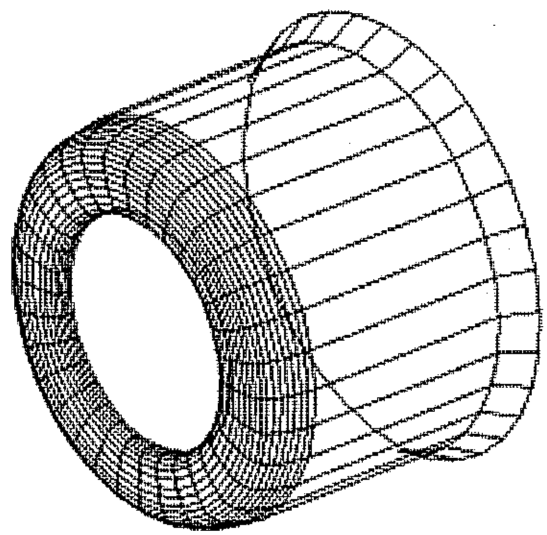

Figure 2 *The swept (lathed) engine nacel.*

cult to model. Figure 2 shows the engine nacel, one of the smaller parts, as a swept profile. The cover illustration shown in Figure 1 can be used to better understand both geometry and materials. Armed with this information, a student should be able to model and map an accurate representation of the part.

Technical illustrations in the past were largely black line drawings because most technical documents that used them (parts books, training manuals, assembly manuals, etc.) were reproduced in black and white with few, if any, photographic halftones. Today, technical illustrations may find their way into Intra- or Internet training courses or onto CD-ROM materials where color carries no cost overhead. For this reason, technical illustrations should be produced with the highest level of realism—something that is natural for 3D modeling and rendering applications.

The following figures show the illustration process as applied to the model in Figure 1. Figure 3 displays a raster material map that represents basic nacel (the part surrounding the front of the engine) materials and paint scheme (left). And the result of applying that material using cylindrical mapping coordinates (right). A small amount of surface reflection has also been applied to produce a soft metallic appearance.

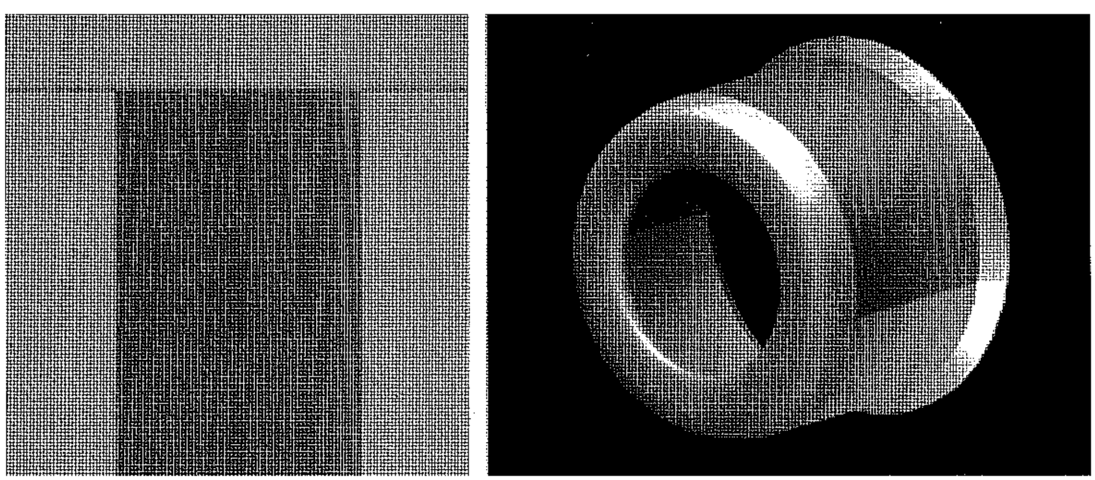

Figure 3 *A material map and the nacel with the map applied.*

If this representation is not realistic enough, additional material representation can be added. Figure 4 shows three maps: a more realistic material map that includes joints, splatters, and streaks (left), a bump map that distresses the part so that it appears to be used (center), and a transparency map that forms the triangular notches in the rear of the nacel (right). Notice that the notches between the rear sections of the nacel were not modeled into the geometry in Figure 2. This reliance on material maps to show detail reduces the complexity of model geometry and is a valuable illustration lesson. When a transparency map is applied to coincide with the material and bump maps the final result, shown in Figure 5, is a dimensionally accurate and visually representative piece that can become part of a final illustration.

Of course, the nacel is only one of many parts that make up the airplane. The general illustration strategy is to model the geometry first, assigning default materials before developing materials maps. This can be problematic when some modeling decisions—like the notches—need to be made while considering material mapping. Because of this, modeling and mapping must be considered together. When the nacel model is merged with the rest of the airplane geometry the result can be a stunning illustration (Figure 6).

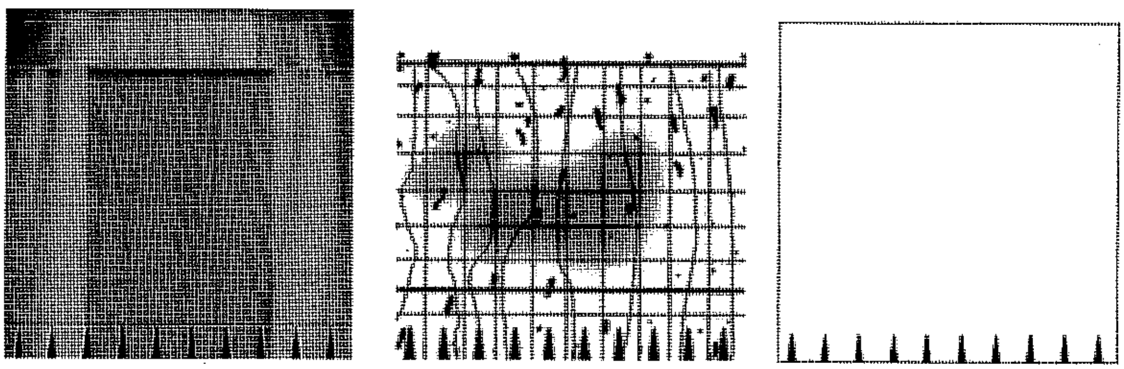

Figure 4 *More sophisticated material maps showing soiling, distress, and transparency.*

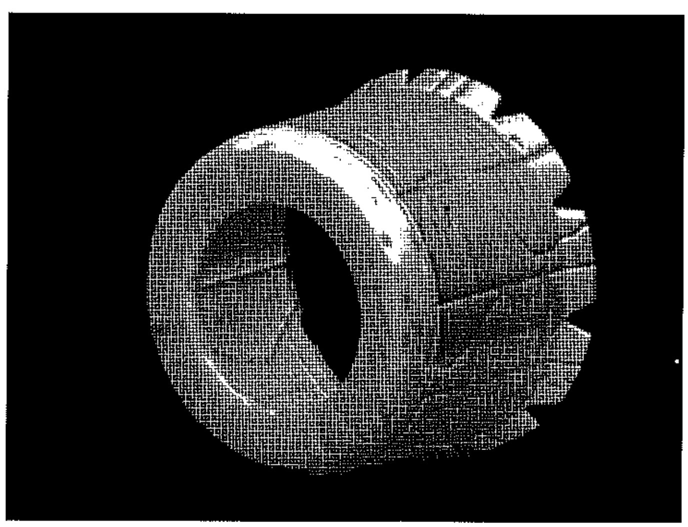

Figure 5 *Nacel after material, bump, and transparency maps have been applied.*

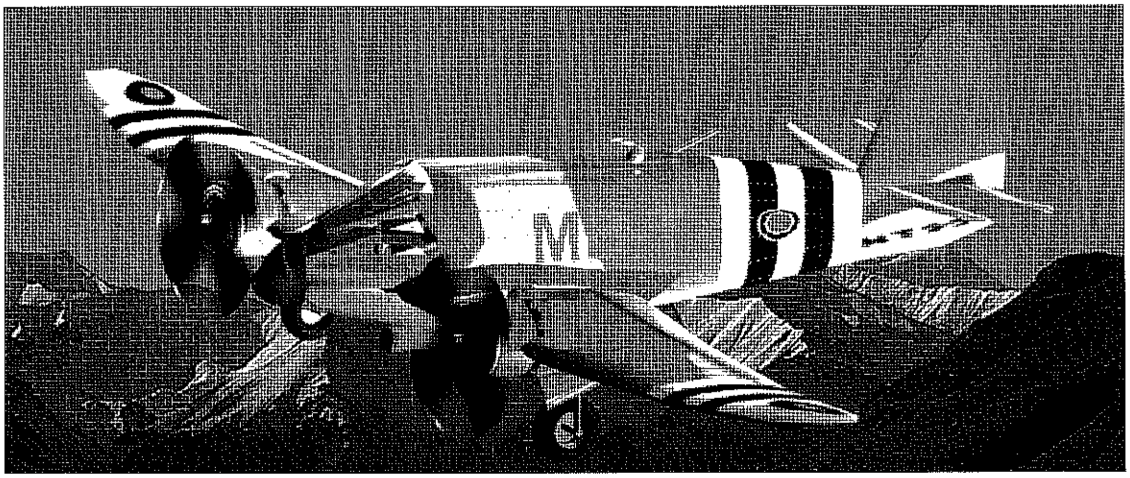

Figure 6 The final illustration with engine nacel in place.

Student Solutions

After becoming familiar with the panoply of available modeling techniques through small focused exercises, students select a subject from a local hobby store. In consultation with the instructor, modeling strategies are entertained with an emphasis on using the simplest modeling approach needed to accurately describe the part. (Students, once they understand nurbs, will want to use this technique for almost every part, even when a slightly edited primitive is preferable.) Students sketch each part, notating sizes and proportions. The final illustration (Figure 6) shows the level of modeling and materials mapping necessary to achieve an effective technical illustration. Students are able to accomplish surprising results, completing the modeling and materials mapping of a typical 1:72 model in the final four weeks of a 16-week semester. Figure 7 displays a number of student illustrations.

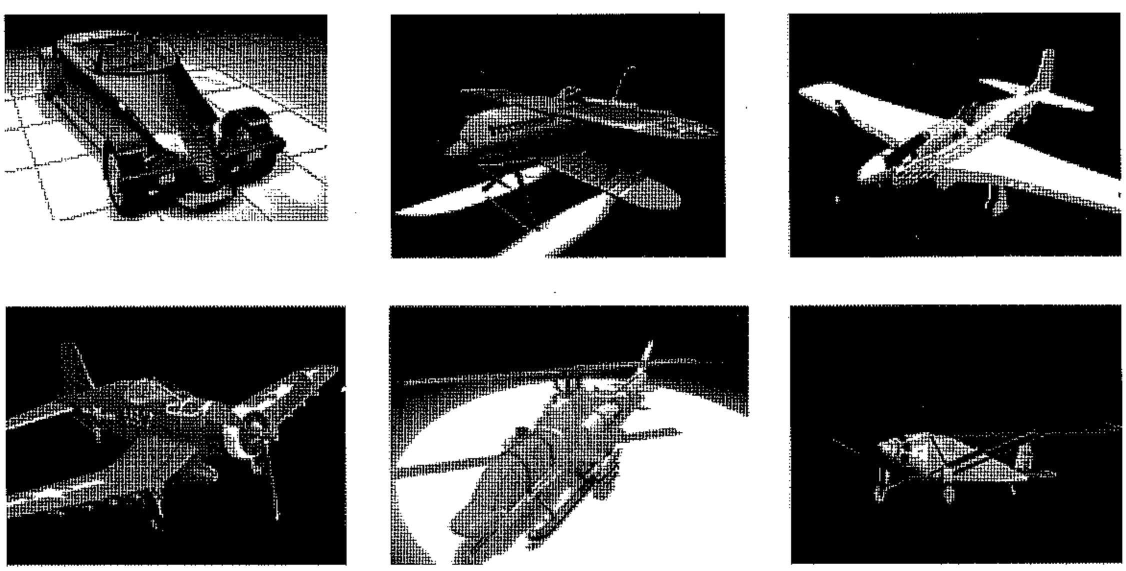

Figure 7 Typical student illustrations made by modeling and mapping inexpensive hobby models.

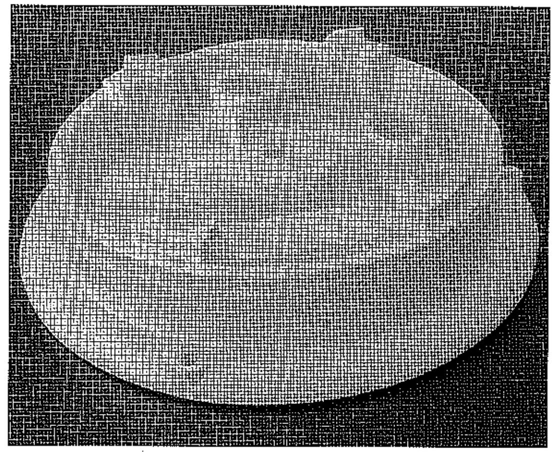

Figure 3 *Prototype of automotive flasher base*

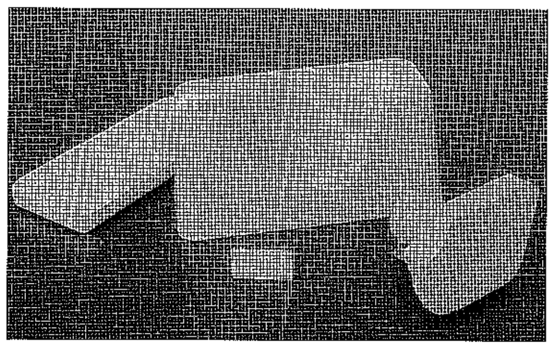

Figure 4 *Prototype parts left to right: base, body, blade, and tape roll support*

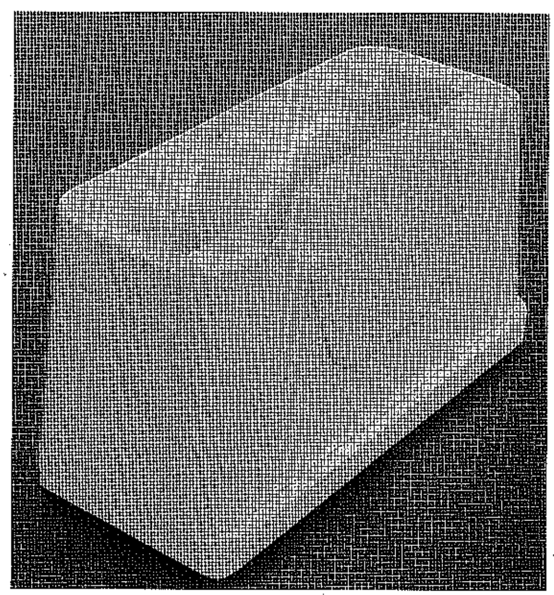

Figure 5 *Prototype tape dispenser, assembled with tape roll*

width matched this value, but the slot width was just 1.0 inch. Again, the errant dimension was in the stacking direction. The effect of these discrepancies is illustrated in the assembly of Figure 5 with an actual tape roll inserted. The tape roll support fits into the body since the stacking axes for both parts are aligned. However, the stacking axes of the base and body are not aligned when these pieces are assembled, and thus, they do not fit together properly. The same is true for blade and body.

The lesson is that when anticipating either assembling parts or fitting pieces of a part together, plan ahead so that the stacking axes will align. If this is not feasible then an alternate scheme is necessary. Unfortunately, The JP System 5 software will not scale along individual axes, it only scales uniformly along all axes (Anderson, 1998). One scheme is to change the software-material thickness value to a smaller value so extra slices are added to the model. For instance, the default software setting for standard paper thickness is 0.0054 inches. In a study at UT at Austin, eleven models were constructed of standard paper with slice thickness reset to 0.0050 inches. The resulting stack dimensions were very close to design dimensions. Because there is some variance in thickness due to compressibility there may be slight differences in height dimensions.

Reducing Wastage

The number of slices placed on a construction sheet is dependent on the largest cross section in the model. The system cannot automatically accommodate a portion of a model that is dramatically smaller in order to conserve the amount of paper used. Two examples shown in Figure 6 are used to illustrate this situation. The model on the left is of a die shoe and on the right is a valve seat. Sliced as complete models the die shoe would require 633 sheets and the valve seat 682. At a cost of about 10 cents per sheet the cost of each prototype would be over $60. As an alternative, each model was divided into two separate pieces where the cross sections dramatically change size. The author then built these pieces separately, those with small cross sections having multiple sub-sections per sheet. Figure 7 illustrates this technique. Here, the upper portion of the valve seat, previously requiring 405 sheets, required only 34 sheets having 12 sections. With this procedure, the die shoe required only 276 sheets and valve seat 311. In each case the cost of each prototype was less that half of the original cost (Krueger, 1999).

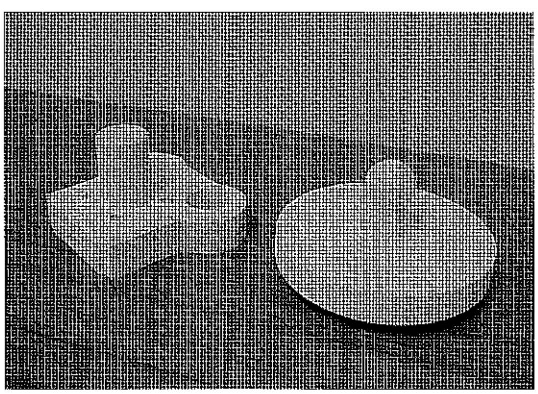

Figure 6 *Prototypes parts with dramatic change in cross section*

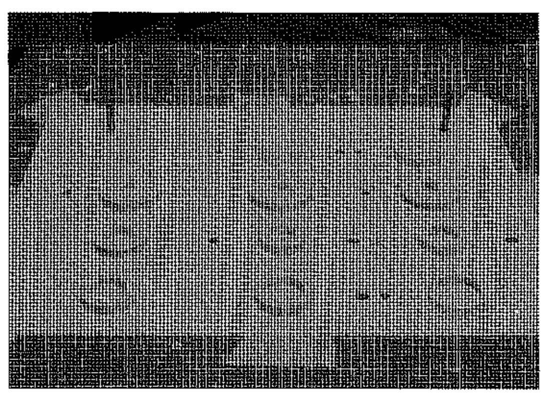

Figure 7 *Sections of upper portion of valve seat on registration board*

Recommendations for Effective Utilization of JP System 5

Introduction to Rapid Prototyping

Introduce students to the various commercial rapid-prototyping technologies. They are encouraged to know that the rate at which they can produce a finished product using the JP System 5 is of the same order as commercial systems.

Training Sequence

Establish a training sequence that contains the following learning modules:

- Introduce rapid prototyping technologies.
- Present basic concepts of JP System 5.
- Create and check a slice file in the computer.
- Cover steps to construct a simple model.
- Construct a simple model (Refer to Figure 1.)
- Discuss models requiring inversions and slice enclosures.
- Construct a model requiring inversions and slice enclosures. (Refer to Figure 2.)

In approximately ten hours of class time students learn to proceed with autonomy. Either students can purchase copies of the textbooks that come with the JP System 5 or instructors can develop their own materials. For example, instructors at University of Texas at Austin incorporated these materials as part of their EDG textbook (Barr, 2000).

Students and Resources

The following strategy has proven effective for making efficient use of available resources in the classroom throughout a training sequence:

- Have not more than two students per computer creating slice files.
- Have not more than two teams per sign plotter creating slices construction sheets.
- Have a registration board for each team to stack sheets and sections.
- Have not more than four students per team in order to avoid "idle hands".

Creating STL Files

Use as fine a triangulation as possible in creating the STL files consistent with amount of computer time available. Finer triangulation will result in more authentic curved surfaces.

Build (Stacking) Direction Orientation

Orient STL file within slicing software to satisfy as many of the following factors as possible:

- Model will stack up starting on a large, flat base.
- Important dimensions (for accuracy) are perpendicular to build direction.
- Axes of cylindrical features are parallel to build direction.
- Build direction coincides with build direction of mating parts if assembling.

Model Scale

In general, although construction takes longer, larger models are more satisfactory: there are fewer sections, which do not stack as accurately as slices, and small features show up better. Features should not have a thickness less than 1/8-inch. Do not expect thin columns to stack up satisfactorily.

Subpart Strategy

Encourage students to evaluate whether dividing a part into subparts is likely to result in more stable build platforms yielding better constructions. This situation occurs when the top and bottom surfaces of a model have a relatively small footprint. Often, sectioning through the part can create much larger footprints.

Inverted Build Strategy

Encourage students to evaluate whether inverting sections and subparts is likely to result in more stable build platforms yielding better constructions. Parts and subparts are built top-to-bottom, and sections are built bottom-to-top; this scheme is embedded and cannot be altered. So always adopt a technique whereby smaller is stacked upon larger.

Wasted Paper Reduction

Encourage students to divide parts having an abrupt, dramatic change in cross section into two pieces at this location. Building such a part in separate pieces and then rejoining them reduces slicing time, assembly time, cost, and paper.

Slice Enclosures

In general enclosing every slice on every sheet and then removing all these enclosures prior to stacking the sheets reduces the possibility of slices or portions of slices remaining with backing material during the stacking process. Here the adage, "An ounce of prevention is worth a pound of cure", applies nicely.

Protective Coating

Instructions with the JP System 5 tell users to apply a spray adhesive to coat the first sheet. Use of spray necessitates ventilation. As an alternative, the authors have had success using a clear glue stick. This glue sets up quickly so the second sheet must be completely prepared to press in place once the glue has been applied.

Clean Up Patrol

A model build generates piles of waste paper and chad, many with adhesive exposed. Give each team a waste paper basket and assign the additional task of cleaning up as they go along.

Strengths of the JP System 5

1. The JP System 5 is an inexpensive means to introduce rapid prototyping compared to industrial systems. For example, the Genisys 3D office printer offered by Stratasys that has a 12x8x8 inch build envelope sells at an educational pricing of $37K. In contrast, Schroff Development Corporation sells the latest version JP System 5 to educators for $8000 equipped with a Graphtec plotter using sheets of 17x22 inches. It is reputed to be four times as fast as previously employed Roland plotters. Apparently, there are Graphtec plotter drivers compatible with the Windows NT operating system. This was not so with Roland plotters.
2. Prototypes produced by this system are safe to handle and (relatively) inexpensive to produce. It has also been easy to maintain. Using Roland plotters only knife blades and platen knife-cutting protectors have needed occasional replacement.
3. The learning process is simple and straightforward. Use of this system can be readily integrated into existing freshmen and sophomore EDG courses.
4. Students acquire tactile models they can use to study and evaluate form (shape) of objects in addition to strictly visual representation supplied by virtual images.
5. Students become familiar by direct experience with issues common to prototyping:
   - Effect of STL file triangulation on curved surface fidelity,
   - Effect of stair stepping on surface texture,
   - Dimensional inaccuracy in the build direction,
   - Choice of scaling on the level of detail obtainable,
   - Need to support cantilevered portions of model.
6. Students experience "hands on" learning wherein they come to appreciate successful application of technology requires strategic thinking and conscientious effort.

Limitations of JP System 5

1. The software slicing routine is inefficient. Geometrically complex models with fine triangulation are liable to take hours to slice.
2. Unlike typical rapid prototyping systems, this one is material subtractive. There is significant waste of paper, and attendent cleanup, in model construction. Additionally, registration chad is likely to have exposed adhesive and will thus adhere to any surface it contacts.
3. The system does not compensate for dramatic changes in cross section size. Unless the user divides the model into separate pieces this contributes to significantly more paper wastage than would be normally expected.
4. It is not possible to register sections one to another as accurately as it is to register slices in building up sections. This results in less visual satisfying models and, of course, less accuracy.
5. Application of the water-based glue, although an excellent preservative, often has a visible warping effect from moisture absorbing into the paper model. However,

several very light coats of glue with adequate drying time between applications minimizes this warping effect.

6. Dimensional discrepancy in model build direction using standard paper is apparent. Finished model height can be expected to measure several percent less than what it is supposed to be unless measures are taken to correct this in the software. Changing the default setting of the material thickness from 0.0054 to 0.0050 eliminates this problem.
7. Inaccuracy in shape and dimensions limits capability of this prototyping technique to check parts for proper fit and functionality.

Conclusions

- JP System 5 has demonstrated its applicability as a cost-effective method for illustrating to students how Engineering Design Graphics, solid modeling in particular, can extend further on into the product development process.
- This is a "hands on" learning device that allows every student the opportunity to take ownership in creating physical models for assisting in visualization of form and tactile examination. Pedagogical advantages outweigh its technological limitations.
- We recommend this system as a starting point to extend virtual modeling into the realm of physical modeling, rapid prototyping. Even if an institution has access to a fully automated commercial system, there is merit in having freshmen and sophomores begin with the JP System 5.

Acknowledgement

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Windows NT is trademark of Microsoft, Inc.

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Creating a Strong Foundation with Engineering Design Graphics

Jeffrey L. Newcomer, Eric K. McKell, & Robert A. Raudebaugh
Western Washington University

David S. Kelley
Purdue University

Abstract

This paper describes the two-course Engineering Design Graphics Sequence in the Engineering Technology Department at Western Washington University. These courses teach introductory design and graphics topics to incoming students They also begin the development of student skills in the areas of visual communication, project management, creative problem solving, and teamwork, all of which are student learning objectives for the Engineering Technology Department, and provide a foundation for a concurrent engineering approach to design. Engineering Design Graphics I is aimed at conceptual design and the development of visualization and sketching skills, while Engineering Design Graphics II concentrates on detail design and parametric modeling. Throughout these courses students complete several individual and team design projects. In addition to the course descriptions, this paper reviews the results and feedback the Engineering Technology Department has received on these courses.

Introduction

Everyone in the field of engineering and engineering technology education has been affected by the push for outcomes assessment caused by EC2000 and the proposed TAC/ABET criteria. In order to achieve desired student learning outcomes by the time students complete their capstone experience, a program needs to begin with a firm foundation. In many programs, a course or courses in Engineering Design Graphics is where students receive their first exposure to their chosen field, and where the foundations of meeting the student learning outcomes are laid. This is the case in the Engineering Technology (ETec) Department at Western Washington University (WWU).

The ETec Department has approximately 425 students in six different majors: Electronics (EET), Manufacturing (MET), and Plastics (PET) Engineering Technologies, Industrial Design (ID), Industrial Technology (IT), and Technology Education (TechEd). In addition, the Industrial Technology program supports options in Vehicle Design, Industrial Graphics, and Industrial Supervision, as well as a Self-Designed option. The six programs in the ETec Department are currently taught by thirteen full-time and six part-time or limited term faculty with backgrounds ranging from Engineering to Art.

All students in the ETec Department take Engineering Design Graphics I as their first course in the Department, and students in the MET, PET, ID, and IT majors take a second course, Engineering Design Graphics II, as well. Along with the obvious missions of introducing students to CAD and Engineering Design, these courses are used to provide students with an introduction to concurrent engineering principles, as well as a number of the ETec Department student learning objectives such as project management and teamwork. This paper briefly describes the ETec Department student learning objectives, and then proceeds to discuss both Engineering Design Graphics I and II in some detail, including student feedback received.

Student Learning Outcomes

Although the initial planning for the curricula in the Engineering Design Graphics sequences slightly predates ETec Department outcomes assessment efforts, both courses have been strongly influenced by outcomes assessment work in the ETec Department during the last two years. Therefore, a brief description of the ETec Department assessment goals is necessary before describing the two courses. As part of the outcomes assessment efforts (Newcomer, 2000), faculty in the ETec Department developed a list of desired student learning outcomes for all graduates regardless of their major. Table 1 gives the learning objectives along with a description of each one. To develop these student learning outcomes, a number of resources were consulted, including publications (McGourty et al., 1998; ASEE, 1998; McGourty, 1999), web sites of NSF sponsored coalitions (Foundation, 1998; Gateway, 1998; Synthesis, 1998), SME reports (SME, 1997; SME, 1999), and ABET criteria (ABET, 1999a; ABET, 1999b), along with drawing from the diverse backgrounds of faculty within the ETec Department.

The Engineering Design Graphics sequence is designed to introduce students to fundamental skills in the areas of Visual Communication, Creative Problem Solving, Project Management, Teamwork, and Self-Learning skills.

Analytical Skills	Visual Communication Skills
Ability to: logically analyze and solve problems from different points of view; translate scientific and mathematical theory into practical applications using appropriate techniques and technology.	Ability to: utilize appropriate technology to create drawings, illustrations, models, computer animations, or tables to clearly convey information; interpret and use similar information created by others.
Oral Communication Skills	**Written Communication Skills**
Ability to: verbally present ideas in a clear, concise manner; plan and deliver presentations; speak and listen effectively in discussions based upon prior work or knowledge.	Ability to: present ideas in clear, concise, well-structured prose; choose appropriate style, form, and content to suit audience; utilize data and other information to support an argument.
Creative Problem Solving	**Business Skills**
Ability to: apply a design process to solve open-ended problems; generate new ideas and develop multiple potential solutions; challenge traditional approaches and solutions.	Ability to: accurately estimate production costs; calculate the cost effects of alternative designs; predict the effects of quality control, marketing, and finance on product or process cost.
Ethics and Professionalism	**Teamwork Skills**
Ability to: understand and demonstrate professional and ethical behavior; understand social and ethical implications and interrelations of work, and respond in a responsible and professional manner.	Ability to: work together to set and meet team goals; encourage participation among all team members; listen and cooperate; share information and help reconcile differences of opinion when they occur.
Project Management	**Programming Skills**
Ability to: set goals; create action plans and timetables; prioritize tasks; meet project milestones; complete assigned work; seek clarification of task requirements and take corrective action based upon feedback from others.	Ability to: use higher level, structured programming languages to write effective and efficient code to complete a task such as modeling or calculation, or control equipment; understand and adapt existing structured programs.
System Thinking Skills	**Self-learning Skills**
Ability to: understand how events interrelate; synthesize new information with knowledge from previous courses and experiences.	Ability to: learn independently; continuously seek to acquire new knowledge; acquire relevant knowledge to solve problems.

***Table 1** Department Student Learning Objectives - Desired Student Skills*

In addition to addressing student learning objectives, the Engineering Design Graphics sequence is intended to develop a concurrent and integrated engineering environment in the ETec Department. Much of the development work of these courses and most of the equipment used in the Engineering Design Graphics Laboratory was accomplished and acquired respectively with the support of The Boeing Company (McKell et al., 2000). The Boeing Company provided a three year grant that allowed for the purchase of new computers, solid modeling software, and rapid prototyping equipment, and also provided consultations and feedback on curricular content. The goal in working with The Boeing Company has been to link the computer graphics to concurrent engineering in much the same manner as the model proposed by Barr and Juricic (1996), which is shown in Figure 1. Between the two courses in the sequence, students are introduced to many of the topics in this model. The first course in the sequence covers topics such as sketching, conceptual design, and solid modeling, while the second expands upon the solid modeling and adds assembly modeling, rapid prototyping, and documentation. Metaphorically, the former concentrates more on creative writing, while the latter has its emphasis in grammar. This paper describes both courses in the sections that follow, including giving results and feedback received.

Engineering Design Graphics I

The WWU approach to Engineering Design Graphics, which is based upon one developed by Barr and Juricic (1991; 1992), is that engineering graphics contributes to the design process in three levels: ideation drawings, communication drawings, and documentation drawings. Ideation drawings are generally sketches done early in the design process to begin the development of design ideas. Communication drawings are used to share ideas with everyone from design team members to customers, and range from those used to continue design development to those that are used in formal design presentations and advertisements. Documentation drawings are traditional engineering drawings that contain the information that is required to build parts in the design and complete the assembly. Documentation drawings are now almost exclusively done on computers, but ideation drawings and many communication drawings are still drawn by hand, sometimes on the nearest blank sheet or flat surface. Engineering Design Graphics I concentrates on developing ideation sketching skills and communication drawings, with only a cursory description of documentation drawings, while Engineering Design Graphics II is centered on the development of a complete set of documentation drawings.

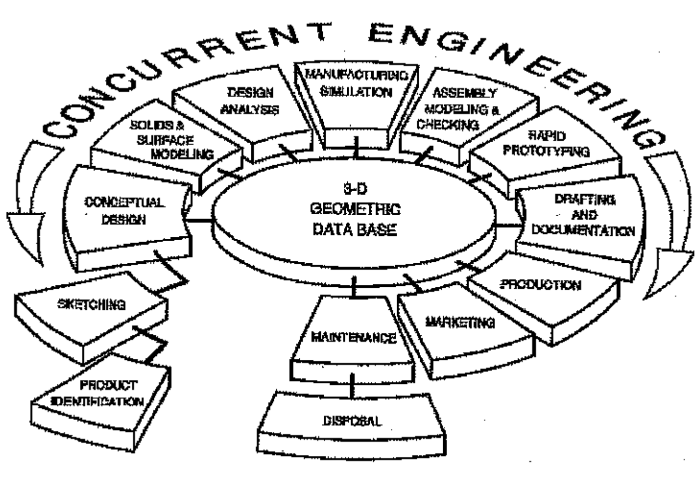

Figure 1 *3D Geometric Models and Concurrent Engineering (Barr and Juricic, 1996)*

The Engineering Design Graphics I (EDG I) course is an introduction to conceptual design, including the design process and tools for design communication such as sketching and basic solid modeling. The stated goals of EDG I are:

- To develop the necessary visualization and freehand drawing/sketching skills which will enable students of design (engineering, industrial, architectural, etc.) to express graphically a rapid succession of ideas in seeking the solution to a specific design problem.
- To develop initial CADD (Computer-Aided Design and Drafting) skills and the understanding of the concepts associated with 3-D solid modeling as part of the design process.

In addition, EDG I addresses the development of students' visual communication skills, project management skills, creative problem solving ability, and self-learning skills. The intention is to provide students with the background to become designers rather than drafters. A major aspect of this effort is the development of visualization skills.

The exact nature of visualization skills and the best way to develop them is still an open question (Sorby, 1999), but in a three dimensional world, it is clear that two dimensional, orthographic projection drawings are not the most effective approach (Bowers, 1993; Devon et al., 1994; Leach & Matthews, 1992; Miller & Bertoline, 1991; Miller, 1992). As a working definition, the ETec Department defines visualization as the ability to take an idea from ones mind, and model it on a medium such as on paper or within a CAD system (Kelley et al., 2000), and the ability to comprehend someone else's model.

In order to teach students to confidently create ideation sketches that actually resemble real objects, EDG I faculty utilize techniques that are often found in beginning drawing classes in art. For the first half of EDG I, students use techniques such as contour, modified contour, gesture, and negative space drawings to help develop their visualization skills (Edwards, 1979; Raudebaugh, 1999). It is somewhat strange to see students in an engineering graphics class drawing pictures of flowers and bookbags, but the approach is effective. The advantage of these art-based methods is that they encourage students to concentrate on drawing what they see rather than their stored mental image of an object. For example, many people have difficulty accurately drawing something as simple as a table. This is because they know in their mind that all of the legs are the same length, yet if a table is drawn with all of the legs equal in length it will have improper perspective. This practice helps students to see and visualize more accurately, and it also gives them more confidence in their drawing abilities.

Along with improving student visualization skills, art-based drawing techniques improve student sketching skills. Freehand sketching seems to be rarely taught in engineering graphics today, but it is still an extremely useful, some would say necessary skill for engineering design. In the middle of the term, students are then taught techniques such as iteration drawings, and asked to sketch their design ideas for their assignments before they create drawings on the computer. Once again, the goal of this is not to make the students into artists, but to help them develop the skills to quickly and clearly sketch their ideas on paper for the purposes of both their own clarification and communication with other members of a design team. This approach is effective; it also is not unheard of in engineering graphics (Bowers, 1986; Weibe, 1992). In fact, the results of using an art-based approach have been positive, so it is somewhat surprising that this approach is not used more often.

Course Description

The EDG I course described herein was first taught as a pilot course during the 1997-98 academic year, and was adopted as the standard model for the course in fall 1998 (Newcomer et al., 1999). Prior to this, EDG I was best described as an introduction to AutoCAD®. The structure of EDG I is centered around open-ended design projects completed by individual students. Each student completes at least two design projects during the course. At the beginning of the class students are taught a design process with the following 5 step structure:

1. State the Problem
2. Develop Design Specifications
3. Develop Design Concepts
4. Select a Design Concept (based upon Specifications)
5. Develop and Document the Design Details

While this is a simplified approach to design, it nevertheless presents the most important steps of a conceptual design process, and gives students a methodology to use while completing their design projects. Having a structured approach to design is important at this level, as students will commonly choose to develop their first idea instead of considering alternatives. The design process is also used to teach students the fundamentals of project management. For their first project, students are asked to solve a storage problem of some kind. The exact project details vary depending upon the instructor, as some allow a wider range of projects than others, but the basic concept is the same. Students are asked to first develop a problem statement and then a set of specifications. Faculty set the intermediate deadlines and milestones as part of the project management instruction. Figure 2 shows an example of a solution to a student storage project. In this case the student needed to better organize a computer desk, including storing compact disks and papers, while also providing a more ergonomic location for the computer monitor.

The other aspects of the course - visualization, freehand sketching, and introductory CAD modeling - are organized in support of the design project structure. During the first four weeks students practice the aforementioned art-based drawing techniques to improve their sketching and visualization skills. Along with this, students also learn some basic computer-based solid modeling techniques such as extrude and revolve. Rhinoceros® (Rhino) currently is the primary CAD package in EDG I. Rhino is a non-parametric conceptual modeling package that is very intuitive.

In the fifth week of the quarter freehand sketching and computer drawing topics converge, with iteration drawing techniques, axonometric drawings, and shading in sketching, and modeling using solids on the computer. This is also when students are starting to develop concepts for their design projects, so they begin to get a chance to use their sketching techniques for drawing their ideas instead of random objects.

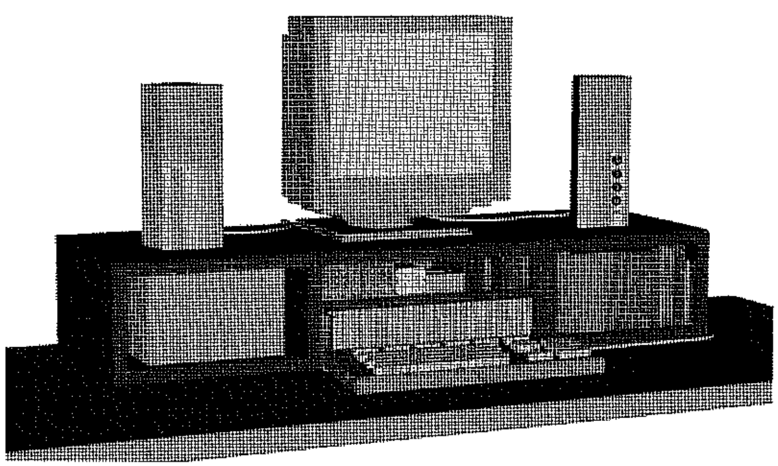

Figure 2 *A Student-Designed Storage Problem Solution*

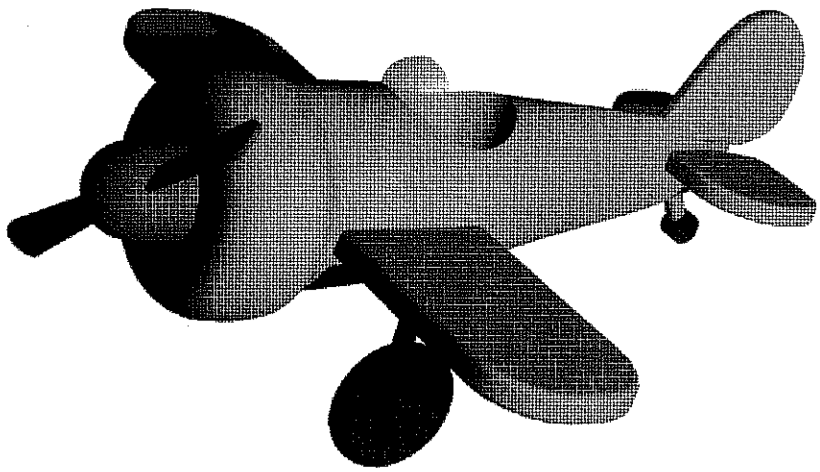

Figure 3 *A Student Designed Toy*

The second half of the course drifts into more traditional engineering graphics topics by introducing orthogonal views, section and auxiliary views, the basics of dimensioning, and assembly drawings. Topics are covered in time to allow students to practice them and get some feedback before they have to apply them to their design projects. Meanwhile students are introduced to surface construction techniques on Rhino, and also asked to develop a handful of computer models of their own design. Common creative computer assignments are 2-D and 3-D logos, and student designed toys. These projects help students develop both their drawing and computer skills, and their self-learning skills, as they are asked to sketch several design ideas and then select one to model on the computer. After they have selected a design they must figure out how to create it based upon what they have learned about the software. Figure 3 shows an example of a student-designed toy.

Currently EDG I also introduces a second computer package to allow students to create dimensioned drawings. EDG I has primarily used IntelliCAD® for this purpose, although some faculty have also experimented with IronCAD®. While it is inconvenient to introduce the second package during a short academic term, it reminds students that they are learning techniques, not how to be an expert in a specific software package. Rapid prototyping was also added to EDG I in the fall 1999 term. Students have one of their logo designs built on a Stratasys Genisys 3-D printer. Mostly this introduces students to the technology, although faculty believe that the process of going from sketch to computer model to rapid prototype also improves their visualization skills.

The course culminates in a final project in which students are required to follow the same process they followed for their storage problem design. Recently students have been designing a flashlight as their final project. This is less open-ended than the storage design problem, but still allows students to state their own problem and develop their own design specifications. Students are required to document their design process, including ideation sketching, and create assembled and exploded view computer models, and a dimensioned drawing of the overall design. In addition students write a brief description of their design. Students are not required to create complete part drawings, although some do.

Figure 4 shows the ideation sketches for a student flashlight design, and Figures 5 and 6 show the computer model of the final flashlight design in assembled and exploded views respectively.

Results and Feedback

The ETec Department Graphics Committee created a qualitative exit survey for EDG I and received feedback from 79 students in fall 1998, 109 students in fall 1999, and 51 students in winter 2000 regarding how the course met their expectations, what they felt they gained from the course, and what role they saw visualization and sketching playing in the design process. In general EDG I exceeded student expectations, and the majority of students found that they had learned more and had more fun than they expected they would. The large visualization and freehand drawing aspect of the class also received general approval. Quite a few students expressed appreciation for the role of visualization and freehand drawing in the design process. A few students even expressed surprise at their own ability to draw at the conclusion of the class, although a small number (<5%) of respondents felt that there was too much freehand drawing in the class.

As with the visualization and drawing sections of the class, students had many comments regarding design projects, and all of them were positive. Many students also expressed an appreciation for the role of a design process. Students' understanding of and appreciation for the design process was also evident in the work that they turned in for their projects, some of which were impressive for an introductory course. It is also worth noting that the number of students expressing disappointment at not learning advanced AutoCAD® techniques declined from 6% in fall 1998 to none in winter 2000. This may be due to an overall change in student background and preparation, and hence expectations, to students entering the class with more information about its structure, or due to a combination of these.

Overall the class is very popular and faculty have been pleased with the skills students develop during it. Students who have completed the class have consistently shown that they have both fundamental graphics skills such as sketching and CAD, and in learning objectives such as project management and creative problem solving ability. The final project shows that students have a good grasp of the design process and can use it to complete open-ended problems. Faculty believe that this course provides students with a firm foundation for both EDG II where they directly build upon the skills obtained in EDG I, and for future design classes where they must utilize these skills to help solve a myriad of problems. EDG I is undergoing some revision at this time to introduce a team project. One of the goals for faculty teaching the class is to develop a quantitative assessment method to replace the qualitative survey that has been used in recent years as part of the revision. A pilot survey was formed and tested in EDG II to get clearer feedback on how the team design project in EDG II affects the student learning outcomes. This survey will be expanded to assess a wider range of learning goals, and then adapted to EDG I as well. A description of the survey is included in the next section.

Engineering Design Graphics II

Engineering Design Graphics II (EDG II), which builds upon EDG I, is an introduction to the utilization of high-end parametric modeling applications within the design process. The stated goals of EDG II are:

- To develop the ability to solve engineering design problems utilizing a parametric modeling application.
- To develop the ability to incorporate design intent into parametric part and assembly models.
- To develop the ability to document an engineering design, including tolerance specification.

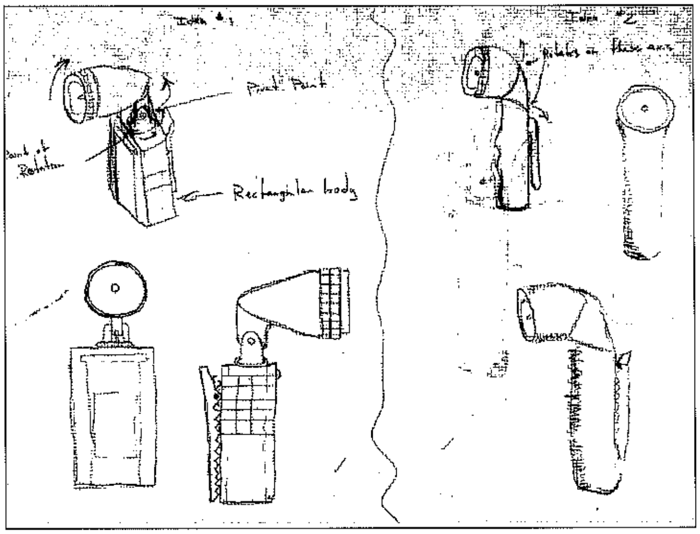

Figure 4 *Ideation Sketches for a Student Flashlight Design*

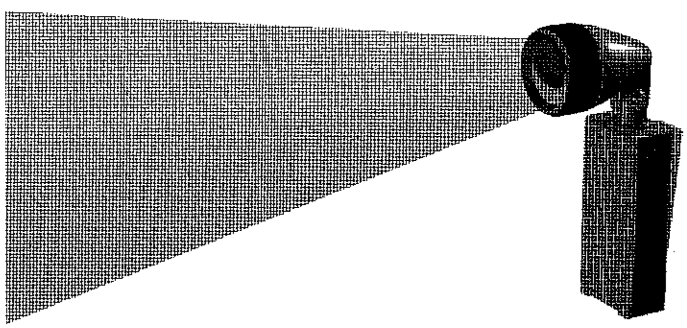

Figure 5 *Computer model of a Student Flashlight Design*

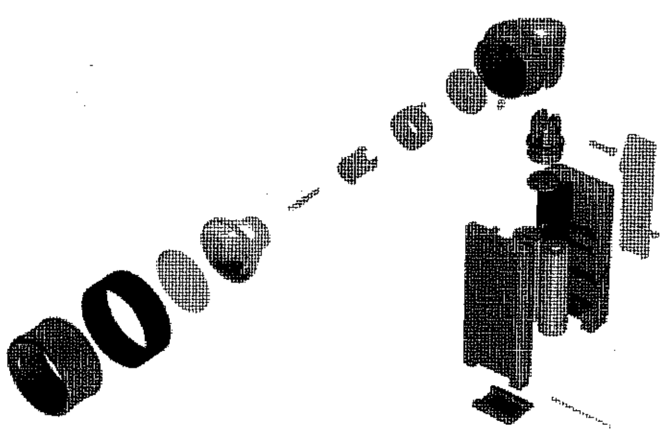

Figure 6 *Exploded view of a Student Flashlight Design*

In addition, EDG II is designed to reinforce the design process and project management skills that students learned in EDG I, while also introducing students to teamwork in the context of an engineering design project.

Course Description

EDG II uses Pro/ENGINEER® (Pro/E) as its primary software package, and I-DEAS® has recently been integrated into the class to provide students with a breadth of software experience. The course was first taught with Pro/E during the Fall 1998 term, and has been evolving to include more aspects of ETec Department student learning goals. Nevertheless, the focus of EDG II is on concurrent engineering and capturing design intent. Parametric modeling and design principles are emphasized to include bottom-up assembly modeling. Students enter EDG II with skills in conceptual CAD modeling, and Pro/E introduces them to an application that is more powerful, but more restricted in its modeling approach. Within this course, students utilize the design process and may use Rhino within the ideation process, but final assembly designs and drawings must be completed in Pro/E. Various modules of Pro/E are used to include Part, Assembly, Drawing, Format, and Manufacturing.

The course begins with an introduction to parametric modeling, followed by basic object and feature creation techniques. In the latter section of EDG II, students are introduced to engineering documentation, including geometric dimensioning and tolerancing, and to basic assembly modeling. The course is taught using a Mastery Learning approach (Newcomer et al., 2000) in which students are given their complete list of assignments at the beginning of the term, and earn their grade based upon the number that are completed without error. Although the format in EDG II is different than EDG I, they are linked together in some areas.

EDG II builds off of the design experiences students gained in EDG I in two manners: students are required to use the same design process, and they design a flashlight. Unlike EDG I, however, students in EDG II work on a design team. Reusing the flashlight project in a team context guarantees that all of the students have some experience with the design. This in turn puts the various members of each design team on roughly equal footing in terms of relevant experience. Students are given instruction in the fundamentals of working on a team, including topics such as team roles and conflict resolution. As part of developing skills to meet overall student learning objectives, each student team determines the exact design problem they will address, develops a set of intermediate deadlines using a Gantt chart for the on-time completion of the project using each step of the design process, and then determines which task each member of the team is responsible for completing. Figure 7 shows an example of a Gantt chart for a student project. In EDG II, student design teams make complete models of their design, including part and assembly drawings. At the end of the project students also build a rapid prototype of pieces that make up the outer portions of their design. Figures 8 and 9 show a bike light designed by a student team in EDG II and an assembly drawing of it respectively.

Results and Feedback

During the 1999-2000 academic year, the ETec Graphics Committee also began to survey students in EDG II. This survey is a modified version of the EDG I survey, with a question on satisfaction with the two course sequence replacing the basic expectations question. Over the course of the year 72 students provided feedback using this form. As with the EDG I survey, the overwhelming majority of students had a positive experience in EDG II. There was general agreement among the students that the more detail-oriented EDG II was more difficult and time consuming, but in many students' opinions more valuable than

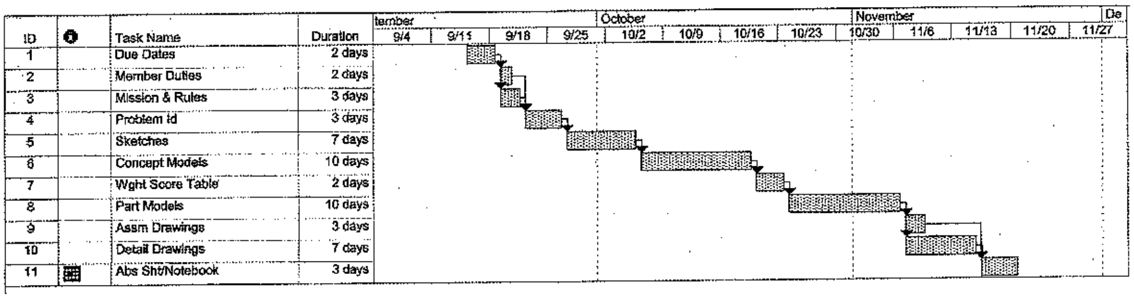

Figure 7 *Gantt Chart for Student Design Project in Engineering Design Graphics II*

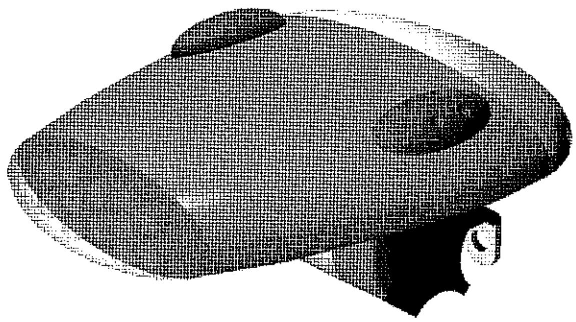

Figure 8 *Team-Design Bike Light*

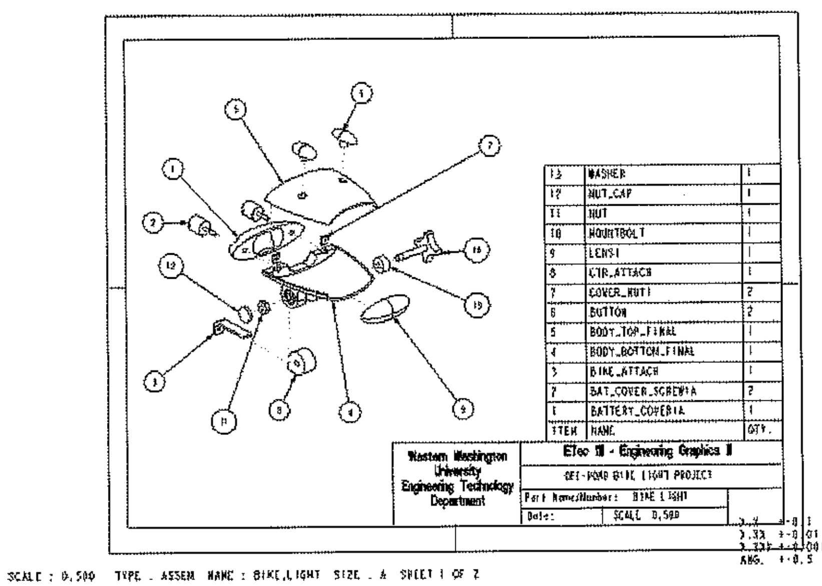

Figure 9 *Exploded View of Team-Designed Bike Light*

EDG I. Nevertheless, many students still commented on how the sketching and design process skills they had developed in EDG I had been very useful during EDG II. The only dichotomy that arose was a roughly fifty-fifty split between the students that felt they spent too much time learning the details of the specific programs (Pro/E and I-DEAS) at the expense of creative design work, and those who believed that they did not spend enough time learning the details of the programs. Overall, however, the survey shows that students are happy with the EDG I and II sequence, and that they are also learning to value the sketching and organization skills along with the CAD skills they all expect to learn in the courses. In addition, students are gaining knowledge and practice in the area of several ETec Department student learning objectives as well.

The team-based design project is the main avenue for addressing the various student learning objectives of the course, and those students that commented on the team project found it to be a very valuable aspect of the class, as well as the part of the class that most resembled a realistic design experience. Students gain their first major teamwork experience, and expand upon the project management and creative problem solving skills they developed in EDG I. An assessment survey was piloted in one section of EDG II during the winter 2001 quarter in order to gain a better understanding of how the design project affects the desired student learning outcomes. The survey asked students to rate their learning gains in eight areas on a five point Likert scale. The eight areas are: project management, teamwork, sketching and ideation, CAD and design documentation, meeting communication, public speaking and presenting, writing, and creative problem solving. The class average ranged from highs of 4.37 and 4.32 for CAD and design documentation, and creative problem solving respectively, and lows of 3.00 and 2.95 for presenting and writing respectively. The remainder of the scores were between 3.72 and 4.05. The results are in line with expectations for the class, and for the most part aligned well with the material emphasis. The highest scores align with topics that received the most class time, and the lowest with tasks that were divided between team members and therefore not completed by all students. The only score that was lower than anticipated was the project management score which should have been at the high end of the middle group based upon class emphasis, but was in fact at the low end. This result, along with the methods of instruction and practice are under review for future revision. In addition to expanding both the scope of questions and the scale of application of the quantitative survey, future plans for both courses include the expansion of the role of design projects and design exercises so that students can spend more of their time and effort extending their skills and less time completing training exercises. This will increase the emphasis on the development of student learning objectives, but should not detract from the coverage of graphics topics, as models and drawings will still be the main final product in the majority of assignments. Students will continue to build upon the foundation they create in EDG I and II as they complete additional design classes throughout the various curricula in the ETec Department.

Conclusion

WWU's Engineering Technology Department considers its engineering design graphics courses to be the main foundation for the Manufacturing and Plastics Engineering Technology, Industrial Technology, and Industrial Design programs. Students majoring in these programs are expected to apply the skills they learn in engineering design graphics in other courses throughout the curriculum. The primary goal of the engineering design graphics curriculum is the development of design skills. Within this goal, specific objectives are the development of visual communication skills, specifically visualization and computer-aided design, as well as providing students with experiences in project management, creative problem solving, and teamwork. Within EDG I, these objectives are met through the use of ideation sketching and conceptual CAD modeling. EDG II reinforces these goals and addresses an additional objective of the graphics curriculum of the capturing of design intent through the use of a parametric modeling application. Within each graphics course, a strong emphasis is placed on the design process. Students are required to identify problems and develop design specifications before developing concepts. Moreover, once they have developed concepts, students are required to justify the selection of one based upon their specifications. Finally, students refine their concepts through sketching, computer modeling and prototyping. Qualitative assessment of the revised engineering design graphics curricula in the ETec Department at WWU shows that the introductory courses are meeting their goals and preparing students well for their future classes.

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Standards Corner

Pat McCuistion
Ohio University

ISO Dimensioning and Tolerancing Standards

ISO standards are considerably different than American standards. Three of the major differences are, 1) cost, 2) length, and 3) scope of the topics. While many of the Y14.5 Dimensioning and Tolerancing Standard members are irritated by the increasing costs of the Y14.5 standard, relative to ISO standards, it is cheap. The Y14.5-1994 standard costs $98.00 while total bill for all the following dimensioning and tolerancing ISO documents is $811.00. When the cost of these standards is compared to the number of pages, it is outrageous! The Y14.5M-1994 Dimensioning and Tolerancing standard has more than 320 pages and over 300 figures. All the listed ISO standards total only 187 pages. Most ISO standards are written generically about very specific topics, whereas the Y14.5 standard covers the entire topic of dimensioning and tolerancing in much more detail. It is clear that American standards are an exceptional value. No wonder they are the most used standards in the world.

The following list of ISO standards are provided for those who want a better understand ISO dimensioning, or you just want know which documents cover what topics. These standards may be ordered from www.iso.ch/iso/en/ISOOnline.frontpage.

The reason ISO standards are so expensive and watered-down is due to the way they are developed. Their meetings are held in the major cities around the world (meeting rooms in major cities are very expensive). Many countries are involved in developing ISO standards, which leads to a much more formal process and long develop times (unless the French are in control – they tend to ram concepts through). It is very difficult to reach agreement on common methods of practice for the world market. This makes ISO standards short (no country wants to over-commit).

There may well be a common world standard for dimensioning and tolerancing some day, but that probably won't happen until there is a common world government. As we all know, there is no resistance to that idea.

No.	Cost	Year	Pages	Title
406	$38	1987	4	Tolerancing for linear and angular dimensions
1101	$98	1983	24	Tolerancing of form, orientation, location and runout; Generalities, definitions, and indications on drawings
1660	$44	1987	5	Dimensioning and tolerancing of profiles
2692-1	$92	1988	5	Maximum material principle
2692-2	$13	1992	6	Least material principle
3040	$44	1990	6	Dimensioning and tolerancing cones
5458	$62	1998	11	Positional tolerancing
5459	$74	1981	16	Datums and datum systems for geometrical tolerances
7083	$56	1983	9	Symbols for geometrical tolerancing; Proportions and dimensions
8015	$44	1985	5	Fundamental tolerancing principle
10578	$44	1992	6	Projected tolerance zone concept
19579	$38	1993	3	Dimensioning and tolerance of non-rigid parts

In addition to the above standards, there is a Technical Report that supports these standards.

5460	$164	1985	71	Geometrical tolerancing; Tolerancing of form, orientation, location, and runout; Verification principles and methods; and Guidelines

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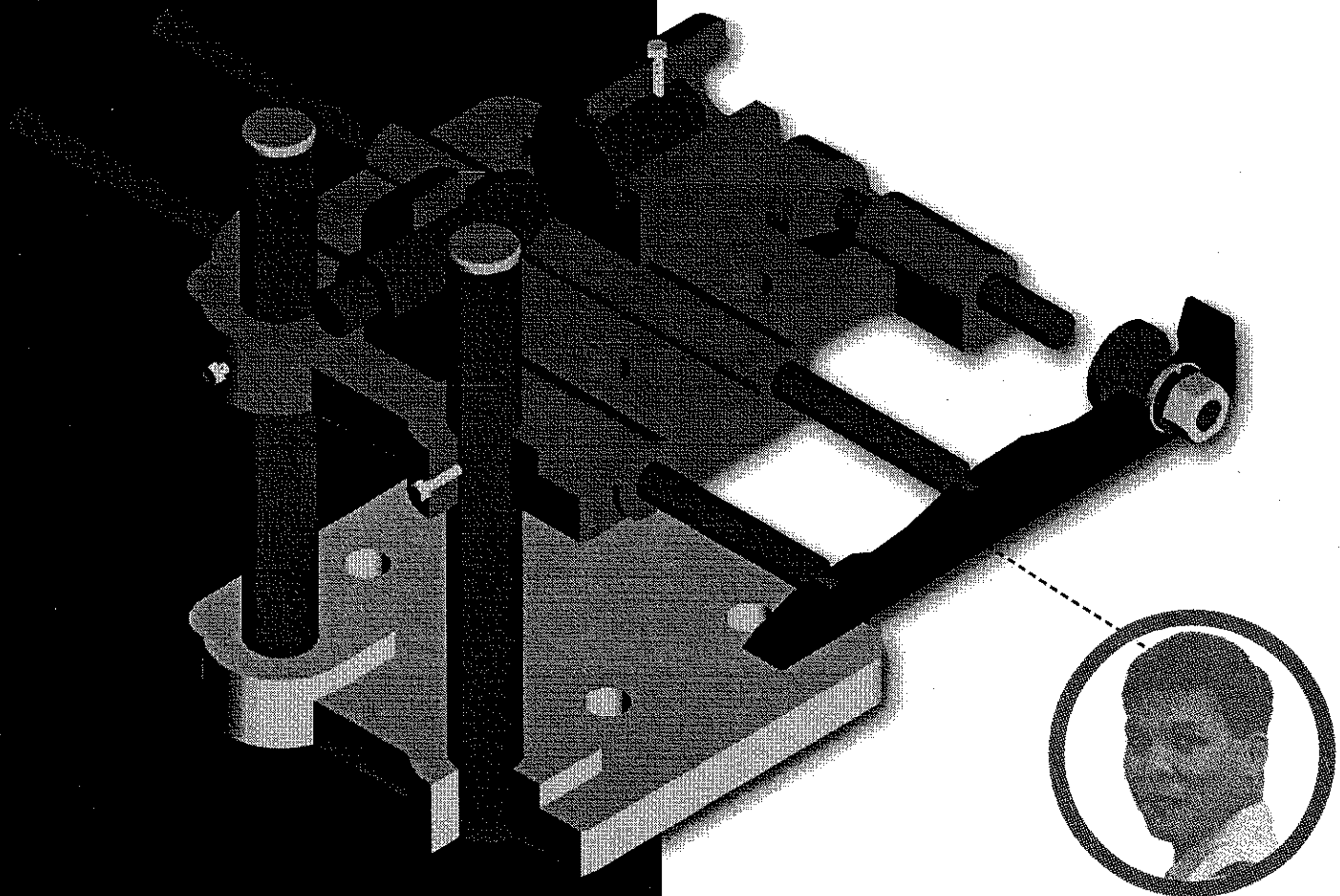

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