Classroom Experiences in an Engineering Design Graphics Course with a CAD/CAM Extension*

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ABSTRACT

This paper reports on the development of a new CAD/CAM laboratory experience for a lower division Engineering Design Graphics (EDG) course. The recent EDG curriculum included freehand sketching, introduction to Computer-Aided Design and Drafting (CADD), and a strong emphasis on 3-D solid modeling. Based on an NSF-sponsored research project, the EDG curriculum paradigm has been extended to include solid model applications to design analysis and prototype manufacturing. Specifically in the analysis lab component, students generate mass properties reports and perform finite element analysis (FEA) of solid models built in previous weeks. In the manufacturing lab, the students build a 3-D solid model and generate an .STL file for exporting to a rapid prototyping (RP) machine. To facilitate use and availability of laboratory resources, the students are divided into four-member teams during the analyses and prototyping exercises. This paper reviews the project and reports on the testing of the new laboratory components which were introduced into a pilot, honors section of EDG during the Fall 1996.

Introduction

In the past, design representation relied heavily on engineering graphics. Engineering drawings were used to convey data for both part analysis and manufacturing. Recently, solid models have been introduced as complete and unambiguous computer descriptions of the part geometry. Having such a formal description available, another computer program or system can directly perform engineering analysis, manufacture the part, and, if needed, generate engineering drawings directly from the solid model data base. Thus, a new design paradigm (Barr & Juricic, 1992) has been established, a paradigm that uses a solid model as the common thread to integrate the design process with engineering analysis and manufacturing. Once universally accepted, this design paradigm will lead to concurrent engineering where the data base generated for the solid model will be available for all aspects of the design enterprise (see *Figure 1*).

This evolving design paradigm has significantly impacted the teaching of engineering graphics. The trend has gone from manual drafting, through the use of Computer-Aided Drafting and Design (CADD) systems, to 3-D solid modeling. Our group has been active in developing and promoting solid modeling in the Engineering Design Graphics curriculum (Barr & Juricic, 1990, Barr et al., 1994), and other groups have reported recent success also in using solid modeling in EDG courses (Leach & Matthews, 1992, Devon et al.,1994). With support from the NSF ILI-LLD program, efforts have now been directed at extending the solid-modeling-based curriculum to have a significant CAD/CAM component which includes application of the solid model to design analysis and to rapid manufacturing of a prototype part (Juricic & Barr, 1996). The rationale of this approach has been described in previous reports (Juricic & Barr, 1993, Juricic & Barr, 1995). This

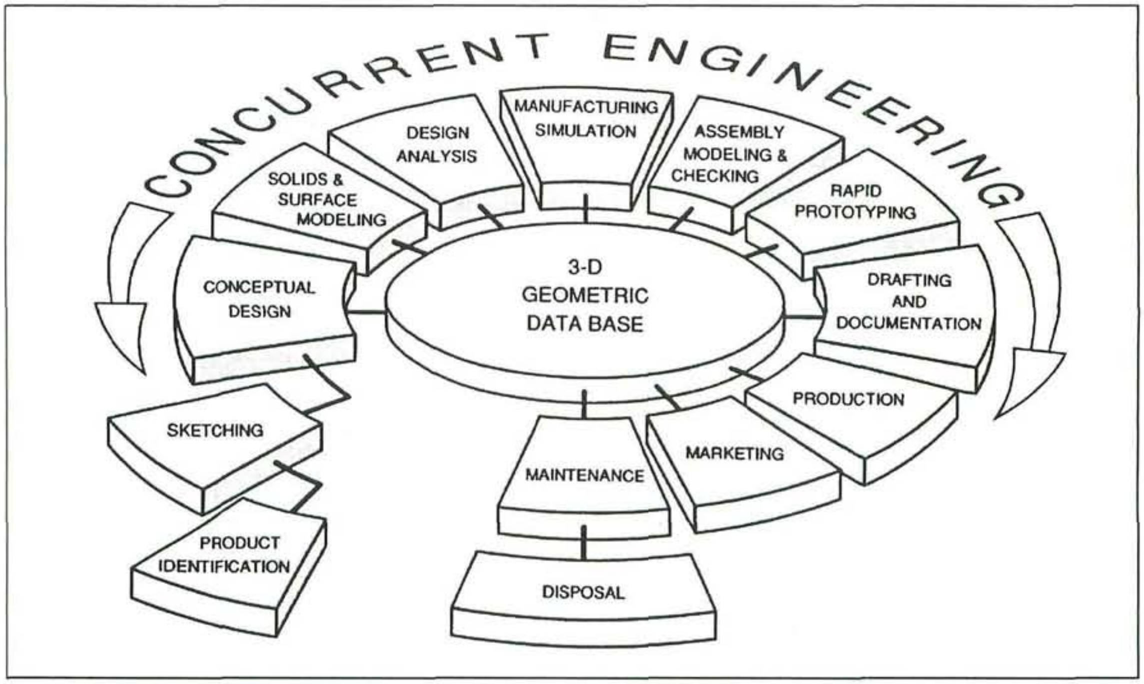

Figure 1 *- The Concurrent Engineering approach to design has a 3-D geometric data base as the hub. (Reproduced from Barr et al., 1994.)*

paper reports on classroom experiences while teaching a pilot section.

In the Fall 1996 semester, a pilot section of the Engineering Design Graphics course at the University of Texas at Austin was taught with a newly developed CAD/CAM laboratory component. The CAD/CAM component consisted of three weekly laboratory exercises that emphasized application of the solid model data base to mass properties calculation, to finite element analysis, and to rapid prototyping using a desktop system. This paper discusses the pilot course, overviews the curriculum, and focuses on the newly-developed CAD/CAM exercise components.

The EDG Curriculum

The EDG course discussed here is a general course on Engineering Graphics that has evolved in conjunction with developments in the modern practice of engineering design. As early as the mid 1980's, it was recognized that solid modeling was the new basis for developing and conveying of design ideas. To this end, a curriculum model was developed in which solid modeling serves as the starting point for all laboratory exercises, from visualization, through analysis and manufacturing, and to final production of engineering documentation. The class each week includes a formal lecture, manual sketching assignments, and a computer lab exercise. A typical laboratory sequence for this course is shown in *Table 1*. The lecture and laboratory topics can be subdivided into four parts. Each part spans a three-week period for a total semester of twelve weeks. The general topics for the four parts are: 1. Introduction to the design process and CADD; 2. Geometric and solid modeling; 3. Model applications to analysis and rapid prototyping; and 4. Design documentation in the form of engineering drawings. If time permits at the end of the semester, a fifth optional design-project part can offer a culminating experience to the course. Each of these parts is delineated further.

Week	Topic	CAD/CAM Component
1	Computer Space, 2-D Lines:	Viewing Computer Space, Drawing 2-D lines, Changing Line Types, Text.
2	2-D Primitives:	Drawing 2-D Primitives, Editing 2-D Primitives, 2-D Transformations.
3	2-D Constructions:	Tangency Construction, Three-Point Circle, Conic Sections, Curved Lines, Splines.
4	Visualizing Solid Model:	Loading Solid Model, Changing 3-D Viewpoint, Hidden Line Removal, Shading Solid Model, Color Hardcopy.
5	Building Solid Model I:	Base 3-D Primitives, Unary Operations, Boolean Operations, 3-D Transformations.
6	Building Solid Model II:	Extrusion Operations, Revolution Operations, 3-D Editing Operations.
7	Analyzing Solid Model I:	Changing Primitives, Redesigning the Model, Mass Properties of a Solid Model.
8	Analyzing Solid Model II:	Reverse engineering, Finite Element Analysis of a Solid Model.
9	Prototyping Solid Model:	Feature-Based Solid Modeling, Prototyping of a 3-D Solid Model.
10	Projecting Solid Model:	Multiview Layout of a Model, Editing Visible Profile Lines, Generating a Drawing.
11	Sectioning Solid Model:	Cut Section Operations, Sectioning Conventions, Generating Section Drawing.
12	Dimensioning Projections:	Dimensioning Conventions, Generating Dimensioned Engineering Drawing.
13/14	Design Project: (optional)	Building, Rendering, and Analyzing Solid Model Assembly, Generating Engineering Drawings.

Table 1 *- A computer laboratory outline used in an EDG course with a CAD/CAM component.*

Part 1. Introduction to Design and CADD

The course begins with an introduction to design and design representation. Historical perspectives and the evolution of the design paradigm are presented. A typical design process for lower division college students is presented, and the rationale for teaching design at that level is explained. The modern design process based on a three-dimensional solid model data base is emphasized.

Fundamentals of CADD are presented in a pedagogical fashion, and laboratory exercises during the first three weeks complement the lectures. The purpose of CADD in the modern 3-D design paradigm is explained as a need for construction on a 2-D workplane in computer space. These construction outlines often form the basis for the start of a 3-D solid model. A set of sketching exercises support the learning of these various constructions on the 2-D workplane.

Part 2. Geometric and Solid Modeling

The next three weeks contain lectures on geometric and solid modeling. The various methods of geometric modeling, including wireframe, surface, and solid modeling, are delineated. Solid modeling is studied in detail. This includes base primitives, Boolean operations, and the sweeping operations of extrusion and revolution. Editing commands are covered and advanced topics like feature-based modeling and machining functions are introduced. Sketching exercises during this part focus on axonometric sketching. The lab exercises include building and visualizing solid models with the various approaches mentioned. Shaded output images and color hardcopy plots enhance the students' enthusiasm for this part.

Part 3. Engineering Analysis and Prototype Manufacturing

Two weeks of the third part of the course cover solid model applications to engineering analysis. The topic of engineering analysis, with emphasis on analysis amenable to the solid model data base, is covered in the lecture. In the computer laboratory, the solid model is built and is analyzed for mass properties in one weekly module. The printout of the mass properties report is then studied. In the next weekly module, finite element analysis is performed on a solid model and color contour plots of the results are generated. These analysis activities, which are the newest development in EDG labs, will be discussed in more detail later in the paper.

One week during this part, weekly module 9, is relegated to prototype manufacturing. The topic of manufacturing, with emphasis on solid model applications to rapid prototyping, is introduced in the lecture. In the computer lab, the students build a solid model and then generate an .STL file directly from the model data base. This .STL file is then transferred to a prototyping machine to produce a physical model of the part. In this case, the rapid prototyping system used

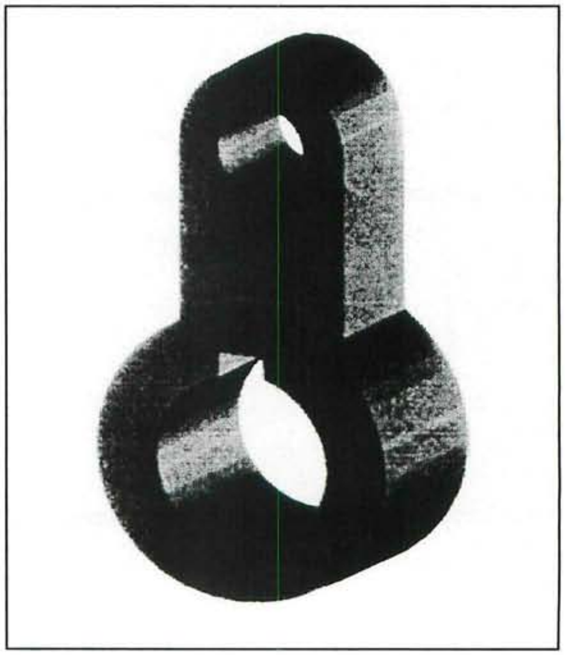

***Figure 2** - Example of the rocker arm solid model used to generate, study, and compare mass-properties report files (.MPR).*

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Ray projection along X axis; level of subdivision: 6.
Mass:                   23.5823 gm
Volume:                  3.000293 cu cm  (Err: 0.04013336)
Bounding box:           X:  0            --  2.574302  cm
                        Y: -1.189354     --  0.8810444 cm
                        Z: -0.7942625    --  1.520838  cm
Centroid:               X:  1.287062   cm    (Err: 0.01789548 )
                        Y: -0.1547844  cm    (Err: 0.008573326)
                        Z:  0.3634186  cm    (Err: 0.0092415  )
Moments of inertia:     X: 10.82575   gm sq cm (Err: 0.192598 )
                        Y: 52.78624   gm sq cm (Err: 0.7257771)
                        Z: 50.36488   gm sq cm (Err: 0.7243447)
Products of inertia: XY: -4.603923   gm sq cm (Err: 0.2695591)
                     YZ: -2.637027   gm sq cm (Err: 0.1030254)
                     ZX:  9.338435   gm sq cm (Err: 0.2765636)
Radii of gyration:      X:  0.6775415  cm
                        Y:  1.496123   cm
                        Z:  1.461406   cm
Principal moments in (gm sq cm), unit vector directions [X-Y-Z]:
                     I: 6.391423 [0.9067523  0.1434951 -0.396496]
                     J: 12.27543 [0.2429932  0.5906563  0.769467]
                     K: 9.821397 [0.3446079 -0.7940619  0.500710]
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Figure 3 *- An example of a mass-properties report generated from a solid model in the week 7 computer lab exercise.*

is the JP System 5 by Schroff Development Corporation. This laboratory module will be discussed in more detail later in the paper.

Part 4. Design Documentation

The last phase of the course includes design documentation derived directly from the solid model data base. In the week 10 module, the students generate a multiview projection of the solid model. Multiple viewports are created and a front, top, and right side profile projections of the solid model are obtained in their respective viewports. During week 11, a section solids command is used to obtain a full section view of the solid model. An orthographic layout completes the section view drawing. In the week 12 module, profile views of the solid model are once again obtained, and the multiviews are then dimensioned to complete the drawing. During this phase, manual exercises support the learning experiences in multiview orthographic sketching, in sketching various section views, and in sketching dimensions on objects with various geometric features.

Engineering Analysis Lab

Engineering Analysis has been recently introduced to the EDG course in order to extend the computer laboratory to have a new CAD component. Two specific analysis methods are introduced. In the first analysis lab during week 7, the students build two solid models with similar profiles but slightly modified geometry (see *Figure 2* for an example). They apply a material property to each solid model and then generate mass properties reports (.MPR files) for both models (see *Figure 3* for a typical AutoCAD example). A comparison of the MPR reports leads to some qualitative observations about the design efficacy of both models. For example, in the case of the rocker arm model shown in Figure 2, the students are asked to observe the change in the moment of inertia about the rotational axis as the upright feature changes geometry.

During week 8 in the computer lab, the students are introduced to the finite element analysis (FEA) method. The students are first divided into four-member design teams based on their seating arrangement proximity. Each team then selects a package that contains a physical model of an object with constant thickness and thus having all features in one plane. Examples of these 2-D objects are shown in *Figure 4*. These objects were selected because they are most amenable to an FEA study and interpretation at this early stage of the student's training in CAD. Each team had a set of calipers, a scale, a pencil, and grid paper. Using reverse engineering, the team studied and sketched the outline of the 2-D object to a full-size scale, taking dimensions directly from the physical object *(Figure 5)*. This sketch in turn serves as an engineering document for building a geometric model of the object.

Using the reverse engineering sketch of the object, the students build a solid model and then take a section slice of the 2-D design object. They then apply finite element analysis to the section using the 2-D AutoFEA program running inside AutoCAD. This effort includes applying pre-specified loads *(Figure 6)* to specific places on the model and then obtaining color contours to display the finite element analysis results *(Figure 7)*. The team studies the results from a qualitative point of view to determine where are the maximal stresses. This qualitative study then would suggest ways to modify the geometry of the design object to reduce the peak stresses observed. They also obtain a hardcopy plot of the color stress contours and submit it for a grade.

Rapid Prototype Manufacturing Lab

Week 9 of the course is devoted to rapid prototype manufacturing. The same design teams are paired again, and each team is assigned a dimensioned drawing of a 3-D object. Examples of these 3-D objects are shown in *Figure 8*. A drawing (see *Figure 9*) of one of the objects is assigned to each team. The drawing is used as an aid to build a solid model of the 3-D object using the

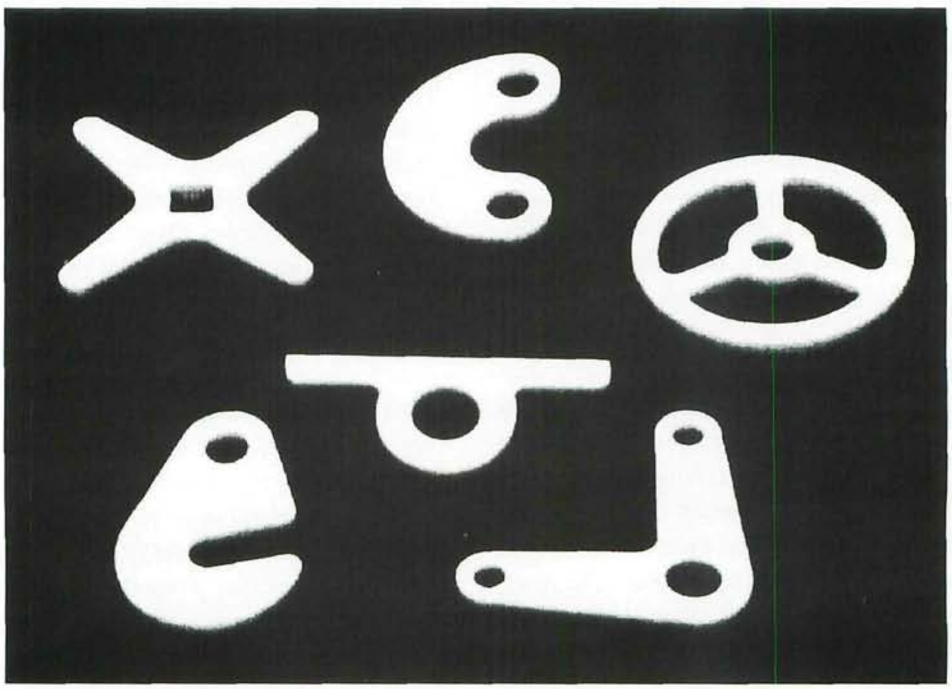

Figure 4 *- The 2-D design objects used in reverse engineering, geometric modeling, and analysis. These objects have primary geometry in a plane and thus are most amenable to FEA study here.*

Figure 5 - The students are divided into four-member design teams. Using reverse engineering, the team studies the 2-D design object and produces a sketch to aid in building a geometric model.

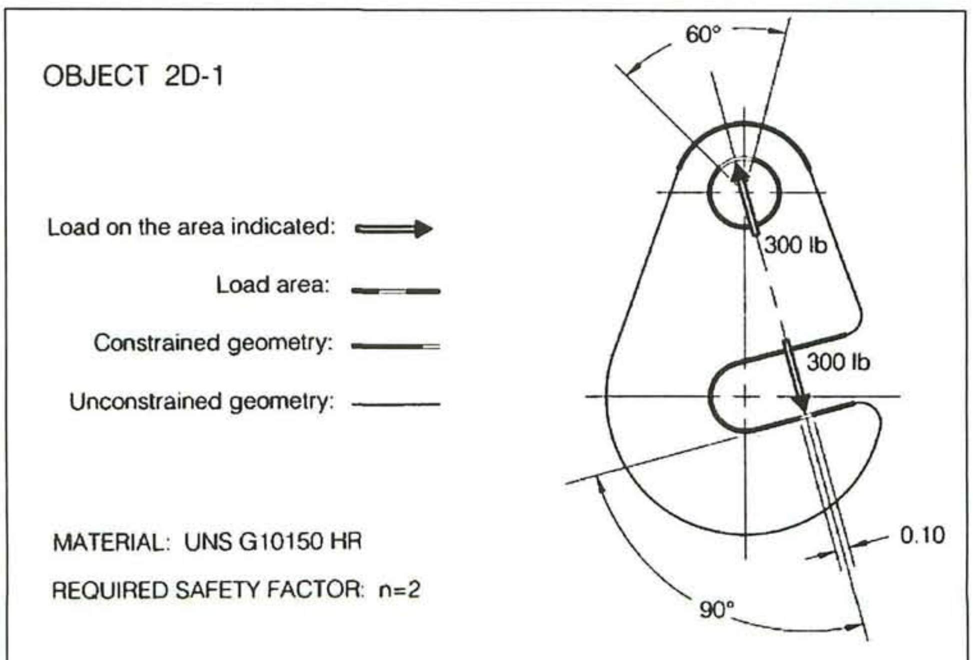

Figure 6 - Example sheet showing the loads to apply to the 2-D design object in preparation for finite element analysis. Excessive stresses have to be reduced by changing unconstrained geometry.

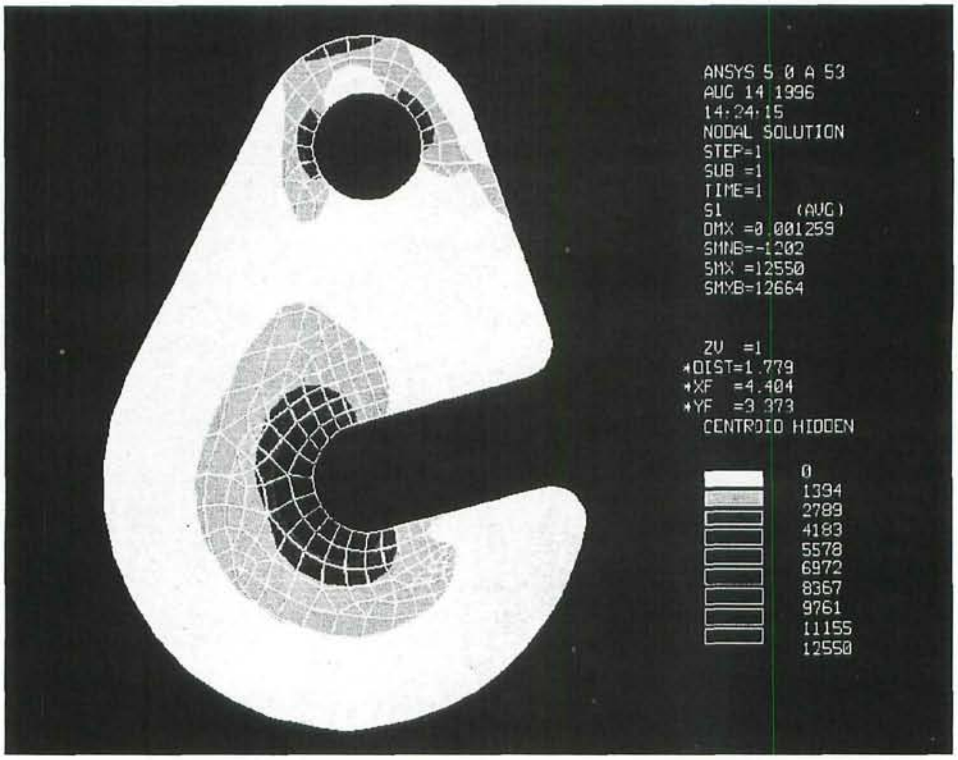

Figure 7 *- Results of finite element analysis of the 2-D design object using AutoFEA inside AutoCad. The stress distribution can be observed by color contours shown against the FEA mesh.*

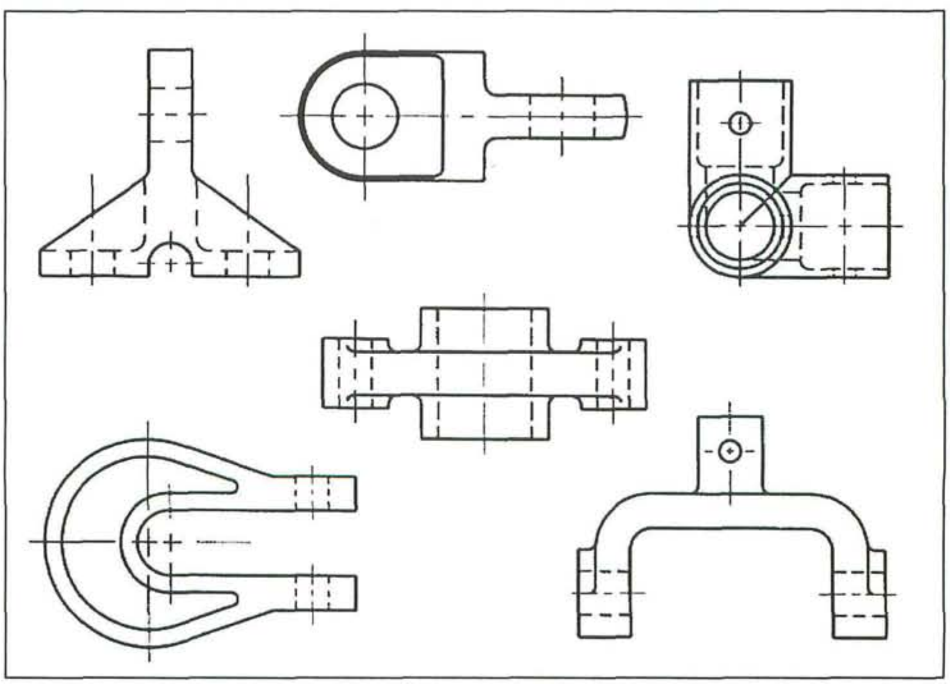

Figure 8 *- Each student design team is given a dimensioned drawing of a 3-D object. The students use this drawing to build a solid model of the object.*

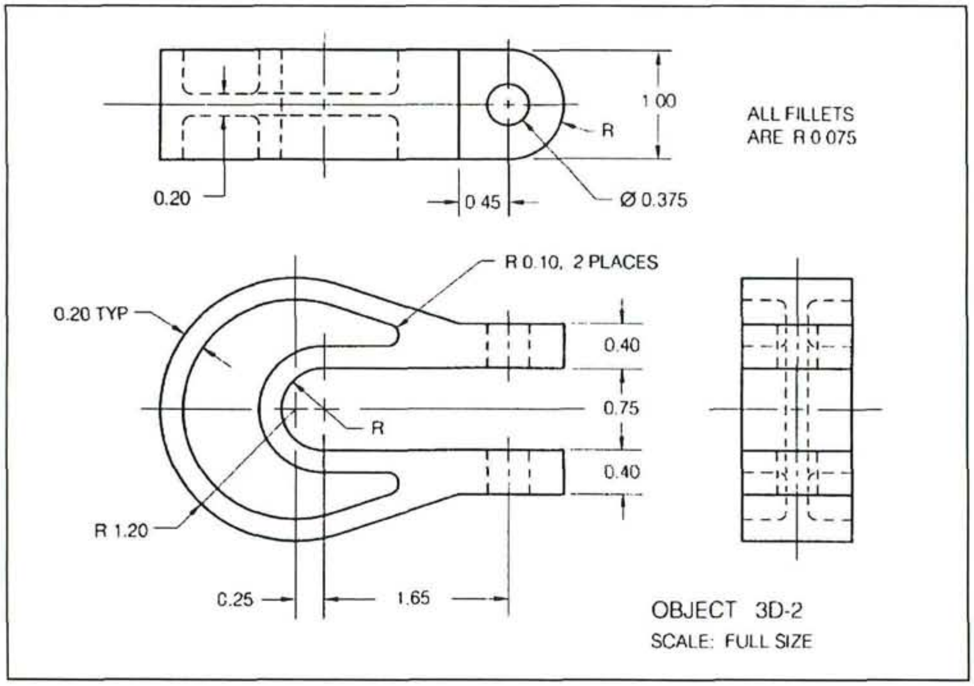

Figure 9 *- Each student team is given a dimensioned drawing of one of the 3-D objects. This drawing is used as an aid in building a 3-D solid model of the object that will be used in the rapid prototyping exercise during week 9 of the semester.*

available Boolean, sweeping, and editing features of the software. The software used for this task was AutoCAD with the AME modeling extension. About 1-hour is spent building and visualizing the 3-D model (see *Figures 10* and *11* for sample visualization exercises).

The student team next generates an .STL file directly from the 3-D solid model data base. This .STL file is copied onto a diskette and transferred to the JP System-5 prototyping system. The system starts with an .STL file of the 3-D model and imports it into the JP System-5 software that works inside SilverScreen (*Figure 12*). The software allows the user to view the slicing process to build the 3-D model layer by layer. The software then shows the layout of the slices as it would appear on the assembly paper and sends commands to the cutter. After all the sheets are cut out, the slices are then manually assembled using a registration board, as shown in *Figure 13*. The slices adhere to each other by peeling off the backing of the sticky paper. This is a time-consuming process, since the 3-D objects usually have 70-100 slices. Also, in most cases, the whole model is built in sub-assembly stages (*Figure 14*). Typically, team members trade turns and the task is finished in 2-3 hours. Some finished models from the JP System 5 are shown in *Figure 15*.

Course Evaluation

The course was evaluated at the end of the semester using the standard University of Texas course-instructor survey (called the "Common Form"). The Common Form consists of five general course-related questions which each require a weighted student response of: excellent (5), very good (4), satisfactory (3), unsatisfactory (2), or very unsatisfactory (1). The five general course-related questions are: 1. course well-organized; 2. communicated information effectively; 3. helped to think for myself; 4. overall instructor rating; and 5. overall

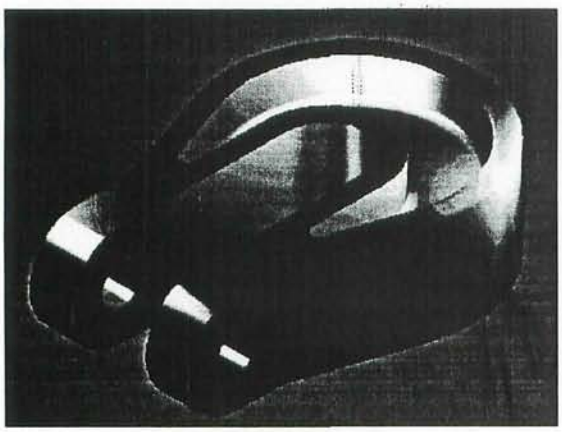

Figure 10 *- The students build the 3-D solid model using available capabilities of the software. A rendered image of the object aids in thier visualization and gives them a softcopy version of the rapid prototype they will build in the next weekly computer lab module.*

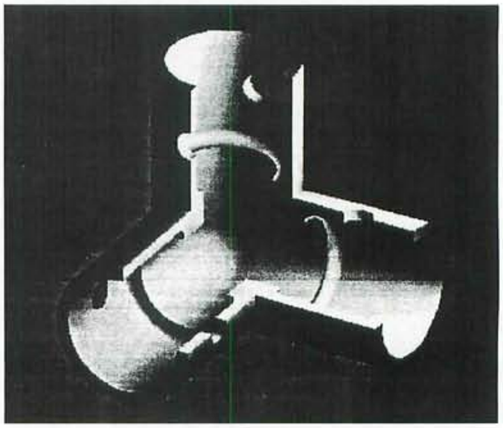

Figure 11 *- The students can use the solid modeling software and rendering capabilities to view the correctness of their design. Here a cut section operation allows the students to view the accuracy of the internal features of the model they just built.*

course rating. The results of the ratings for this Fall 1996 pilot course are shown in *Table* 2. As can be seen, all five categories received an average score of 4.3 or higher on the weighted ranking scheme. These scores are well above the university-wide means of 3.9±0.1 received for the same five categories during that academic term. Hence, these results would be deemed as a very good outcome for the course.

Summary and Conclusions

A CAD/CAM component for the Engineering Design Graphics laboratory has been developed and tested at the University of Texas at Austin. The CAD/CAM component focuses on introducing engineering analysis and rapid prototype manufacturing early in the engineering curriculum. Specifically, the students were divided into design teams during the semester and were

Figure 12 *- The student team next generates an .STL file directly from the 3-D model data base. This .STL file is transferred to the JP System 5 prototyping system (Schroff Development Corp.).*

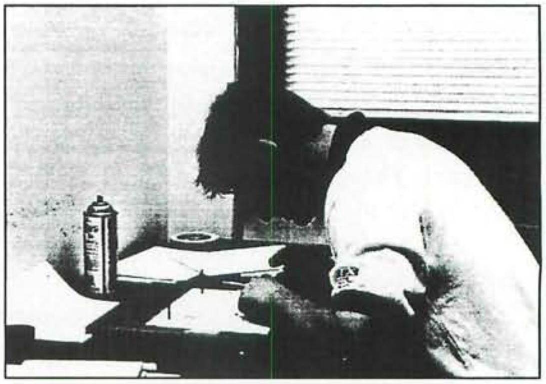

Figure 13 *- Student assembling a 3-D model. The software takes an .STL file and lays out the slices. The slices are cut out on sticky paper using a cutter and manually assembled using a registration board.*

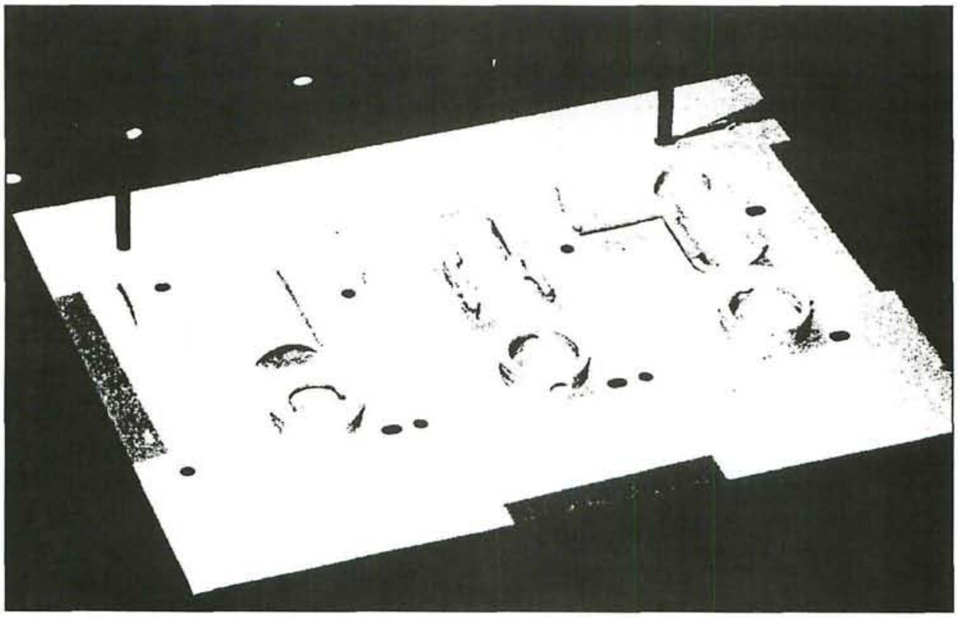

Figure 14 - *Subassemblies of the prototype model are joined together to complete the building process.*

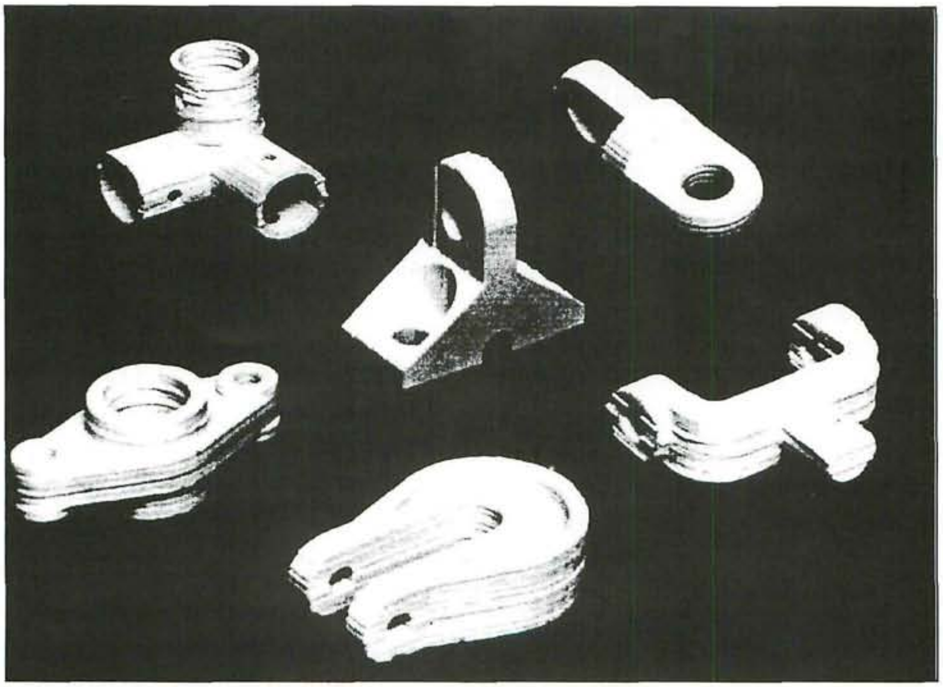

Figure 15 - *Finished physical prototype models from the JP System 5.*

	Number of Responses (N=25)					
	Excel.	Vy. Gd.	Satis.	Unsat.	Vy. Un.	Ave.
1. Course Well Organized	17	7	0	1	0	4.6
2. Communicated Information Effectively	14	10	1	0	0	4.5
3. Helped to Think for Myself	13	7	4	1	0	4.3
4. Overall Instructor Rating	16	7	2	0	0	4.6
5. Overall Course Rating	11	11	2	1	0	4.3

***Table 2** - Course-Instructor Survey Results*

assigned objects with 2-D and 3-D features for making geometric computer models. The students then performed finite element analysis on the model with 2-D features and generated a rapid prototype model from an .STL file of the full 3-D object.

Other groups have tested finite element analysis (Howell, 1993) and rapid prototyping (Nee, 1994) in engineering graphics courses. Our results support these previous efforts, and our curriculum model (*Table 1*) offers a uniform coordinated effort to infuse a CAD/CAM component into EDG. This CAD/CAM component reflects the modern approach to engineering design and will lead to a better understanding of the near-future concurrent engineering environment (Barr et al., 1994). It will motivate students in their early years of engineering study and will serve as a vital starting point for continuous academic experiences in modern design and manufacturing. It can be concluded that the near-future norm for the EDG curriculum will definitely include a CAD/CAM component.

Acknowledgment

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Footnote

*This is an edited version of a paper that was presented at the 1997 Annual Meeting of the Gulf-Southwest Section of ASEE, where it received the Best paper Award.