Journal for Geometry and Graphics
Volume 2 (1998), No. 2, 169–179

The Freshman Engineering Design Graphics Course at the University of Texas at Austin

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Abstract. This paper discusses the course on Engineering Design Graphics (EDG) that has evolved at The University of Texas at Austin in conjunction with developments in the modern practice of engineering design. In particular, the course focuses on solid modeling, which is the new methodology for developing and conveying engineering design ideas. To this end, a curriculum model was developed in which solid modeling serves as the starting point for design representation and for all laboratory exercises, from visualization, through analysis and manufacturing, and to final engineering documentation. The class each week includes a formal lecture, manual sketching assignments, and a computer lab exercise. The lecture and laboratory topics can be subdivided into four parts: 1. introduction to design and computer-aided design; 2. geometric and solid modeling; 3. application to analysis and manufacturing; and 4. engineering documentation. Each of these parts will be detailed in the paper, and some examples of student exercises will be included.

Key Words: Engineering Design Graphics, Engineering Education

1. Introduction

In the past, design representation had been traditionally relegated to engineering graphics. Engineering drawings were used to convey data for both part analysis and manufacturing. During the past ten years, 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 has been established, a paradigm that uses a solid model as the common thread to integrate the design process with engineering analysis and part manufacturing.

ISSN 1433-8157/$ 2.50

This evolving design paradigm has significantly impacted the teaching of engineering graphics. The trend has gone from eliminating the use of drafting machines, to the use of Computer-Aided Design and Drafting (CADD) systems, and now to a curriculum based on solid modeling. Our group has been active in developing and promoting solid modeling in the Engineering Design Graphics curriculum [1], [2], and other groups have reported recent success also in using solid modeling in EDG courses [6], [3]. With support from the National Science Foundation (NSF) through a series of projects and workshops, EDG has been transformed from a CADD-based curriculum to a solid-model-based curriculum which now has a significant applications to design analysis and to rapid manufacturing of a prototype part [5]. This latter development extends EDG to have a significant Computer-Aided Design and Manufacturing (CAD/CAM) component, which portrays concurrent engineering as the design environment for the near future (see Fig. 1). All EDG students at the University of Texas at Austin, which number approximately 500 per year, are now being introduced to the modern practice of engineering design using concurrent engineering as the model paradigm.

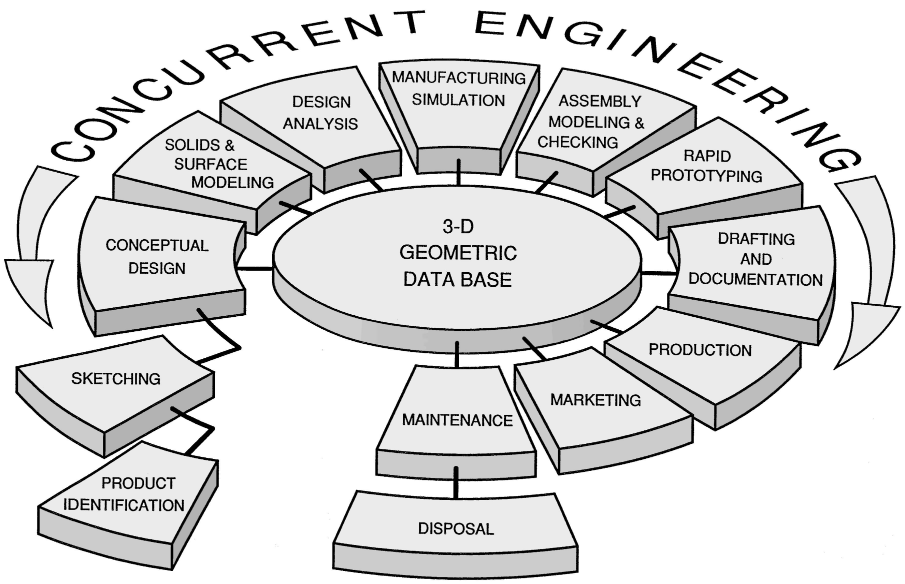

Figure 1: The Concurrent Engineering approach has the 3-D digital geometric database as the central hub for use in all aspects of the design process

2. 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 middle of the 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 computer laboratory sequence for this course is shown in Table 1.

Week	*Topic*	*Computer Lab 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, Splines, Curved Lines
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: (instructor's option)	Building, Rendering, and Analyzing Solid Model Assembly, Generating Engineering Drawings

Table 1: A computer laboratory outline used in the EDG course at The University of Texas at Austin

2.1. 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 database is emphasized.

Fundamentals of CADD are presented in a pedagogical fashion, and laboratory exercises the first three weeks complement the lectures. The basic concepts of constructive geometry are presented in parallel with the fundamentals of Computer Aided Drafting. Topics in planar and spatial geometry build on the geometry that was learned in freshman math courses. Those topics of geometry that are needed in a specific course are taught as a part of that course later in the curriculum (e.g., the geometry of gearing is taught in Machine Elements and computational geometry is taught in the courses on Computer Graphics).

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. Sketching exercises support the learning of these various 2-D constructions.

2.2. 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 computer lab exercises include visualizing and building solid models with the various approaches mentioned. Color hardcopy and line prints of the models are obtained.

2.3. Engineering Analysis and Manufacturing

The third part of the course, covers solid model applications to engineering analysis and manufacturing. The topic of engineering analysis, with emphasis on analyses amenable to the solid model database, is covered in the lecture. In the computer laboratory, the solid model is analyzed for mass properties in one weekly module, and in the next module, finite element analysis is performed on a solid model. These analysis activities are the newest development in EDG labs and require new teaching skills on the part of the faculty.

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 is the JP System 5 by Schroff Development Corporation.

2.4. Design Documentation

The next phase of the course includes design documentation derived directly from the solid model data base. In one computer lab, the students generate a multiview projection of the solid model. Multiple viewports are created and front, top, and right side profile projections of the solid model are obtained in their respective viewports. During the next week, 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 last weekly module, profile views of the solid model are once again obtained, and the multiviews are then dimensioned to complete the drawing. During this last phase of the course, manual exercises support the learning experiences in multiview orthographic sketching, in sketching section views, and in sketching dimensions on objects with various geometric features.

2.5. Design Project

The EDG curriculum model incorporates a final design project (instructor's option). The project consists of building a solid model assembly of several parts. The assembly is then rendered to obtain a 3-D color pictorial of the assembly. Analysis and rapid prototyping of the assembly parts then ensues. As a final documentation, working drawings of the parts in the assembly are generated directly from the solid model database. The drawings are dimensioned and a hardcopy set of the drawing package is obtained.

3. Example Student Exercises

3.1. Building a Solid Model

During the computer labs, students learn to work in 3-D computer space by building, visualizing, editing, and documenting solid models. Fig. 2 shows an example of a typical solid model, the rocker arm. The part is built using a combination of profile extrusions and Boolean subtraction operations to create the holes and the keyway groove.

3.2. Analyzing a Solid Model for Mass Properties

Figure 2: Example of the rocker arm solid model built in the computer lab

In the first analysis lab, the students apply some material property, such as that of mild steel or aluminum, to a solid model. They then generate a mass properties report (.MPR file) directly from the solid model data base. Fig. 3 shows a typical AutoCAD printout example. A study of the MPR report leads to some qualitative observations about the design efficacy of the model. For example, in the case of the rocker arm model, the students are asked to study the moment of inertia about the rotational axis and to comment on how the geometry affects this mass property.

3.3. Finite Element Analysis of a Solid Model

In another analysis 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. Each team selects a package that contained a physical model of an object with constant thickness and thus having all features described in one plane. Examples of these 2-D objects are shown in Fig. 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

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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 the rocker arm solid model (AutoCAD version)

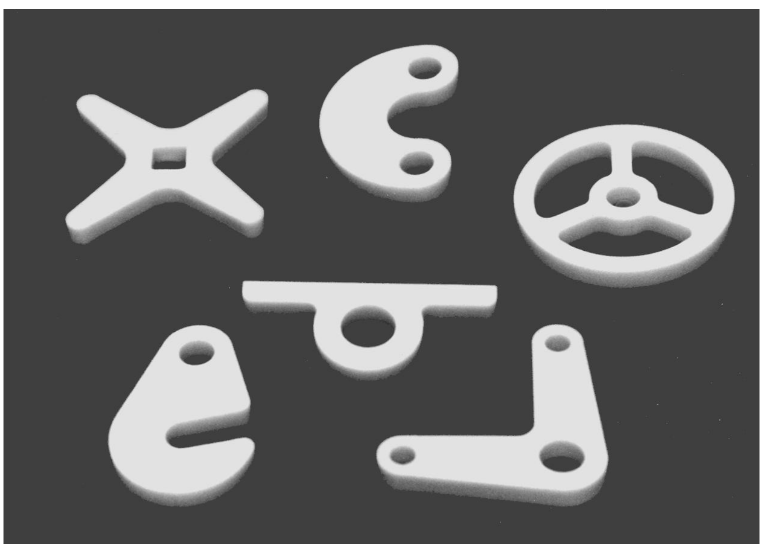

Figure 4: The 2-D design objects used in reverse engineering, geometric modeling, and analysis. These objects have primary geometry in a plane, and thus are most amenable to FEA study at this stage

student team has a set of calipers, scale, pencil, and grid paper. Using reverse engineering, the team studies and sketches the outline of the 2-D object to a full-size scale, taking dimensions directly from the physical object. This sketch then serves as a document for the FEA analysis.

Using the reverse engineering sketch, the students build a solid model and then take a section slice of the 2-D design object. They next apply finite element analysis to the section using the 2-D AutoFEA program running inside AutoCAD. This effort includes applying prespecified loads (Fig. 5) to specific places on the model and then obtaining color contours to display the finite element analysis results (Fig. 6). The team studies the results and suggests

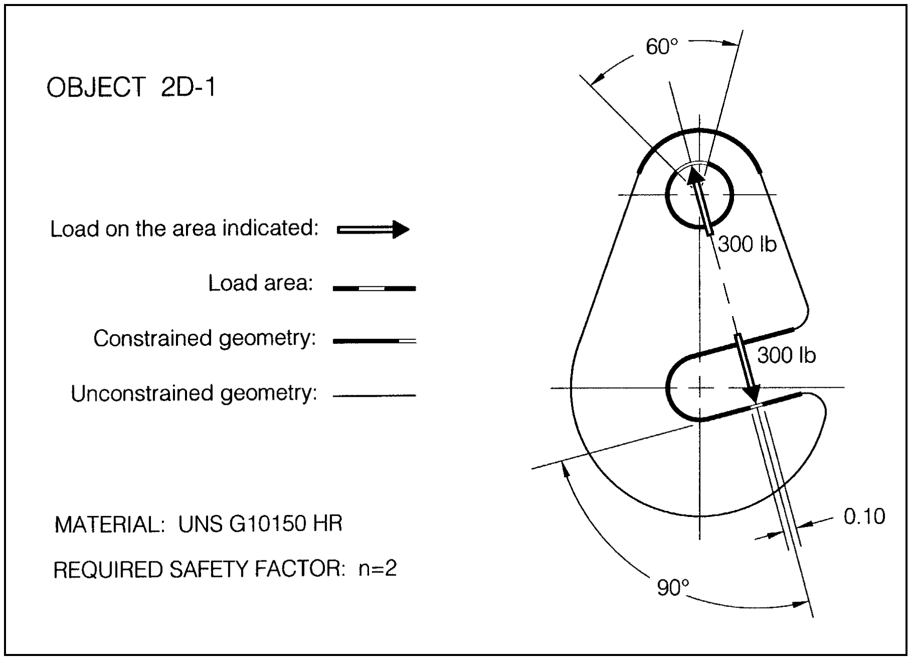

Figure 5: Example sheet showing the loads to apply to the 2-D design object in preparation for finite element analysis. Excessive stresses had to be reduced by changing unconstrained geometry

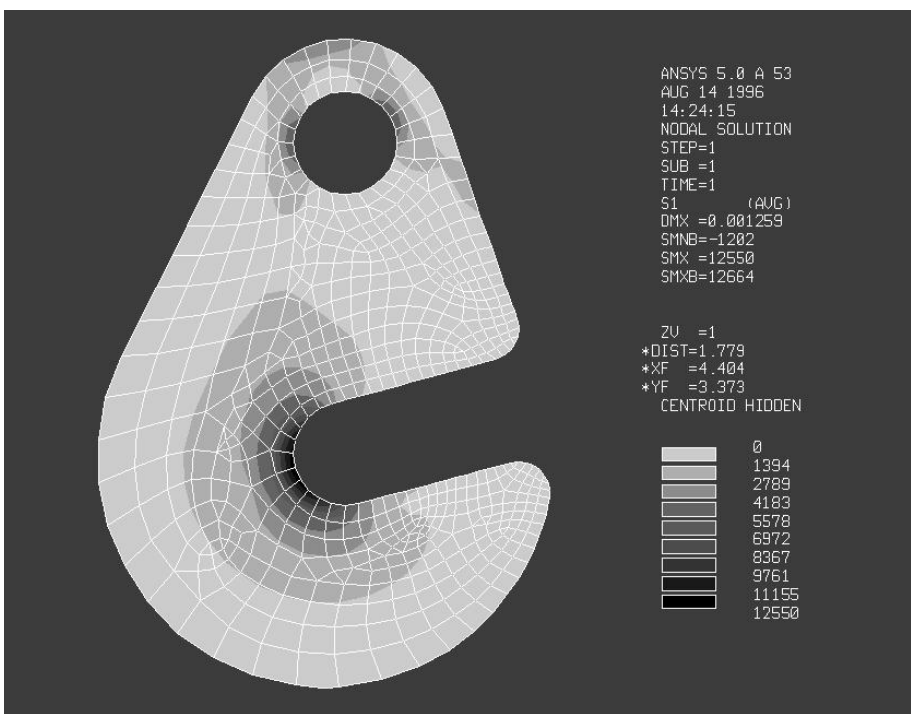

Figure 6: Results of finite element analysis of the 2-D design object using AutoFEA inside AutoCAD. The stress distribution can be observed by color contours

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.

3.4. Rapid Prototyping a Solid Model

For the rapid prototyping lab, the same design teams are paired again, and each team is assigned a dimensioned drawing of a 3-D object. The drawing is used to build a solid model using the available Boolean, sweeping, and editing features of the software. About 1-hour is spent building and visualizing the 3-D model (see Fig. 7). The student team next generates an .STL file directly from the 3-D model data base. This .STL file is copied onto a diskette and transferred to the JP System-5.

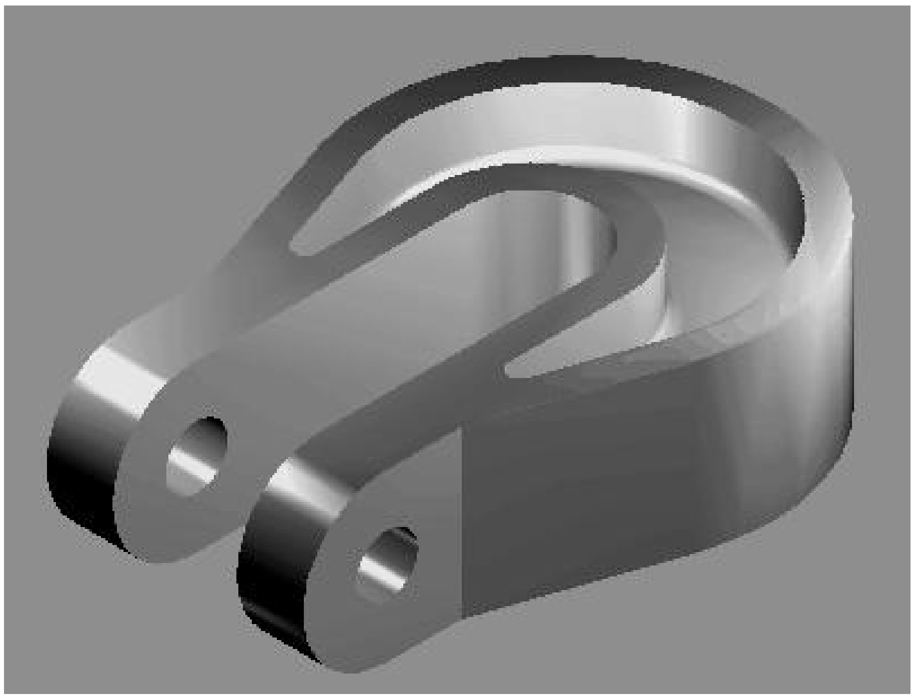

Figure 7: The students build the 3-D solid model using available capabilities of the software. A rendered image of the object aids in visualization. An .STL file is then generated from the solid model database

The .STL file of the 3-D model is now imported into the JP System-5 software that works inside SilverScreen. 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 to cut the slices (Fig. 8). After all the sheets are cut out, the slices are then manually assembled using a registration board. 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. Typically, team members take turns and the task is finished in 2-3 hours. Some finished models from the JP System 5 are shown in Fig. 9.

3.5. Generation of an Engineering Drawing

The final computer lab exercises deal with documentation of the engineering design. Multiview projections of the solid model are obtained in multiple viewports on a sheet of paper in computer space. Profile outlines of front, top, and side views are obtained. The drawing is then finished with dimensioning and other annotation techniques, as shown in Fig. 10.

Figure 8: The .STL file is transferred to the JP System 5 prototyping system from Schroff Development Corp. The system cuts the .STL slices of the prototype on sticky paper using a plotter that has a knife blade

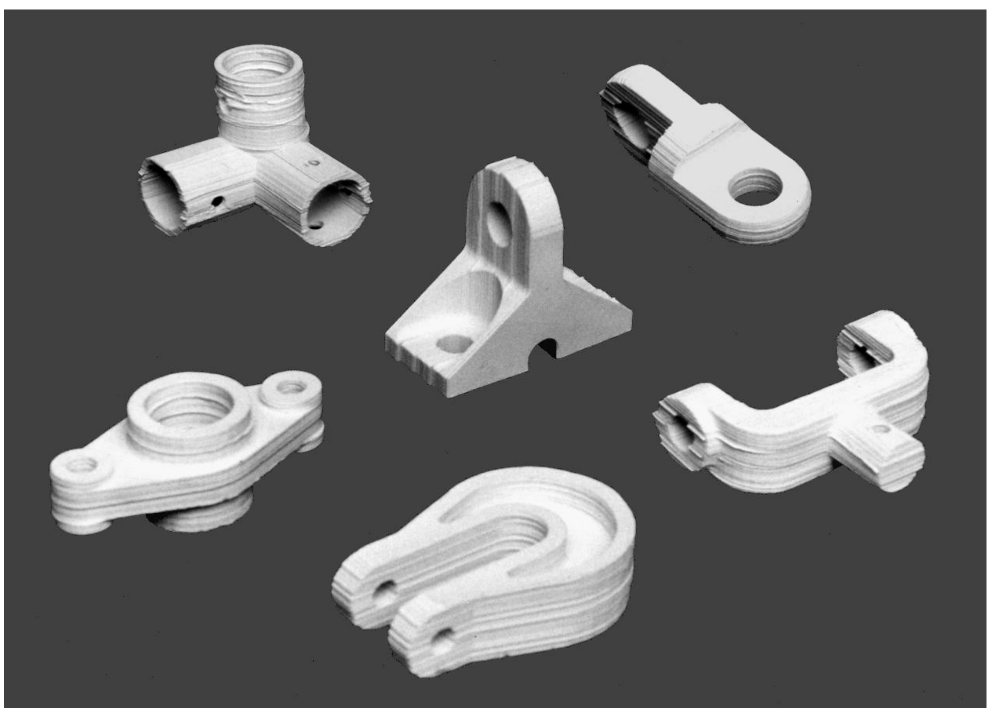

Figure 9: Finished physical prototype models are generated from the JP System 5. Each model consists of approximately 70-100 slices, which are assembled manually using a registration board approach

4. Conclusions

A curriculum model for Engineering Design Graphics has been developed and tested at the University of Texas at Austin. The curriculum is based on the central theme of solid modeling

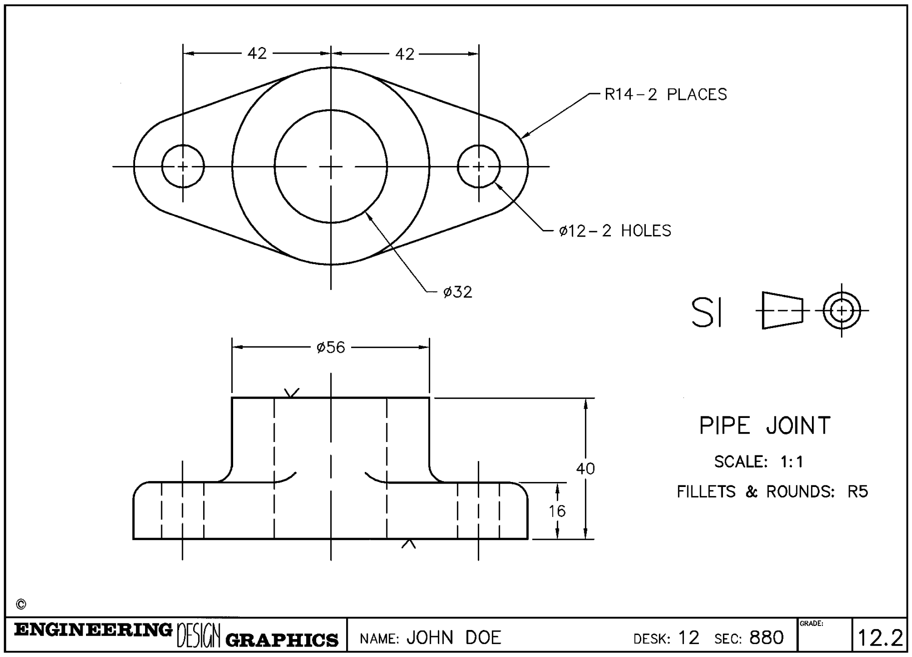

Figure 10: The students generate an engineering drawing directly from the solid model database. Dimensions and annotations then complete the document

and its application to all aspects of the engineering design process, from initial visualization exercises to final design documentation. A particular feature of this EDG curriculum focuses on engineering analysis and rapid prototype manufacturing. Specifically, the students are assigned objects with 2-D and 3-D features for making geometric computer models. The students then perform finite element analysis on the model with 2-D features and generate a rapid prototype model from an .STL file of the full 3-D object.

Other groups have tested finite element analysis [4] and rapid prototyping [7] 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 new EDG curriculum reflects a modern approach to engineering design and will lead to a better understanding of the near-future concurrent engineering environment. It motivates students in their early years of engineering study and serves as a vital starting point for continuous academic experiences in modern graphics, design, and manufacturing.

Acknowledgements

This work was supported in part by the National Science Foundation (NSF), Directorate for Education and Human Resources (EHR), Division of Undergraduate Education (DUE), through the Instrumentation and Laboratory Improvement — Leadership in Laboratory Development (ILI-LLD) Grant No. DUE-9451939, and through the Undergraduate Faculty Enhancement (UFE) Grant No. DUE-9455067.

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Received August 14, 1998