Assembly Modeling

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ABSTRACT

Over the past decade, several new developments have taken place in the world of computer graphics. These include features-based, parametric solid modeling and assembly modeling. Assembly modeling and its applications are treated in this paper. The paper begins with an overview that includes basic terminology and applications. Next, assembly constraints are discussed with particular reference to Pro/ENGINEER and Mechanical Desktop, since these CAD software are popular in both academia and industry. Finally, a case study that was conducted at Southwest Texas State University involving the application of assembly modeling and rapid prototyping to tool design is presented to illustrate the principles discussed.

Introduction

The advent of computer graphics has irrevocably changed the world of design graphics. Prior to the development of computer graphics, many engineering labor-hours were lost in the laborious drafting and detailing activities. Thus engineers could only explore a few "what-if" design scenarios for design optimization (Groover and Zimmers, 1984). Computer Aided Drafting (CAD) gave a tremendous boost to the productivity of the drafting and detailing processes, thereby permitting several what-if scenarios to be easily considered. This in turn generally resulted in superior designs.

Geometric modeling was developed next, which is a mathematical model that captures the three-dimensional geometry of the physical object. Additionally, geometric modelers can also capture mechanical, physical, electrical and other such properties of the product. Geometric modeling (particularly solid modeling) contributed to the productivity of the engineering design process by enabling the designer to automatically generate multiviews, sectional views, mass properties etc. Also, solid models provide the database with complete part information to support downstream design and manufacturing activities such as finite element analysis, rapid prototyping, process planning, NC code generation, etc.

The next major development in computer graphics was represented by CAD software that offered parametric, features-based capability. The last in this series of developments is assembly modeling, which is offered by some CAD systems today. Assembly modeling is currently very popular in industry. According to an article in the *Automotive Manufacturing & Production* magazine, which is published in cooperation with the Society of Automotive Engineers (SAE), "whereas in '88 it was parametric solid modeling; in '98 it is assembly modeling and its applications that represents the newest trend in the world of CAD/CAM" (Vasilash, 1998). In this paper, assembly modeling, which has many applications for design and manufacturing, is treated. ***Assembly modeling should be introduced along with solid modeling in graphics courses to better prepare students bound for subsequent design and manufacturing classes.***

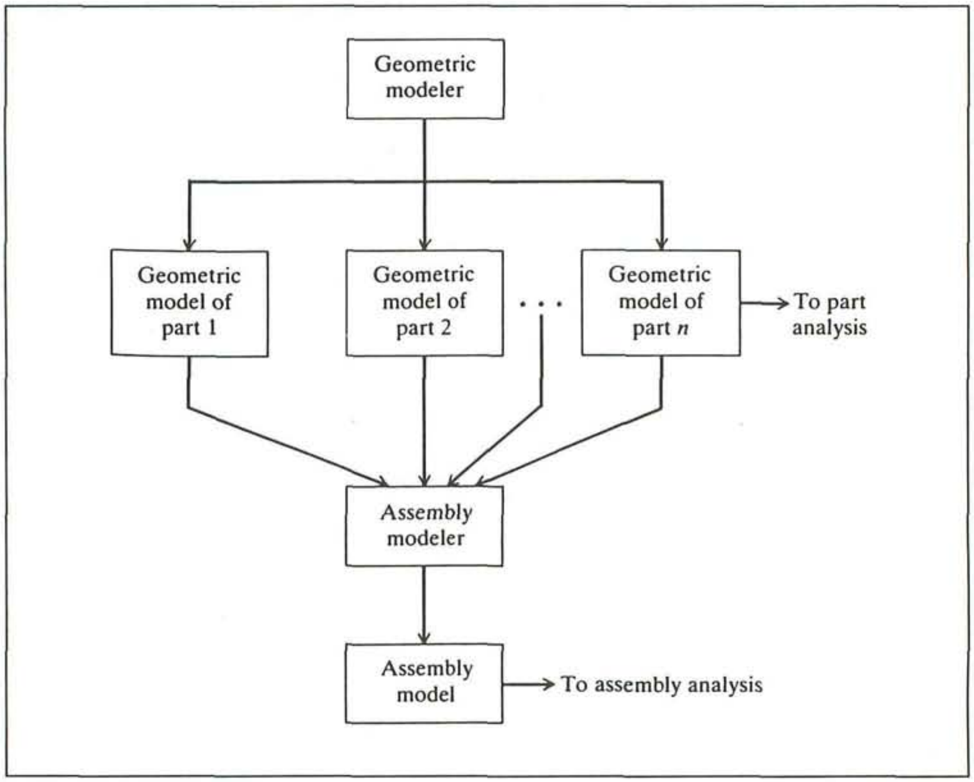

Figure 1 *- Geometric and Assembly Modelers (From Zeid, I. "CAD/CAM Theory and Practice." Copyright © 1991 by McGraw-Hill, Inc. Reproduced with permission of The McGraw-Hill Companies).*

Assembly Modeling

Many of the modelers available today may best be classified as **geometric modelers**. These systems have data structures that have been designed to store and manipulate geometric data of individual parts only. **Assembly modelers** can be thought of as more advanced geometric modelers where the data structure is extended to allow representation and manipulation of **hierarchical relationships** and **mating conditions** that exist between components in an assembly (Zied, 1991). As shown in *Figure 1*, the geometric modeler acts as a front end to the assembly modeler. Individual parts may be modeled using the geometric modeler. These models may be analyzed individually at this stage. After each part has been analyzed and optimized, the designer would use the assembly modeler to synthesize an **assembly model** and analyze the entire system.

Inherent in all assemblies is the notion of hierarchical relationships. This implies a layered or tree-like structure for the assembly, as shown in *Figure 2*. The tree (also called assembly tree) explodes the overall assembly into subassemblies and parts, as well as illustrates where within the tree structure the various parts and subassemblies are connected or attached. Thus at the topmost level of the hierarchy or depth 0, we have the overall assembly. The next level, i.e. depth 1, shows how the major subassemblies and parts fit into the overall assembly. This process of exploding and detailing continues until all subassemblies, parts and components have been accounted for. With the benefit of such hierarchical relationships, questions such as whether gear 1 belongs to subassembly 1 or subassembly 3 can be addressed.

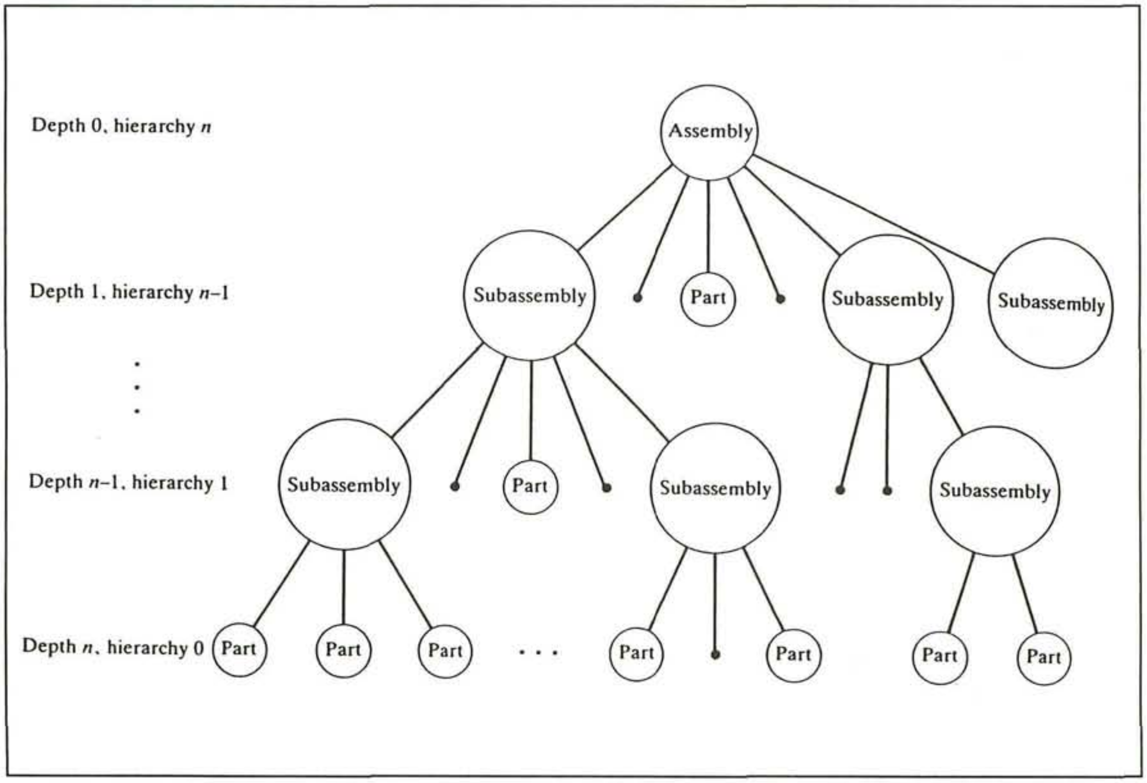

Figure 2 *- Assembly Tree (From Zeid, I. "CAD/CAM Theory and Practice." Copyright © 1991 by McGraw-Hill, Inc. Reproduced with permission of The McGraw-Hill Companies).*

In assembly modeling, individual parts modeled by a geometric modeler are combined together using "**merge**" commands to form the assembly. Typically a designer would start with a base part (the largest component into which most others fit) and add other components to the **base part** using merge commands. These merge conditions define spatial relationships (also called mating conditions or assembly constraints) between individual parts. For example, mating conditions specify whether two planar surfaces butt against each other, or if the axis of a hole and shaft are coaxial or otherwise. Mating conditions are interactively specified with great ease in assembly modelers.

Each part has associated with it **degrees of freedom** or independent movements. Generally there are six degrees of freedom to be considered: three translational and three rotational movements. As parts are assembled using merge commands, their associated degrees of freedom are constrained or restricted. For example, when a nut is assembled onto a hole in a part, the nut loses three translational and two rotational degrees of freedom. Such constraining of the degrees of freedom is essential for fully describing the spatial relationship between mating parts.

Once hierarchical relationships and mating conditions have been described for a set of mating parts, the result obtained is called an assembly model. The difference between assembly and solid modelers in terms of assembly building may be understood by the following example. If a robot consisting of six rigid links that are connected together by some translational (prismatic) and some rotational (revolute) joints is modeled by a solid modeler and assembled together by using mere "move" and "translate" commands, then an analysis program may not be able to use this assembly to decide if a torque applied to link 1 will cause link 4 to move or not. Furthermore, if movement should result, the program may not be able to decide whether the resulting movement would be translational or rotational. If the same robot were built using an assembly modeler, then it could support this analysis.

Assembly modelers can also automatically generate bill of materials (BOM), determine mass properties for the entire assembly, graphically "explode" the assembly to show how the components fit together, list parent-child relationships and generate multi-views of the assembly. Once an assembly model has been created, it can be subjected to some sort of engineering analysis. These analyses are listed in the next section.

Importance of Assembly Modeling in the Design Graphics Curriculum

One of the important end functions of any engineering drawing (hard copy or electronic) and/or geometric model is to support design and manufacturing analysis. Also, most all engineered products from electric toasters to aircraft are assembled products. Regardless of its complexity, assembled products may be subject to analysis that includes:

1. Kinematic Analysis
2. Dynamic Analysis
3. Tolerance Analysis
4. Finite Element Analysis
5. Design for Assembly Evaluations

Assembly models are ideally suited as the input for the aforementioned analyzes because such analyzes require hierarchical relationships and mating conditions related information in addition to shape and size information which geometric modelers typically provide. Also in much the same manner in which parametric, constraints based solid models capture the designer's intent from a component standpoint, assembly modelers, through the use of hierarchical relationships and mating conditions, capture the designer's intent from an assembly standpoint. Thus the graphics curriculum must incorporate assembly modeling as one of the last topics to be covered so as to produce mechanical and manufacturing engineering/technology students who are prepared for advanced design and manufacturing analysis in senior and graduate level classes. Today, solid modeling, which is an essential prerequisite to assembly modeling, is an integral component of the graphics curriculum. Parametric, features-based CAD and rapid prototyping are also gradually being incorporated into the graphics curriculum. Assembly modeling is an important component of the curriculum that readily interfaces with and is a logical extension of the aforementioned topics. Since AutoCAD (Mechanical Desktop) and Pro/ENGINEER are two of the common CAD software used in both industry and academia, the following section briefly presents assembly modeling in the particular context of these systems.

Assembly Modeling in Pro/ENGINEER and Mechanical Desktop

Assembly modeling in Pro/ENGINEER is briefly presented and is followed by a summary of the same in Mechanical Desktop. The focus here is not to get into the minutiae of the commands or their sequences but to present modeling procedures from a practical, albeit global perspective. To start with, all parts and components of the assembly are created as separate solid models and stored as ".PRT" or part files. Assembly modeling is invoked next, by opening an assembly file or ".ASM" which is where the assembly will be stored. The base part is brought into the assembly mode first, followed by other components that would fit into the base part. As each part is brought in, the system requires that assembly constraints be specified which describe how the mating parts fit together. Towards this end, a dialogue box (*Figure 3*) opens up and apprises the user as to whether

Component Placement

No.	Type	Comp. Ref.	Assy. Ref.	Offset
1	Mate	Surface	Surface	0.000

Status: Component placement is not fully constrained.

Figure 3 *- Constraint dialogue box (Courtesy of Parametric Technology Corportion*).*

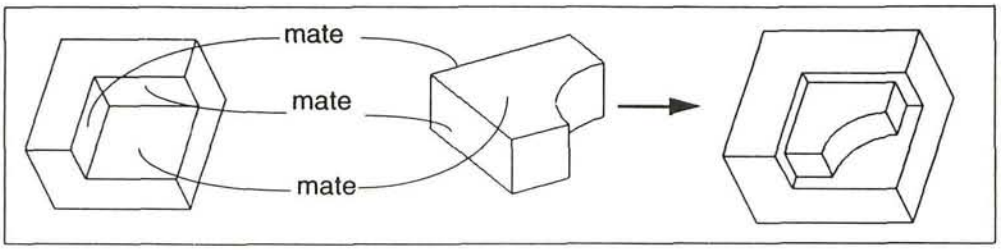

Figure 4 *- The mate constraint (Courtesy of Parametric Technology Corportion*).*

the part is fully constrained. Component parts have to be fully constrained before the assembly modeler can generate an unambiguous assembly model.

Some of the constraint options in Pro/ENGINEER are as follows:

Mate and Mate Offset: The mate option permits two surfaces to touch one another, i.e. the two surfaces would become coincident and facing each other, as shown in *Figure 4*.

In the case of the mate offset option, the two mating surfaces are separated by a distance equal to the user-specified offset value.

Align and Align Offset: The align option (*Figure 5*) causes two planar surfaces to become coplanar, coincident and facing in the same direction as shown below. Using this option, revolved surfaces or axes can also be made coaxial.

The offset option aligns two surfaces and permits the two to be offset by a user-specified distance.

Insert: This option (*Figure 6*) is used to insert a "male" revolved surface into a

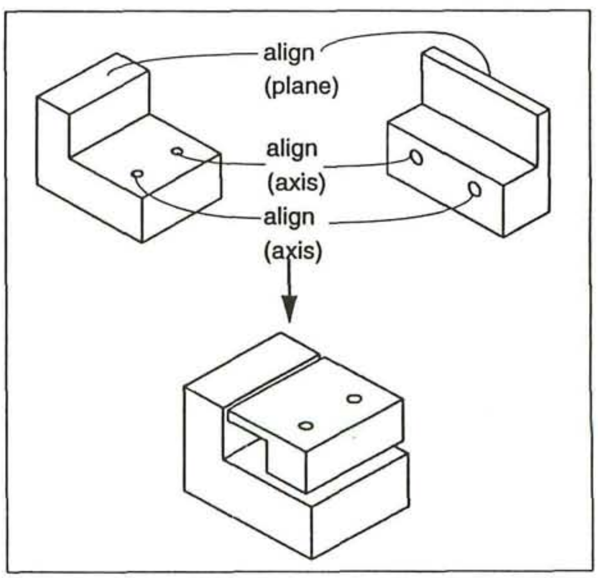

Figure 5 *- The align constraint (Courtesy of Parametric Technology Corportion*).*

"female" revolved surface and aligns their respective axes as shown below.

Orient: The orient option (*Figure 7*) causes two planar surfaces to become parallel and face each other as shown below.

Coord Sys: This option (*Figure 8*) assembles a part onto the assembly by aligning their local coordinate system origins as shown below.

In addition to the aforementioned, Pro/ENGINEER also supports **Tangent, Pnt on Surf** and **Edg on Surf** constraints. More details on these constraints are described in *Pro/ENGINEER - Assembly Modeling User's Guide* (1997).

In Mechanical Desktop, the principal constraint types are: **mate, flush, align** and **oppose.** *Table 1* summarizes the details of each of these constraints. *AutoCAD Designer Release 2 - Assembly Modeling* (1996) may be consulted for more information on these constraints.

Case Study - Punch and Die Design

The case study involves designing tooling for sheet metal work. In what follows, an overview of the design process is presented.. The tooling consists of eight separate components as well as fasteners for joining purposes. These components are die shoe, die block, punch, punch holder (shoe), two bushings, and two guide posts, as shown in *Figure 9*. These components are first designed according to the principles of sheet metal processing. Next, the individual components were created as solid models and stored as part (.PRT) files in Pro/ENGINEER. Finally, these components were assembled together in the assembly modeling mode of Pro/ENGINEER.

The case study was undertaken as a final class project by students in a design graphics course at Southwest Texas State University. The aim of the project was to design a complete punch and die set that would produce a sheet metal product (a stamping, this product is shown in *Figure 10*. The raw material for the process is in the form of coils (or rolls)

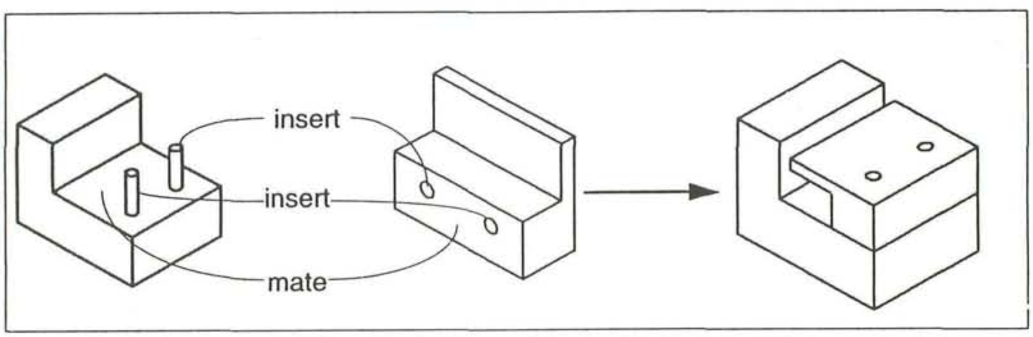

Figure 6 *- The insert constraint (Courtesy of Parametric Technology Corportion*).*

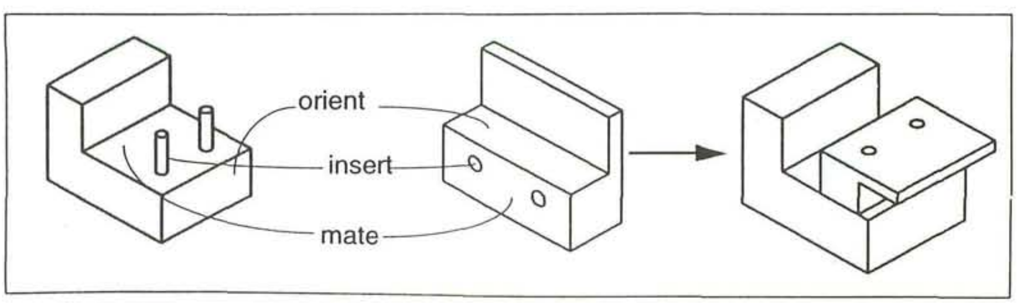

Figure 7 *- The orient constraint (Courtesy of Parametric Technology Corportion*).*

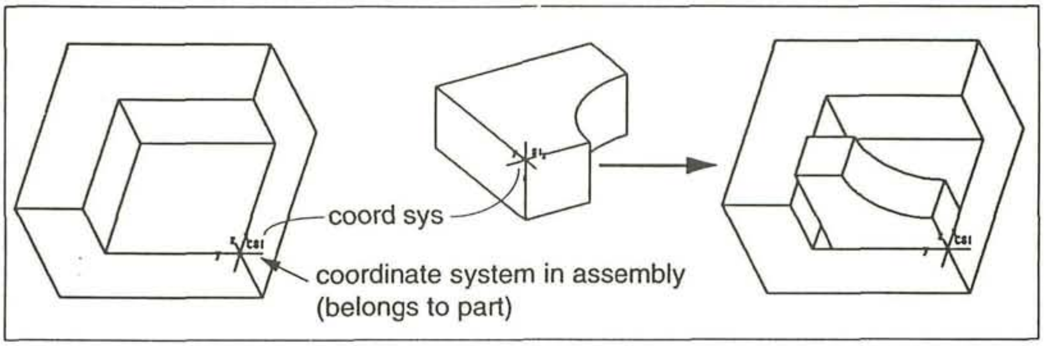

Figure 8 - The coord sys constraint (Courtesy of Parametric Technology Corportion).*

Constraint geometry type	*Plane Plane*	*Plane Line*	*Plane Point*	*Line Line*	*Line Point*	*Point Point*
AMMATE	X		X	X	X	X
AMFLUSH	X					
AMALIGN	X	X		X		
AMOPPOSE	X	X		X		

Table 1 - Mechanical Desktop constraints (Courtesy of Autodesk, Inc.)

of sheet metal (also called strip) which is spool fed into a punch press. The punch press consists of a movable ram (powered by hydraulic or mechanical means) and a stationery table. The die shoe, guide posts and die block (called subassembly 1) are fixed to the table by means of bolts. The ram holds subassembly 2, which consists of the bushings, punch and punch holder. In operation, when the ram is lowered, so is the punch, and the sheet metal strip between the punch and die is sheared, resulting in the product.

The design starts with the die block. The die block is made of tool steel and has an opening in the center. This opening has the same shape as the stamping. Design handbooks specify the minimum distance between the die block opening and the sides of the same. These distances were used to specify the length and width of the die block. Also, the die block opening requires draft angles all around to allow the sheared material, which expands because of plastic deformation, to fall through the opening without obstruction. The draft angle as well as the block thickness depend on the strip thickness and can be selected from standard tables. Once these parameters were determined, the die block was modeled in Pro/ENGINEER. The punch was also designed using a like approach and design methodology.

The remaining components of the tooling-fasteners, guide posts, bushings, punch holder, and die shoe are standard parts and can be selected from a catalog (for instance from the *Danly Machine Works* catalog). The particular choice of the die shoe and punch holder (which are selected as a set) depends largely on the die block size. This is because the die block which is to be mounted on the die shoe must maintain certain prescribed (by design handbooks) distances to the sides of the die shoe. Bushings and guide posts selected have to match with the particular choice of the die set, as well as provide for certain interference and clearance fits in the final assembly. Interference fits are required between the die shoe and guide posts in the subassembly 1 and between the bushings and the punch holder in subassembly 2. A clearance fit is required between the bushings and the guide posts in order to permit relative motion. Once these components were designed, they were all modeled and stored as part (.PRT) files.

Assembly modeling was performed next. Subassemblies 1 and 2, shown in *Figures 11* and *12,* were created independently and stored as separate assembly model (.ASM) files. The several constraints discussed earlier, such as mate, align, insert etc., were used to constrain these subassemblies. Finally the two subassemblies were assembled together to form the final product, as shown in *Figure 13*.

Results

This project has several implications for student learning. Specifically:

a. It provides a single integrated project wherein a student is able to apply all the design/graphics principles to the attainment of a "real-world" product. For example, in this project, students had to select specific force (FN) and running clearance (RC) fits for functionality and use dimensions obtained to complete the modeling activity. Students usually merely perform a table lookup to solve worksheet-like, stand-alone problems to find mating part dimensions and tolerances, given a specific fit such as FN 5.

b. It helps students to "see" the marriage between graphics/modeling and the

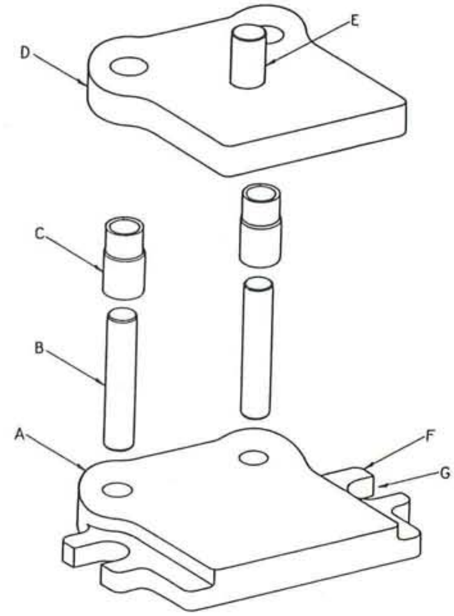

Figure 9 *- A typical die set (From Ostergaard, D. E. "Basic Diemaking". Copyright © 1963 by McGraw-Hill Book Company, Inc. Reproduced with permission of The McGraw-Hill Companies).*

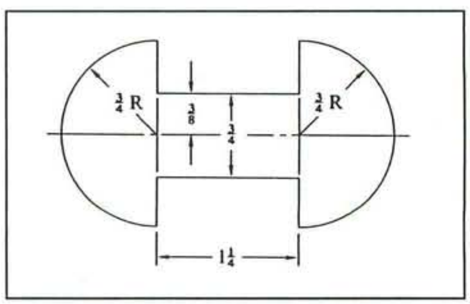

Figure 10 *- The Stamping (From Donaldson, C., LeCain, G. H., and Goold, V. C. "Tool Design". Copyright © 1957 by McGraw-Hill, Inc. Reproduced with permission of The McGraw-Hill Companies).*

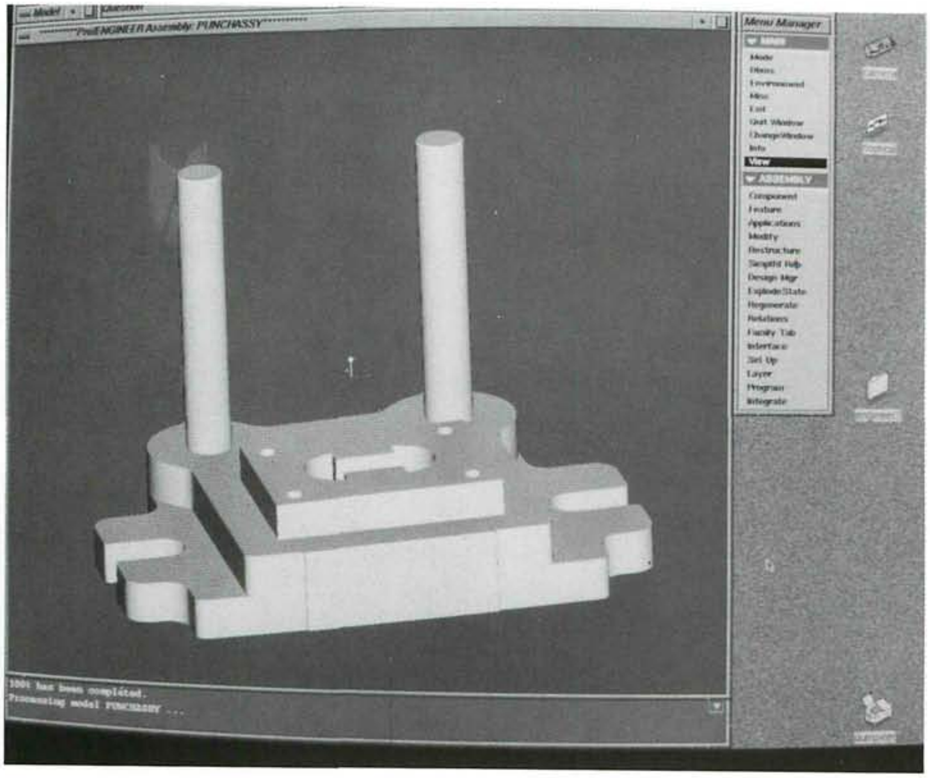

Figure 11 *- Subassembly 1.*

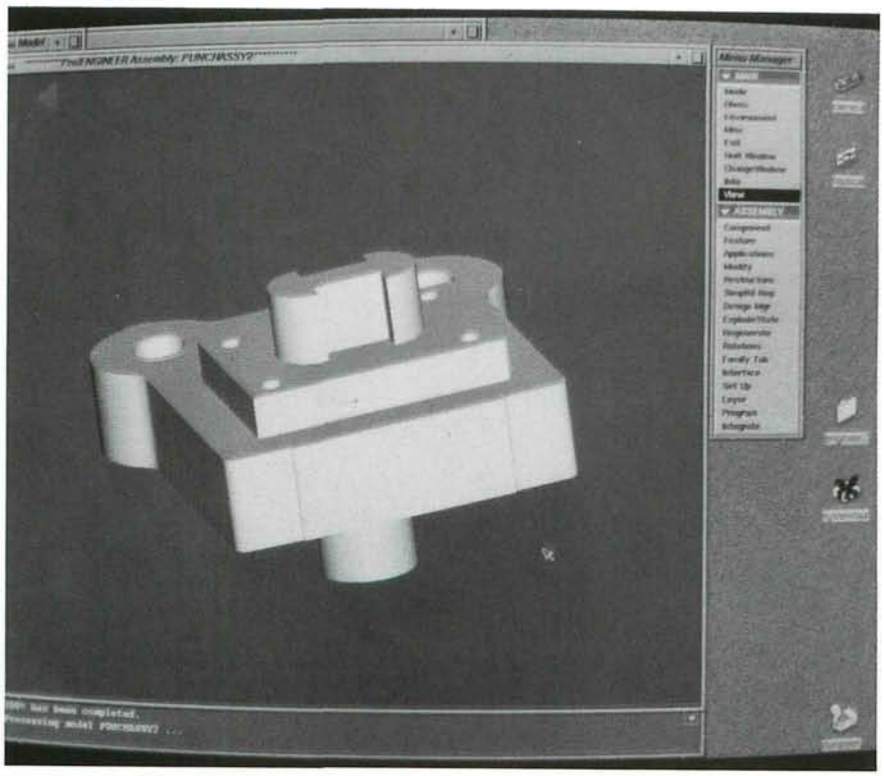

Figure 12 - Subassembly 2.

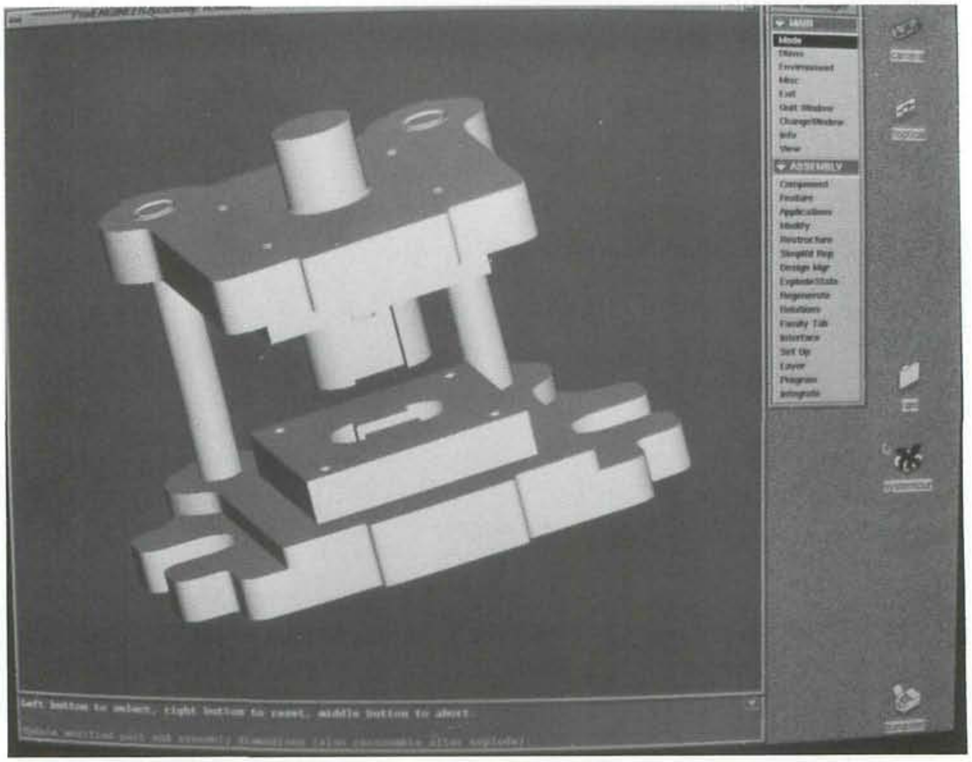

Figure 13 - The complete design.

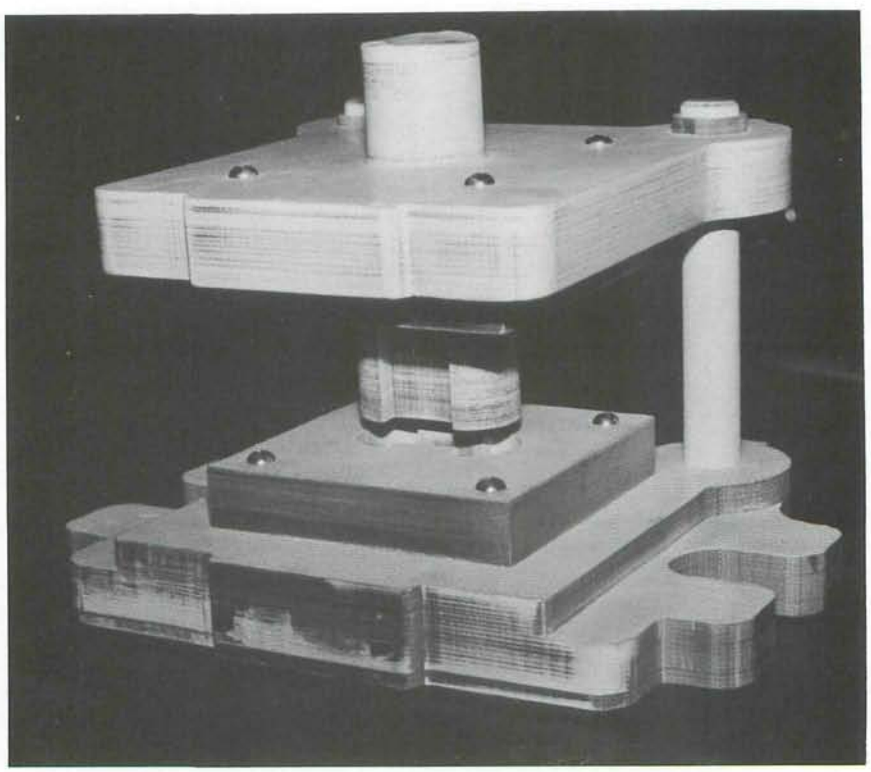

Figure 14 - Rapid prototype of the assembly.

engineering design process. This is very important because students frequently are exposed to distinct and disjointed graphics and design courses, which may be covered in different semesters.

c. It provides students an opportunity for applying assembly modeling to the solution of a design problem that involves a product assembly. This is also important because most engineered products require some degree of assembly.

d. Students may be encouraged, as in our class project, to generate STL files for rapid prototyping each component and physically assembling the prototyped components to check for form, fit and function. *Figure 14* shows a rapid prototype of the entire tooling that was built on a Helisys LOM 1015 rapid prototyping machine.

e. The process of geometrically constraining the assembly and building a prototype will enable students to apply design for manufacture (DFM) and more importantly design for assembly (DFA) guidelines and thereby implement Concurrent Engineering (CE).

Conclusions

Assembly modeling, which is a relatively new addition to the world of modeling is an important tool in the hands of design engineers. This is because most products are assembled units as opposed to a single monolithic product. The use of traditional solid modeling to assemble components, while adequate for visualization purposes, cannot support downstream design and manufacturing analyzes. Assembly modeling, which augments solid models by providing hierarchical relationships and mating conditions, is able to capture the designer's intent and support the aforementioned analyzes. Therefore, it is important that assembly modeling be included in the engineering design graphics curriculum.

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