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A Feasibility Study Of The Application Of A Computer Graphics System To The Integrated Design And Analysis Of A Mechanical Component.

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by

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ABSTRACT

A Feasibility Study Of The Application Of A Computer Graphics System To The Integrated Design And Analysis Of A Mechanical Component

by John Jung-Chung Chen

The investigation reported on in this thesis is a feasibility study concerned with the evaluation of a three dimensional interactive graphics system for the designing, drafting and analysis of a forged mechanical component.

Initially, a three dimensional interactive graphics system was examined. Extending this examination, a description of the systems approach was demonstrated in a detailed application. Problems and solutions were explored and listed for discussion. These included geometric manipulation and structure modeling. Finally, recomendations were proposed to achieve better efficiency of using a computer graphics system.

As a result of this analysis, this feasibility was demonstrated for a three dimensional interactive computer graphics system applied to computer-aided design of a

complex mechanical component.

1. Introduction

This thesis examined the feasibility of using a three dimensional interactive graphics system for improving the efficiency of designing, drafting, and analyzing a complex metal part. The basic objectives of the thesis can be stated as follows:

- Examination of basic features of the computer graphics system to be used.
- Evaluation of important functions of the computer graphics system.
- Use of computer-aided design (CAD).
- Presentation of potential problems encountered in CAD process.
- Development of solutions to the problems.

Basic features are examined to provide a brief overview in system configuration and software specifications making up the computer graphics system. To sucessfully apply computer-aided design and manufacturing (CAD/CAM) techniques, it is necessary to fully understand the specifications and functions of the system [22].

The main thesis work performed consisted of designing, drafting, and analyzing machine parts by using computer graphics system. Furthermore, several flow charts of programs using graphics software packages are suggested, followed by a more detailed discussion on the problems and difficulties encountered in the computer-aided design processing function. Finally recommendations for achieving optimum efficiency in using computer graphics are proposed for advanced users.

2. Problem Definition

The primary problem area which this thesis addresses is the man-machine interface arising from design activities. For example, misunderstanding of the geometric data base can lead to poor efficiency of using a graphics system [21,22]. Furthermore, in view of the complexity of geometric data, it is a difficult task to select an appropriate algorithm with which to work.

Computer graphics can be defined as a human-oriented system that uses the capabilities of a computer to create, transform, and display pictorial and symbolic data [15]. A critical aspect of using computer graphics is the knowledge of fundamental concepts of graphic processes, geometric data base, and computer processing.

3. Background

Two dimensional mechanical drawings have traditionally been used to describe solid objects, but designers must deal with three dimensional objects and their interrelations [22]. The system used in this thesis is an advanced three dimensional graphic operating system for high precision engineering design and drafting applications. It offers the design engineer a solution to the problem of three dimensional representation of solid objects. The computer graphics system helps engineers and drafters to be more productive in their work by solving problems quickly and easily. The system used in this thesis will now be briefly described.

3.1 System Configuration

Interactive multi-station computer graphics system hardware is based on a dual processor design incorporating [16]:

- Minicomputer.
- Graphics Processor.

The graphics processor handles much of the work involving the tabletizer terminals, improving system performance by decreasing the computer work load.

Typically both computer and graphics processor can communicate directly with each other through a shared block of memory.(Refer to Figures 3-1 and 3-2)

3.2 Software Capabilities and Specifications

The computer graphics software consists of two major parts [1]:

- PDP-11/34 using the RSX-11M Operating System.
- Graphics System.

The RSX-11M operating system provides an environment within which the graphics system can operate. The minicomputer software handles scheduling, disk, tape input/output and other monitor functions. It also provides program development functions. The computer graphics software exists as a series of RSX-11M tasks, data files and memory which operate under the overall control of RSX-11M.

The computer graphics system specification summary is as follows:

Resolution: 16,777,215 points in each principal axis (x, y, and z). Basic units may be expressed as a natural unit in inches, and millimeters.

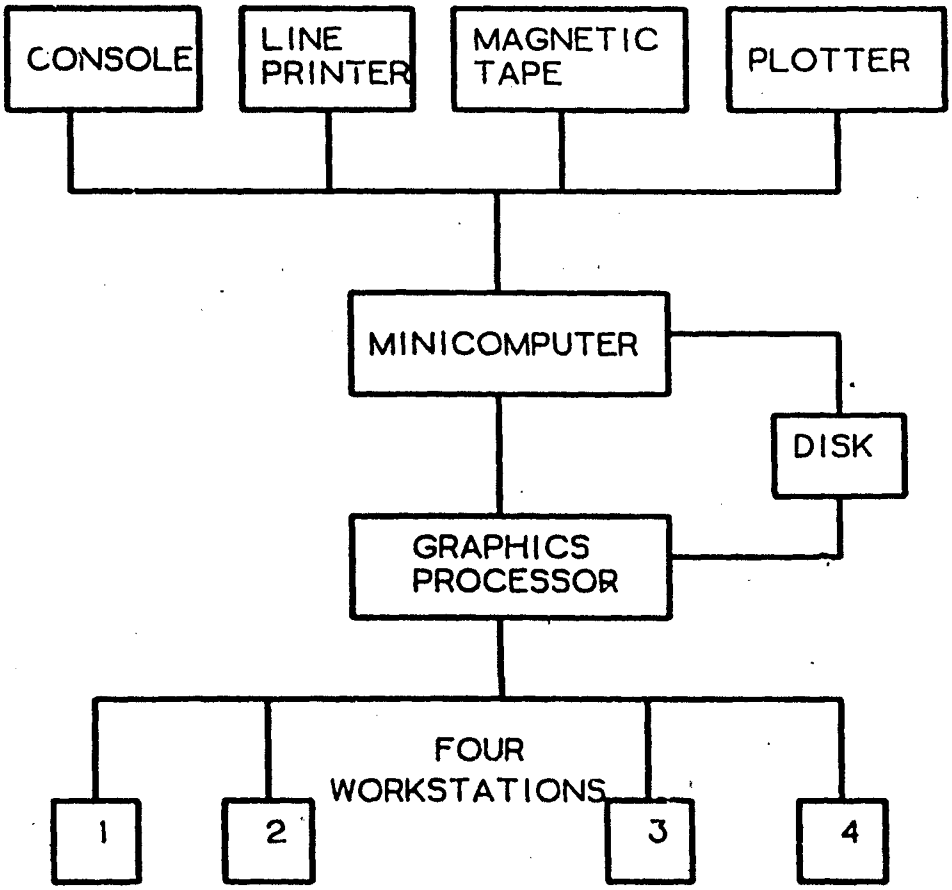

Figure 3-1: Typical Hardware Configuration.

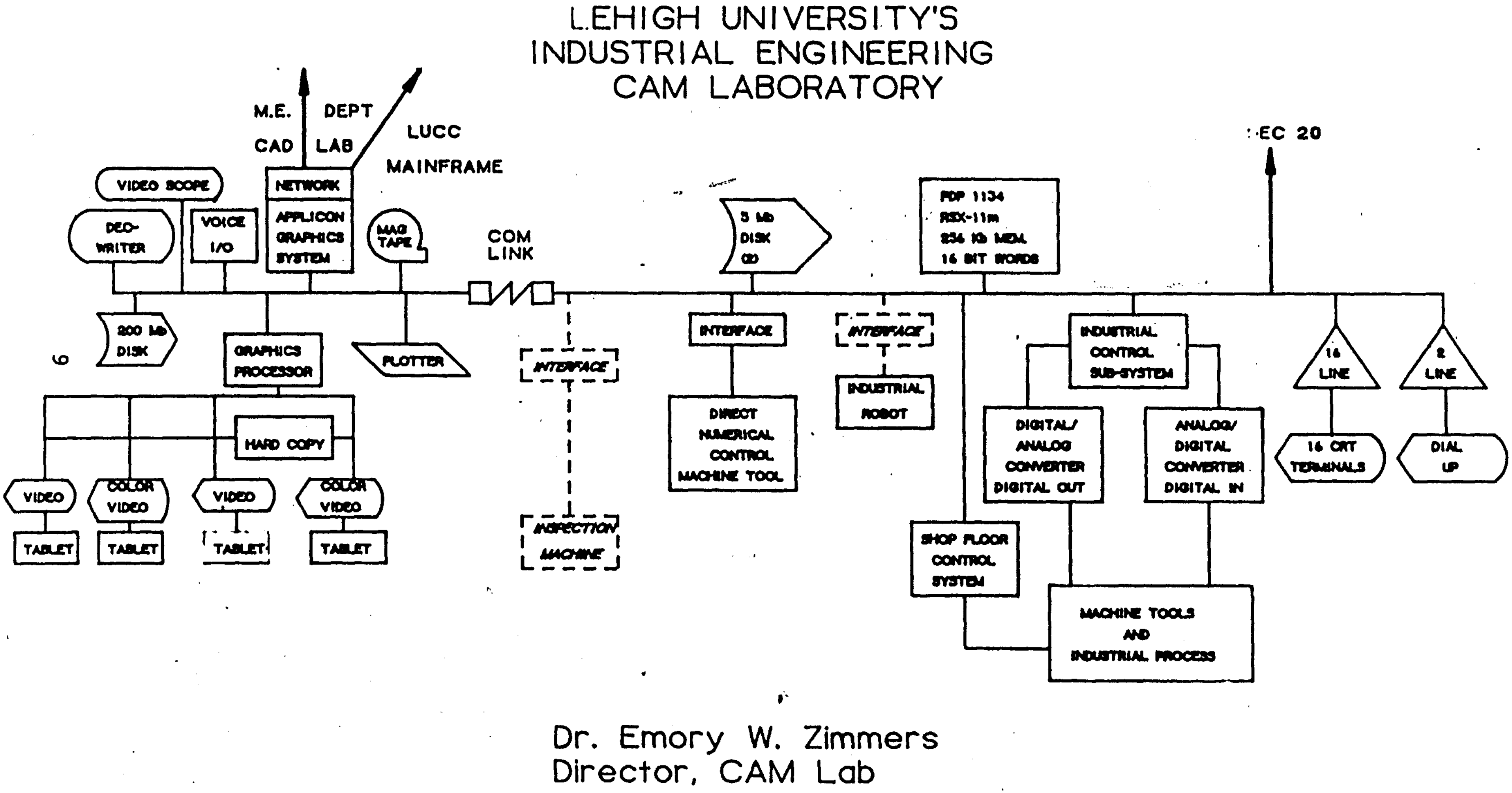

Figure 3-2: Computer Aided Manufacturing Laboratory.

Grids: Independent x, y and z grids with offset in each axis. Radial grids and angular grids are also available.

Level and bins : A total of 16 levels with 15 bins each. In addition to levels and bins, grouping operations may be organized for drawing manipulation.

Commands : More than 150 commands enable the operator to perform complex tasks more easily. A basic set of 25 or 30 commands is sufficient for most operations. The remainder allow more sophisticated manipulations to be easily performed.

Drawing components : There are a total of 14 components in the user's library. These include Points, Paths, Conics, Polysplines, Polytexts, Revolutions, Faces, Rules, Warps, Dlines, Cells, Ccells, Snapshots and Formats [1].

Drawing File Storage and Manipulation : A drawing file has three parts :

- Symbol Dictionary

- Component Library
- Component Instance File (the drawing itself)

Multiple workstation areas on the disk for drawing storage allow the computer to perform time-share drawing production with more than one user. Individual users can build a library of standard parts as well as a dictionary containing stylus symbols, menus and macros for their own use [1].

Text : Text may be added at any angle on the three planes of the drawing cube. Different sizes and fonts of text are also available.

System software packages :

- Interactive Modeler - for finite element analysis programs.
- Numerical control programming package - for labelling, tool paths, APT source files and cutter location files.
- System interface options [1,16]. Fortran and macro interface.

4. Evaluation of Important Computer Graphics Features

The capabilities of the computer graphics system could be summed up as follows [4,22]:

- Computer Assisted Drafting.
- Geometric Modeling.
- Structural Analysis.
- Numerical Control.

Numerical control considerations were omitted because this area is not pertinent to this thesis. All other features will be detailed, described and commented upon in this subchapter.

4.1 Setpoint Facilities

Setpoint [1] enables the user to manipulate graphic data using a built-in system geometric calculator. Setpoint has a memory for storing such geometric entities as scalars, vectors, line segments, arcs, and planes [20]. Setpoint routines for geometric and mathematical functions free the user of continuously resolving tedious and complex three dimensional problems. Once a setpoint geometric or computational problem has been solved, it is remembered by the system. It can be used repeatedly for a variety of operations.

The geometric entities stored in setpoint memory may be used as arguments to standard graphics commands and may be included in the system macro commands [1]. Listed below are two basic setpoint examples showing their capabilities and functions.

1) True distances of selected, skewed line segments may be obtained with the following user's defined setpoint macro command:

```
TRDI = SET @VI=@S @V2=@S; DIST @V1 @V2; GOSH;
```

This verifies the accuracy of distance in the three dimensional drawing.

2) This macro command draws a line between two selected vertices:

```
SNAP = SET @V1=@S @V2=@S; ADD @V1 @V2; GOSH;
```

4.2 Geometric Property Calculation

The system automatically calculates geometric properties for a wide variety of two and three dimensional shapes. Sectional properties features will compute the following [20]:

Volume and weight
Centroid
First and second moments of inertia
Polar moments
Principal axes
Radii of gyration

In order to fully use these features, engineers must master the constraints of these software routines. Figure 4-1 displays the routines of the software to calculate the volume and weight of a machine part.

4.3 Macro Commands

Frequently used command sequences may be strung together with setpoint facilities to form a macro command that further simplifies the operating process [1]. In addition to geometric entities which are explicitly defined from a keyboard, tablet input is allowed when a tablet symbol has been defined as a setpoint macro.

The following is an example of setpoint macro set-up for three dimensional sectioning which allows the designer to determine the profile of a cross section at any desired location or orientation. This macro provides a simplified way of cutting a section through the three

```
EDIT LEVELS: 1  REF. LEVELS: NONE
GRID: 0.0001" 0.0001" 0.0001"  OFF: 0.0000" 0.0000" 0.0000"
VUE CENTER: 3.1249" 5.1624" -8.0000"   WIDTH: 30.0000"

IO 123;

CHOOSE:
   0. ABORT
   1. AREA PROPERTIES
   2. PERIMETER ONLY
   3. VOLUME AND WEIGHT
 TYPE 0,1,2 OR 3, THEN EOCIO 123;

3;
INPUT PRECISION. RANGE IS 0-256, WHERE 0 MEANS ABORT.
THEN HIT EOC. 3;

25;
SHOULD SETPOINT REMEMBER RESULTS OF CALCULATIONS?25;

Y;
ENTER SETPOINT CONSTANT WHICH  RECEIVES VOLUME
ENTER '@CX;', X=1,2...12, OR ELSE ENTER 'N;'Y;

@C1;
ENTER SETPOINT CONSTANT WHICH  RECEIVES WEIGHT
ENTER '@CX;', X=1,2...12, OR ELSE ENTER 'N;'@C1;

@C2;
CHOOSE:
   0. ABORT
   1. CROSS-SECTION OF SOLID OF REVOLUTION
   2. SOLID OF CONSTANT THICKNESS
 TYPE 0,1,OR 2@C2;

2;
INPUT THICKNESS (WHERE 0 MEANS ABORT) 2;

8IN;
INPUT DENSITY (WHERE 0 MEANS ABORT) 8IN;

.283;
ENTER 2 POINTS IN THE PLANE OF THE SECTION..283;

4 0 0 -4 0 0;
4 0 0 -4 0 0;

AXIS POINTS: 4.0000"   ,  0.0000"   ,  0.0000"
            -4.0000"   ,  0.0000"   ,  0.0000"
PRECISION PARAMETER: 25.0000
SOLID OF CONSTANT THICKNESS
THICKNESS: 8.0000"
DENSITY:   0.2830
VOLUME:    594.3750"   3
WEIGHT:    168.2019
FRONT
IPS: 1.00000
USING: P1   NUMBER SELECTED: 6
ON LEVELS: 2   SAVED POINTS: 12
EDIT LEVELS: 1  REF. LEVELS: NONE
GRID: 0.0001" 0.0001" 0.0001"  OFF: 0.0000" 0.0000" 0.0000"
VUE CENTER: 3.1249" 5.1624" -8.0000"   WIDTH: 30.0000"
UU;

UNSA;
```

Figure 4-1: Volume And Weight Calculation Routines.

```
EDIT LEVELS: 2  REF. LEVELS: NONE
GRID: 0.0001" 0.0001" 0.0001"  OFF: 0.0000" 0.0000" 0.0000"
VUE CENTER: 3.1249" 5.1624" -8.0000"   WIDTH: 30.0000"
SE;

NATU;SELC -8388600 -8388600 -8388600 8388600 8388600 8388600;NATU;
IO 123;


CHOOSE:
   0. ABORT
   1. AREA PROPERTIES
   2. PERIMETER ONLY
   3. VOLUME AND WEIGHT
 TYPE 0,1,2 OR 3, THEN EOCIO 123;

3;
INPUT PRECISION. RANGE IS 0-256, WHERE 0 MEANS ABORT.
THEN HIT EOC. 3;

25;
SHOULD SETPOINT REMEMBER RESULTS OF CALCULATIONS?25;

Y;
ENTER SETPOINT CONSTANT WHICH  RECEIVES VOLUME
ENTER "@CX;", X=1,2...12, OR ELSE ENTER "N;"Y;

@C3;
ENTER SETPOINT CONSTANT WHICH  RECEIVES WEIGHT
ENTER "@CX;", X=1,2...12, OR ELSE ENTER "N;"@C3;

@C4;
CHOOSE:
   0. ABORT
   1. CROSS-SECTION OF SOLID OF REVOLUTION
   2. SOLID OF CONSTANT THICKNESS
 TYPE 0,1,OR 2@C4;

2;
INPUT THICKNESS (WHERE 0 MEANS ABORT) 2;

5.8IN;
INPUT DENSITY (WHERE 0 MEANS ABORT) 5.8IN;

.283;
ENTER 2 POINTS IN THE PLANE OF THE SECTION..283;

2.875 0 0 -2.875 0 0;
2.875 0 0 -2.875 0 0;

AXIS POINTS: 2.8750"  ,  0.0000"  ,  0.0000"
            -2.8750"  ,  0.0000"  ,  0.0000"
PRECISION PARAMETER: 25.0000
SOLID OF CONSTANT THICKNESS
THICKNESS: 5.8000"
DENSITY:    0.2830
VOLUME:     127.0497"   3
WEIGHT:     35.9537
FRONT
IPS: 1.00000
USING: P1   NUMBER SELECTED: 4
ON LEVELS: 2   SAVED POINTS: 8
EDIT LEVELS: 2  REF. LEVELS: NONE
GRID: 0.0001" 0.0001" 0.0001"  OFF: 0.0000" 0.0000" 0.0000"
VUE CENTER: 3.1249" 5.1624" -8.0000"   WIDTH: 30.0000"
UU;
```

```
SET @C6=(@C2-@C4)!

OK!
VSET @C6 0!
@C6= 132.24814VSET @C6 0!
FRONT
IPS: 1.00000
USING: P1   NUMBER SELECTED: 0
ON LEVELS: 2   SAVED POINTS: 0
EDIT LEVELS: 1  REF. LEVELS: NONE
GRID: 0.0001" 0.0001" 0.0001"  OFF: 0.0000" 0.0000" 0.0000"
VUE CENTER: 3.1249" 5.1624" -8.0000"   WIDTH: 30.0000"
```

dimensional wireframe geometry using the system sectioning and setpoint features [1,20].

1) Define tablet stroke

```
DEF = GRID .0001; GRID OFF; SCTS; SCTN;
```

2) Define macro SCTS

```
macro DEF = SAUE 7; GN; SET @V1 = (@S1+@S2+@S3)/3
@V2 = (1000 * PNRM (@P1  @S)) + @V1;
```

3) Define macro SCTN

```
macro DEF = SET @V5 = @V1+((WDTH/2)*NRM(@V2-@V1));
    SH FLY @V2@V1 R; CVUE @V5; GN; SECT;
```

Several results of sectioning are shown in Figure 4-2 and Figure 4-3 of machine parts.

4.4 Geometry Selection Concept

Geometry selection is a key concept in all kinds of graphic processing [1]. The selection concept is used in the manipulation of components in a design.

Before the computer can operate geometric elements displayed on the screen, the operator must select the desired elements. Typically components are selected or unselected with tablet commands along with other system commands. Selected components or named group of components may be moved, rotated, mirrored, copied, scaled, deleted and arrayed. The users should study the

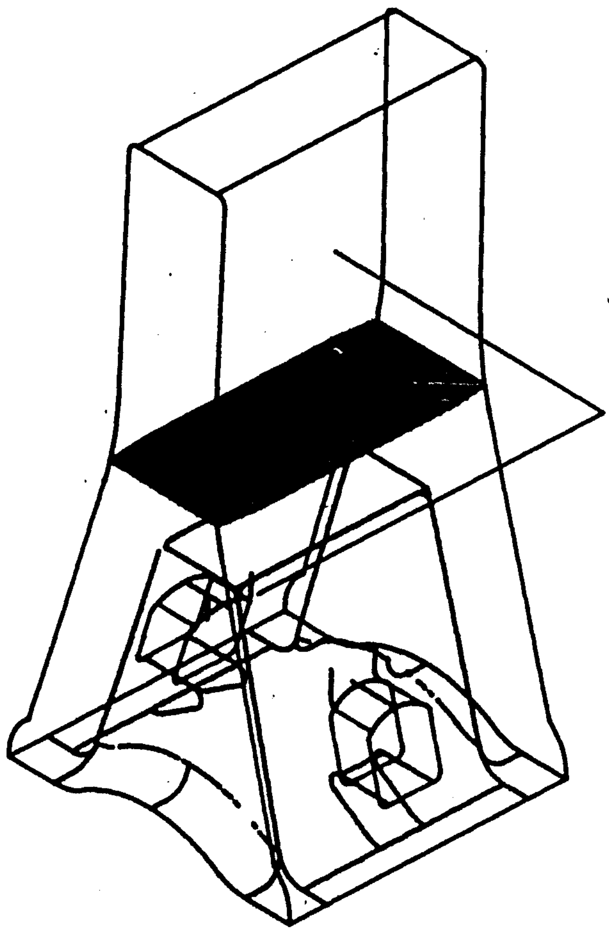

Figure 4-2: Sectioning View of a Machine Part.

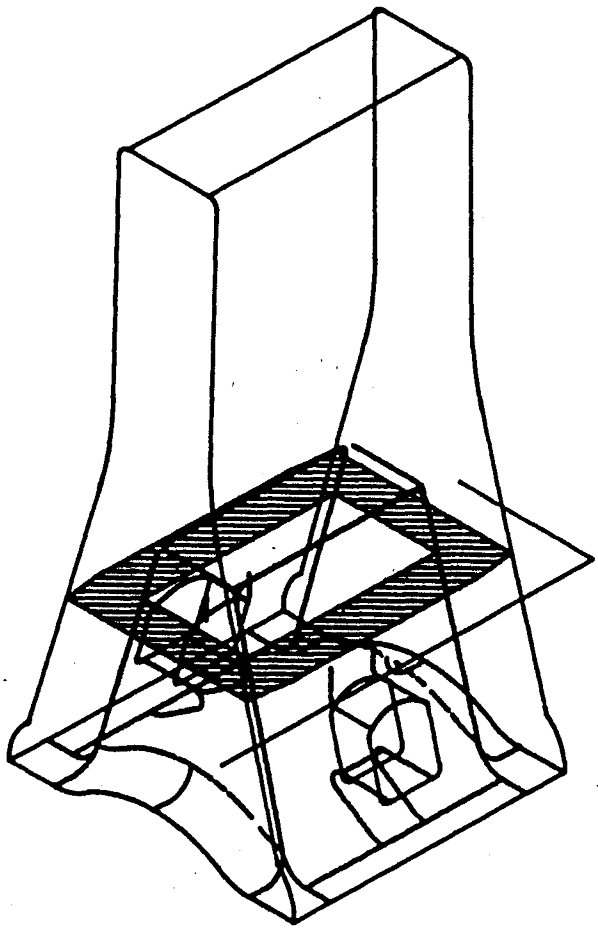

Figure 4-3: Sectioning View of a Machine Part.

differences among available select and unselect commands. The user should bear in mind how select and unselect commands may be implemented to achieve optimum efficiency.

4.5 Automatic Dimensioning

There are two time-consuming tasks involved with manual drafting [2,13,22]:

- Repetitive jobs for standard shapes and parts.
- Dimensioning.

Computer-assisted drafting has the potential to increase productivity [13]. Repetitive drafting can be overcome by using the component library. Dimensioning problems can be eliminated by automatically setting default dimensional values. Dimensional lines and values can be increased or decreased automatically where dimensional lines were previously specified. All automatically created dimensions in a drawing may be converted from English to Metric notation or from Metric to English. The user can specify that output dimensions be labeled with Inch, Centimeter, or Inch notation ("). (Refer to Figure 4-4 and Appendices for original drawings).

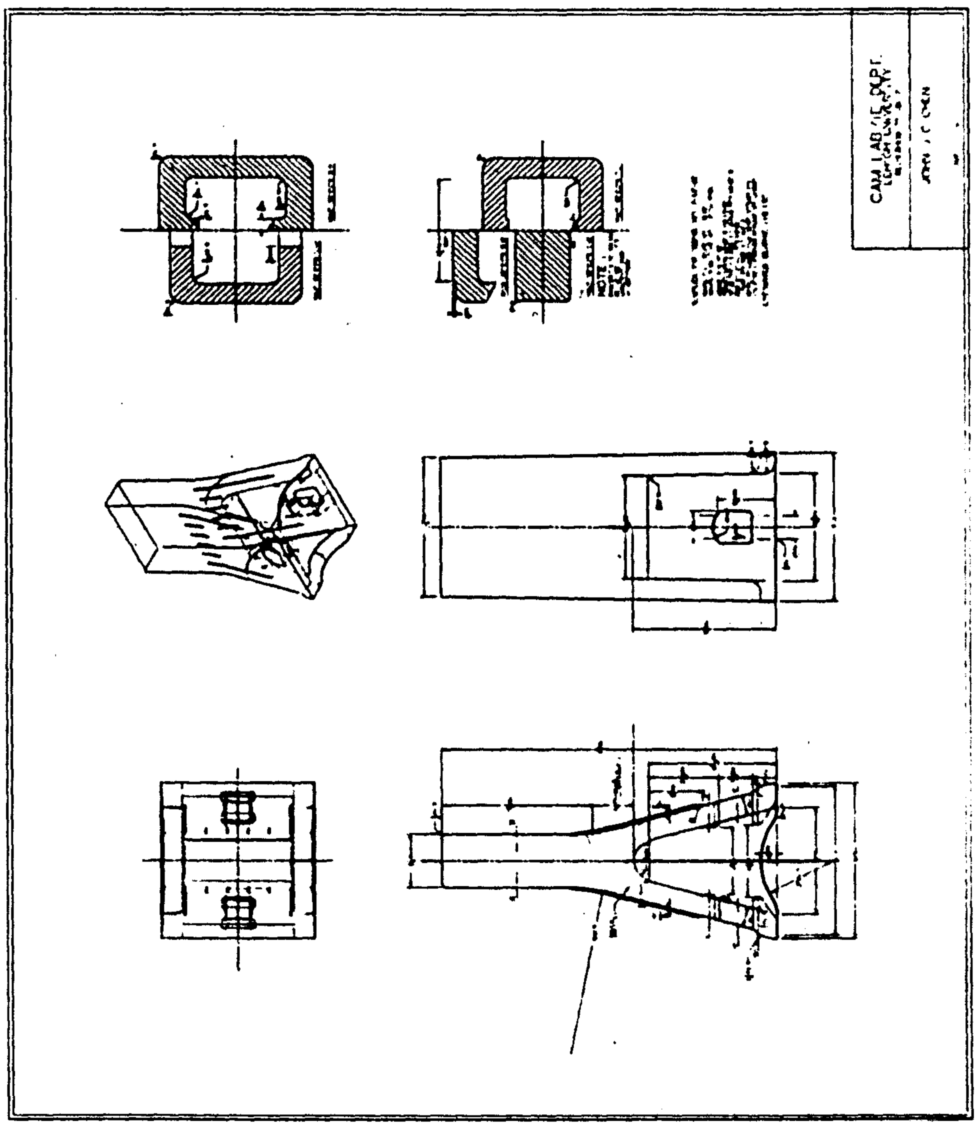

Figure 4-4: Blueprint with Automatic Dimensioning.

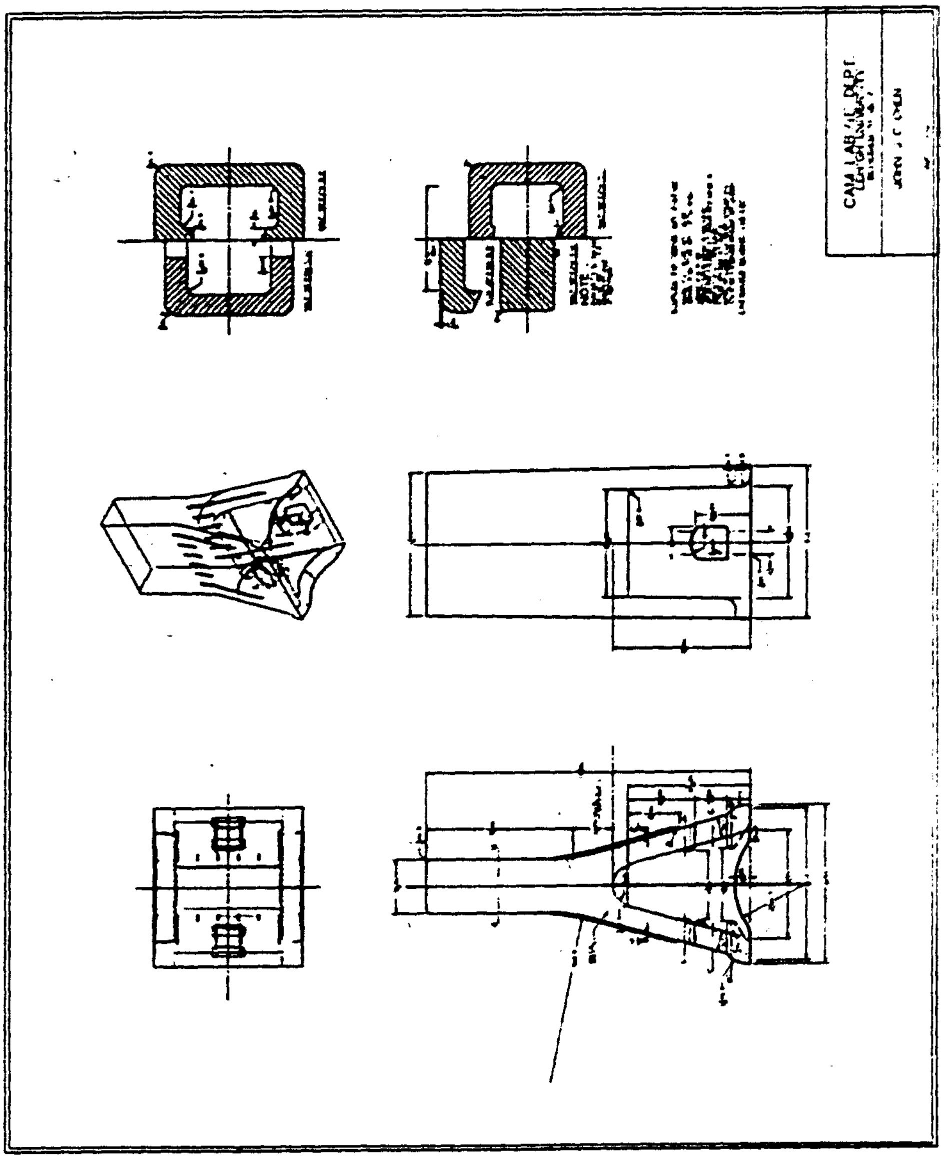

Figure 4-4: Blueprint with Automatic Dimensioning.

4.6 Structural Analysis

4.6.1 Introduction

Finite element analysis is a powerful tool for determining stresses and deflections in a structure too complex for manual analytical methods [5]. Today, nearly all stress analyses are done on computers by using the finite element method.

Commercial programs and packages of finite element analysis such as ANSYS, SAP, or NASTRAN [17] reduce the time involved in calqulations and computations for engineers. However, the program inputs require that the structure be "modeled" in great detail. Elements and nodes at the corners of the elements are numbered and entered the analysis program on a mainframe computer. This preparation job is done manually, and is very tedious and time consuming. A computer interactive modeler permits rapid construction of two and three dimensional finite element models using an automatic mesh generator. It permits full model editing and allows input of data for several general purpose finite element analysis models.

4.6.2 Finite Element Modeling

Finite element modeler is a general purpose software package which works within the system so that the original model may be accessed directly. Working with the original model provides benefit to the process which is labor intensive and error-prone.

The operational capabilities of the software are classified into three groups:

- Viewing and editing capabilitites of the model.
- Interactive construction capabilities of the finite element model.
- Post-analysis processing capabilities.

These combined capabilities can save engineers time in constructing, verifying and interpreting the result of a finite element analysis.

The finite element modeling work flow diagram is shown in Figure 4-5. Output from modeling is transferred to a mainframe computer for analysis since the minicomputer would take too much time for this function.

Figure 4-6 shows a flow chart of using an interactive modeler. It is a recommended algorithm to increase productivity of modeling.

Figure 4-7 and 4-8 show mesh generation from computer graphics with node and element text showed in Figure 4-9.

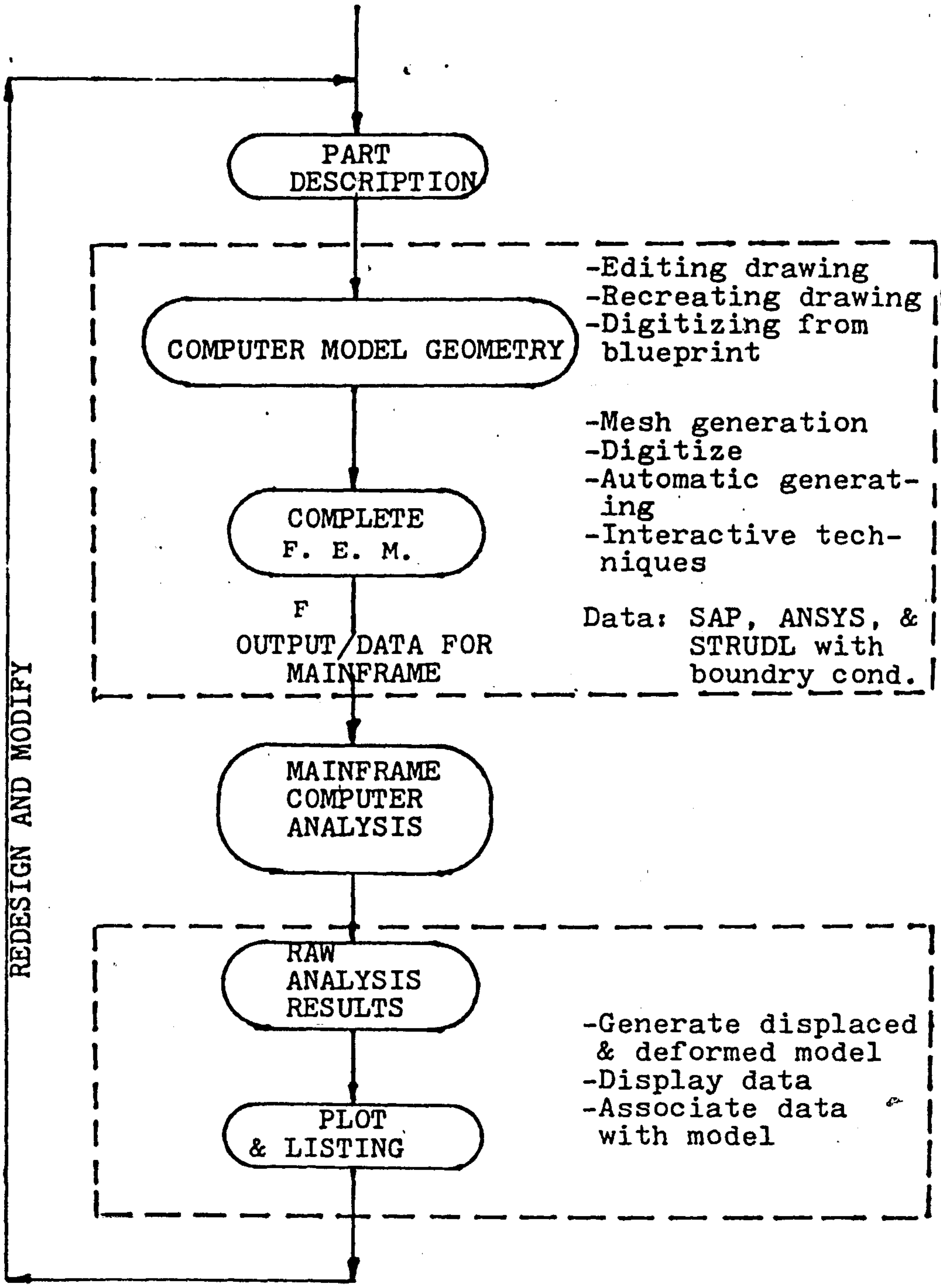

Figure 4-5: Finite Element Modeling Work Flow Diagram.

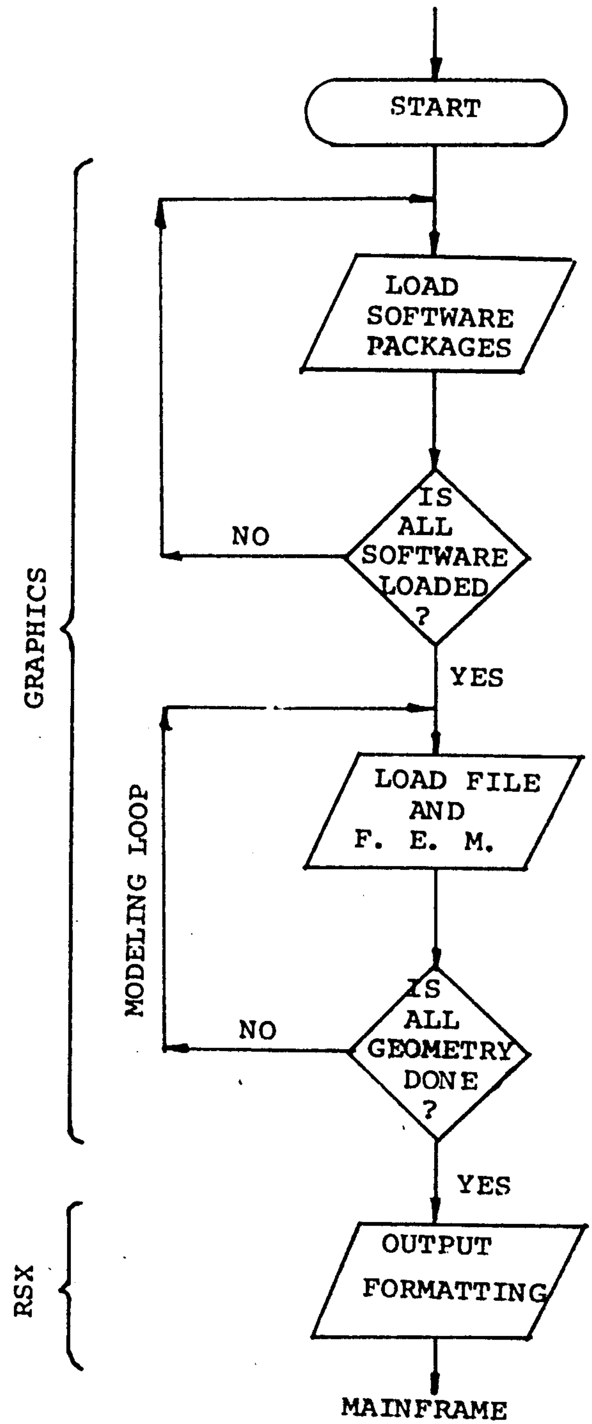

Figure 4-6: Flowchart of Using Interactive Modeler.

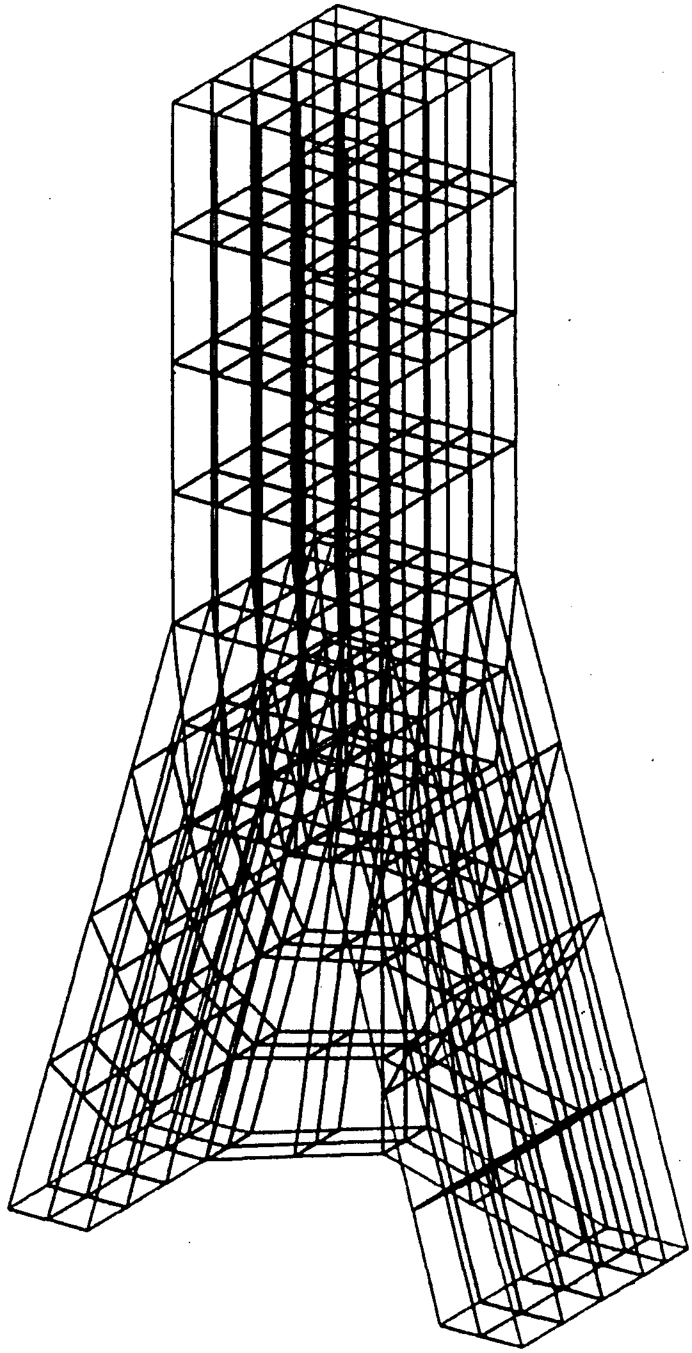

Figure 4-7: Mesh Generation.

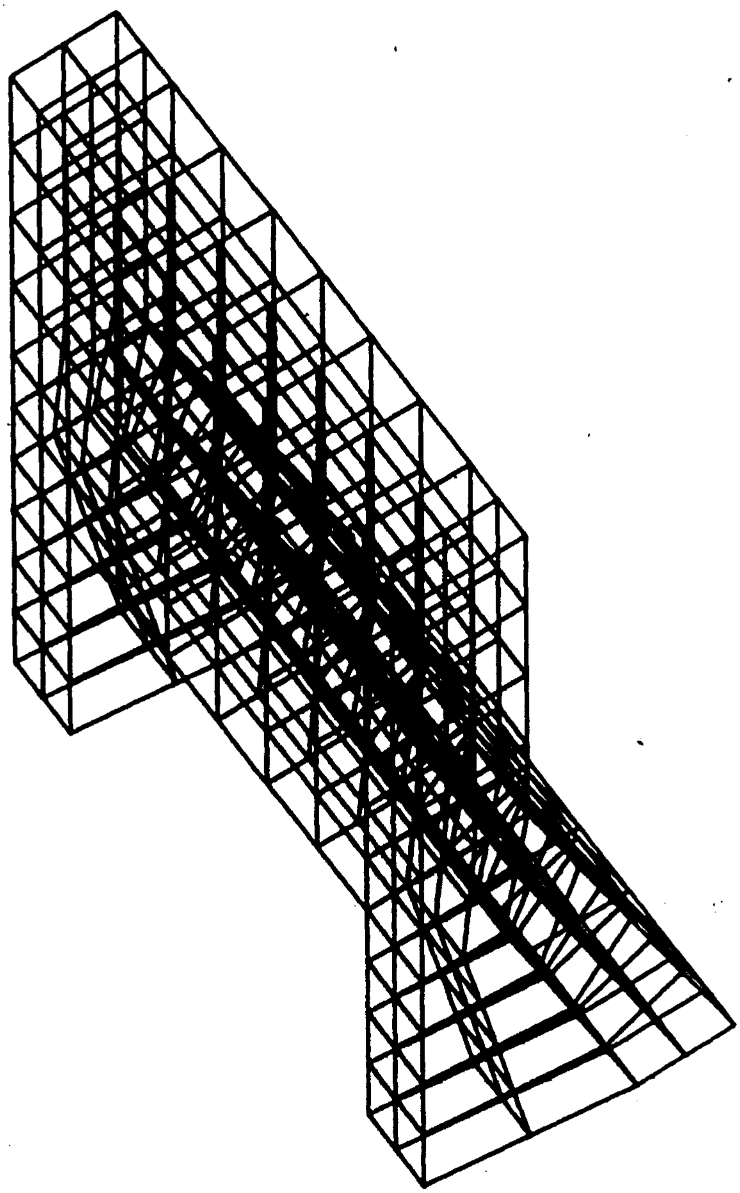

Figure 4-8: Mesh Generation.

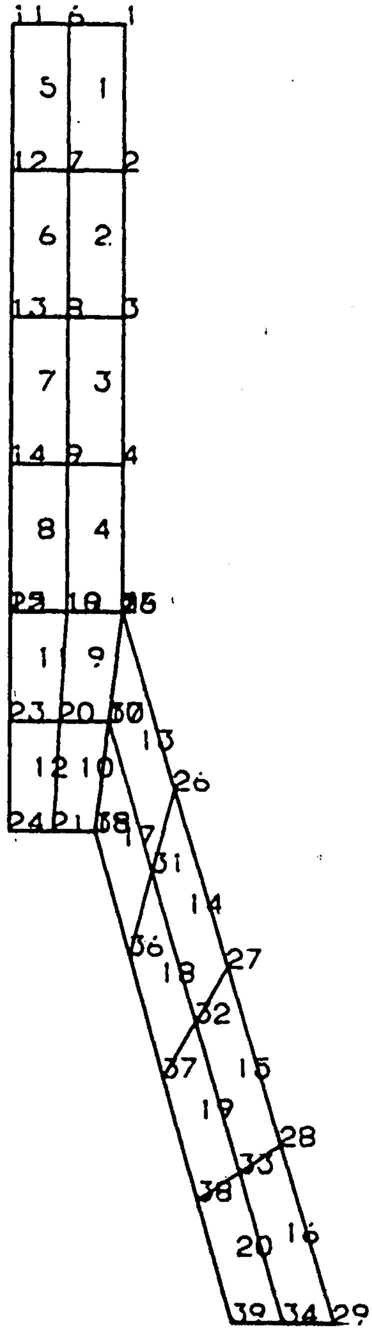

Figure 4-9: Node and element text.

5. Analysis

Based on work conducted during this thesis study of the feasibility of the designing, drafting and analysis of a forged mechanical component, the following can be stated :

A. In general sculptured-surface creations are difficult [9]. A sculptured surface represents one of the most challenging aspects of geometric modeling. All surfaces are not well-defined. In many systems the differences among surfaces are not explained in detail. Often users have no information on the program's constraints, creation process or application .

B. Clear rules for creating tablet symbol commands are a necessity. Their clarity is essential. Since the tablet command plays an important role , it is necessary to have a clear cut rule for creation of tablet commands. Specifically, the following must be addressed:

- When is it necessary to use the tablet for input ? (What command is valid only with tablet command ?)
- How many strokes and dots are needed for a particular command? (especially for a macro command)
- Does "stroke syntax" exist ?

- Placement of tablet stroke ?

C. Software manuals should be carefully designed. In many cases there are no well-defined rules or process (algorithms) for the solutions of all potential problems. Users often must develop the techniques or skills in dealing with real-world problems.

D. Error message must assist the user to a greater extent. It is not possible to provide all kinds of error messages for debugging purpose, the user is often in a puzzle about what is going on with the system . For instance, in doing the crosshatch process , all of the following conditions must be met.

- Only polyarcs and polyspines are workable boundaries.
- Crosshatch areas must be bounded by boundaries.
- Crosshatch line component must be different from the boundary components.

If the user misses any one of the above, the system will always accept and echo commands but will give no error message or result.

E. An interactive modeler can help engineers to reduce the time involved in modeling. However, there are some problem which exist in many software packages:

- The modeling macro is limited, and uses commands different from system commands.
  Also, the keyboard name is not complete. Users have to experiment with new macro's for themselves.
- It is difficult to control and change the numbering pattern of nodes and elements.
- Some system commands such as for mirror and brick will upset ordering of geometric data base. No warnings are provided by the software.
- Since no fixed algorithms exists, it is difficult to determining the most optimum method of designing a part.
- No special editors or tools are available to change the original drawing into free-body geometry.

6. Recommendations for Future Work

To extend this study, there are several areas which could be examined to achieve better efficiency of using a graphics system:

1. Methods to help the user initialy create geometric entities which are conducive to analysis should be explored [14]. For example, there are several ways to create with different data bases:

Strokes	Geometric Data Base
ADD;	One line, Two vertices
ADD; ADD;	Two lines, Four vertices
ADD; ADDV;	One line, Three vertices
ADD; ADD; JOIN;	One line, Four vertices

The above concept and its relationship is very important when it comes to manipulation later for mirror, rotation and copy.

2. The most efficient macro length could be examined [1]. For example, creating a macro will give better efficiency over inputing commands one-by-one. However, very long strings of macros are extremely difficult to

debug.

Furthermore in order to create a powerful setpoint macro the user should have reasonable knowledge of analytic geometry, vector, setpoint features, polar coordinates and command priority. productivity increases will depend heavily on this technique.

3. An investigation should also include the advisability of using dummy components [14]. For example, dummy components are very often necessary to aid manipulation for automatic drafting, dimensioning, crosshatching, and mesh generation.

4. Future work should include the examination of preparation procedures before working on a computer graphics system [2,14]. For example, levels and bins assignment sheet could aid the user in effectively grouping, isolating and separating the geometric components. Refer to Figure 6-1 level assignment sheet. Preparation work is typically useful to the modeling. A study could also examine the structure before a model is prepared for finite element modeling such as numbering

policy, symmetry, density and size of the element, and highest stress areas.

COMPONENT	LEVEL ASSIGNMENT 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
P1	V															
DT1		V														
CL1			V													
BNDRY 1				V												
BNDRY 2					V											
BNDRY 3						V										
NODES							V									
NODES TEXT												V				
ELEMENTS													V			
ELEMS TEXT														V		
......								V								

Figure 6-1: Level assignment sheet.

LEVEL ASSIGNMENT

COMPONENT	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
P1	V															
DT1		V														
CL1			V													
BNDRY 1				V												
BNDRY 2					V											
BNDRY 3						V										
NODES							V									
NODES TEXT												V				
ELEMENTS													V			
ELEMS TEXT														V		
......								V								

Figure 6-1: Level assignment sheet.

7. Summary

This thesis evaluated the feasibility of applying a three dimensional computer graphics system for the designing, drafting, and analysis of a forged mechanical component. Since an understanding of a interactive graphics techniques was considered a prerequisite to efficient operation, all important features of the system were explored. With this foundation, the evaluation of the approach was developed. A forged mechanical component was manipulated in the computer-aided design process. Finally, difficulties and solutions were explored and discussed. As a result of this investigation, the feasibility was demonstrated for the computer interactive graphics system applied to computer-aided design of a forged mechanical part.

8. Conclusion

As a result of this study, it can be concluded that a three dimensional interactive graphics system is capable of performing the designing, drafting, and analysis of a forged mechanical component.

However, there remain several areas which need special attention for enhencement. First, the geometric data base should be well created and managed for subsequent application. Second, with respect to macro development it is imperative to deal with particular problems which a standard computer graphics system software package could not solve. Finally, preparation work for the different tasks should be further developed prior to working with a computer graphics system. The preparation indicated a sharp reduction in the manipulation work in the computer graphics system, and could lead to greatly inproved productivity.

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Appendices

Finite Element Output for Mainframe.

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```
IO 70 0 0 0 0 0 0 10 GD ANSYS-NODES;
IO 70 0 0 0 0 0 0 10 GD ANSYS-NODES;
INOUT VER. 003.20-I
```

1	1.4351	17.3736	-3.9980
2	1.4351	15.4076	-3.9980
3	1.4351	13.4417	-3.9980
4	1.4351	11.4757	-3.9980
5	1.4351	9.4996	-3.9980
10	0.7188	9.4996	-3.9980
11	0.0000	17.3736	-3.9980
12	0.0000	15.4076	-3.9980
13	0.0000	13.4417	-3.9980
14	0.0000	11.4757	-3.9980
15	0.0000	9.4996	-3.9980
6	0.7188	17.3736	-3.9980
7	0.7188	15.4076	-3.9980
8	0.7188	13.4417	-3.9980
9	0.7188	11.4757	-3.9980
16	1.4351	9.4996	-3.9980
17	1.2675	8.0315	-3.9980
18	1.1024	6.5608	-3.9980
21	0.5537	6.5608	-3.9980
22	0.0000	9.4996	-3.9980
23	0.0000	8.0315	-3.9980
24	0.0000	6.5608	-3.9980
20	0.6350	8.0315	-3.9980
25	1.4351	9.4996	-3.9980
26	2.1209	7.1272	-3.9980
27	2.8067	4.7549	-3.9980
28	3.4925	2.3825	-3.9980
29	4.1859	0.0000	-3.9980
34	3.5306	0.0000	-3.9980

Figure 8-1: ANSYS-NODES Output.

```
EDT;
EDT;
IO 70 0 0 0 0 0 0 10 GD ANSYS-ELEMS;
IO 70 0 0 0 0 0 0 10 GD ANSYS-ELEMS;
INOUT VER. 003.20-I
```

1	2	7	6	21	22	27	26	1	4
2	3	8	7	22	23	28	27	1	4
3	4	9	8	23	24	29	28	1	4
4	5	10	9	24	25	30	29	1	4
6	7	12	11	26	27	32	31	1	4
7	8	13	12	27	28	33	32	1	4
8	9	14	13	28	29	34	33	1	4
9	10	15	14	29	30	35	34	1	4
11	12	17	16	31	32	37	36	1	4
12	13	18	17	32	33	38	37	1	4
13	14	19	18	33	34	39	38	1	4
14	15	20	19	34	35	40	39	1	4
21	22	27	26	41	42	47	46	1	4
22	23	28	27	42	43	48	47	1	4
23	24	29	28	43	44	49	48	1	4
24	25	30	29	44	45	50	49	1	4
26	27	32	31	46	47	52	51	1	4
27	28	33	32	47	48	53	52	1	4
28	29	34	33	48	49	54	53	1	4
29	30	35	34	49	50	55	54	1	4
31	32	37	36	51	52	57	56	1	4
32	33	38	37	52	53	58	57	1	4
33	34	39	38	53	54	59	58	1	4
34	35	40	39	54	55	60	59	1	4
61	62		64	73			30	1	4
62	63	66	65	74	75	78	77	1	4
64			67	76			79	1	4

Figure 8-2: ANSYS-ELEMS Output.

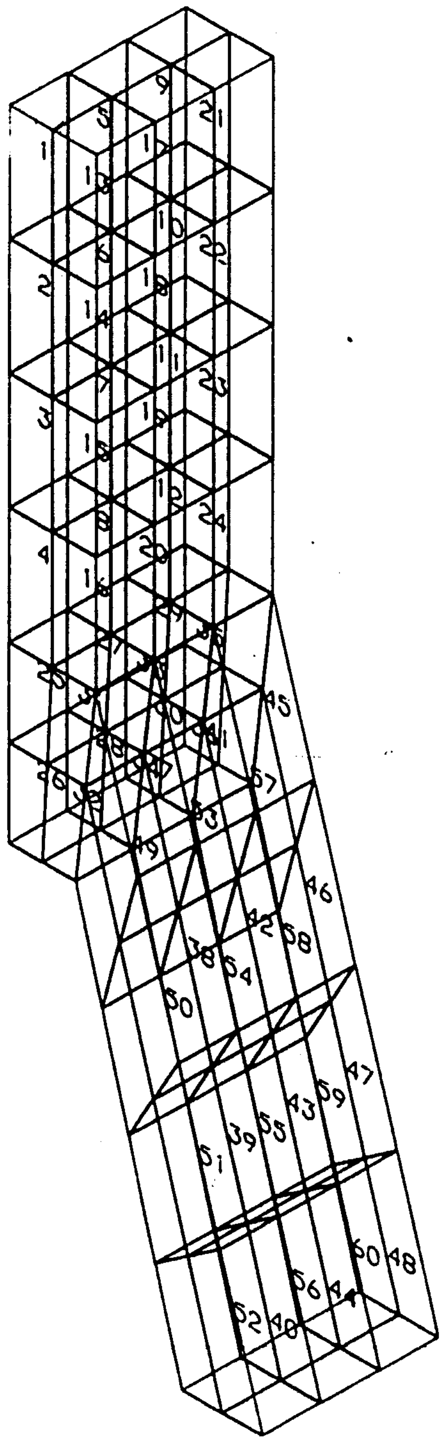

Figure 8-3: Element Generation with Labelling.

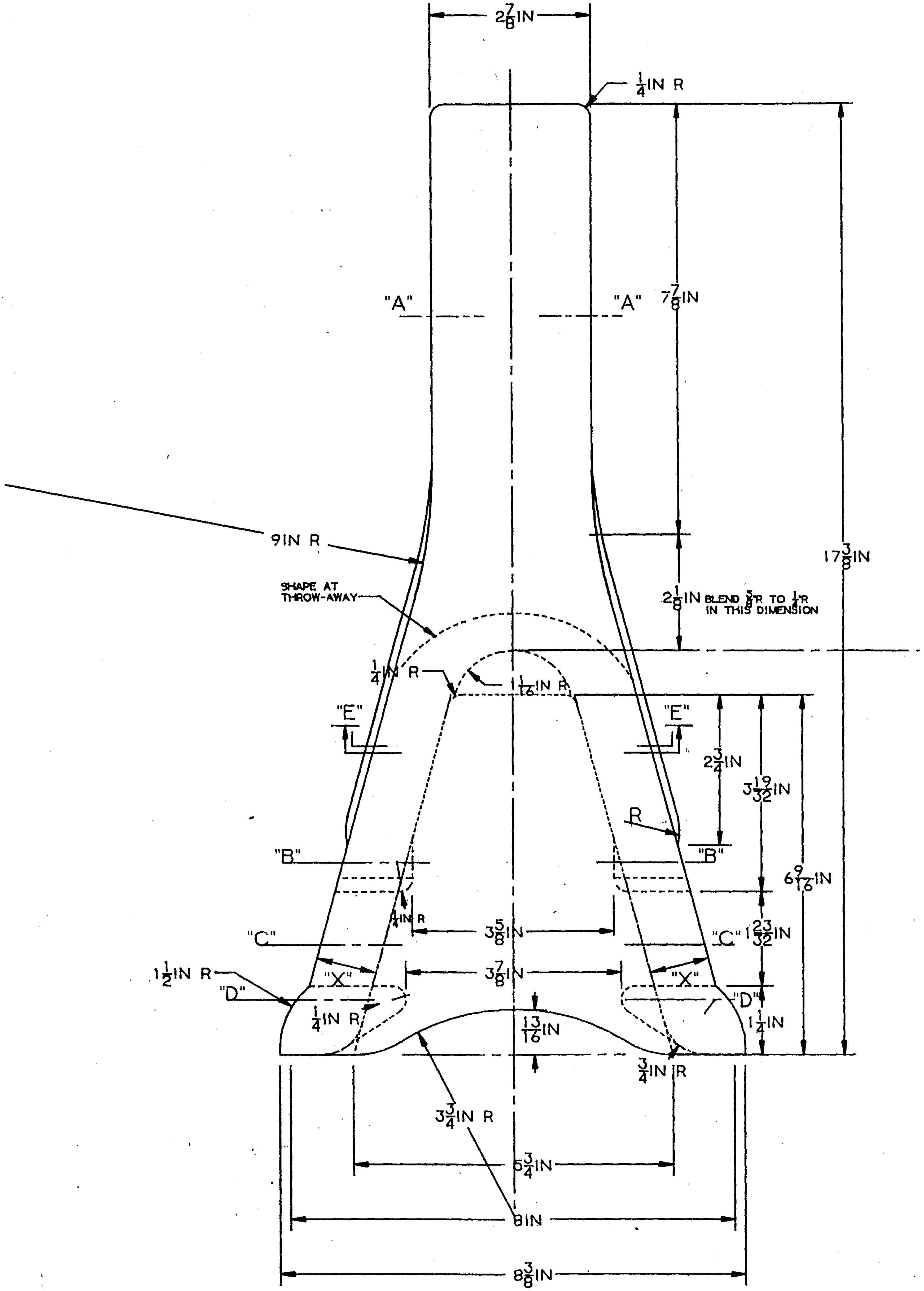

Figure 8-4: Front View with Dimensioning.

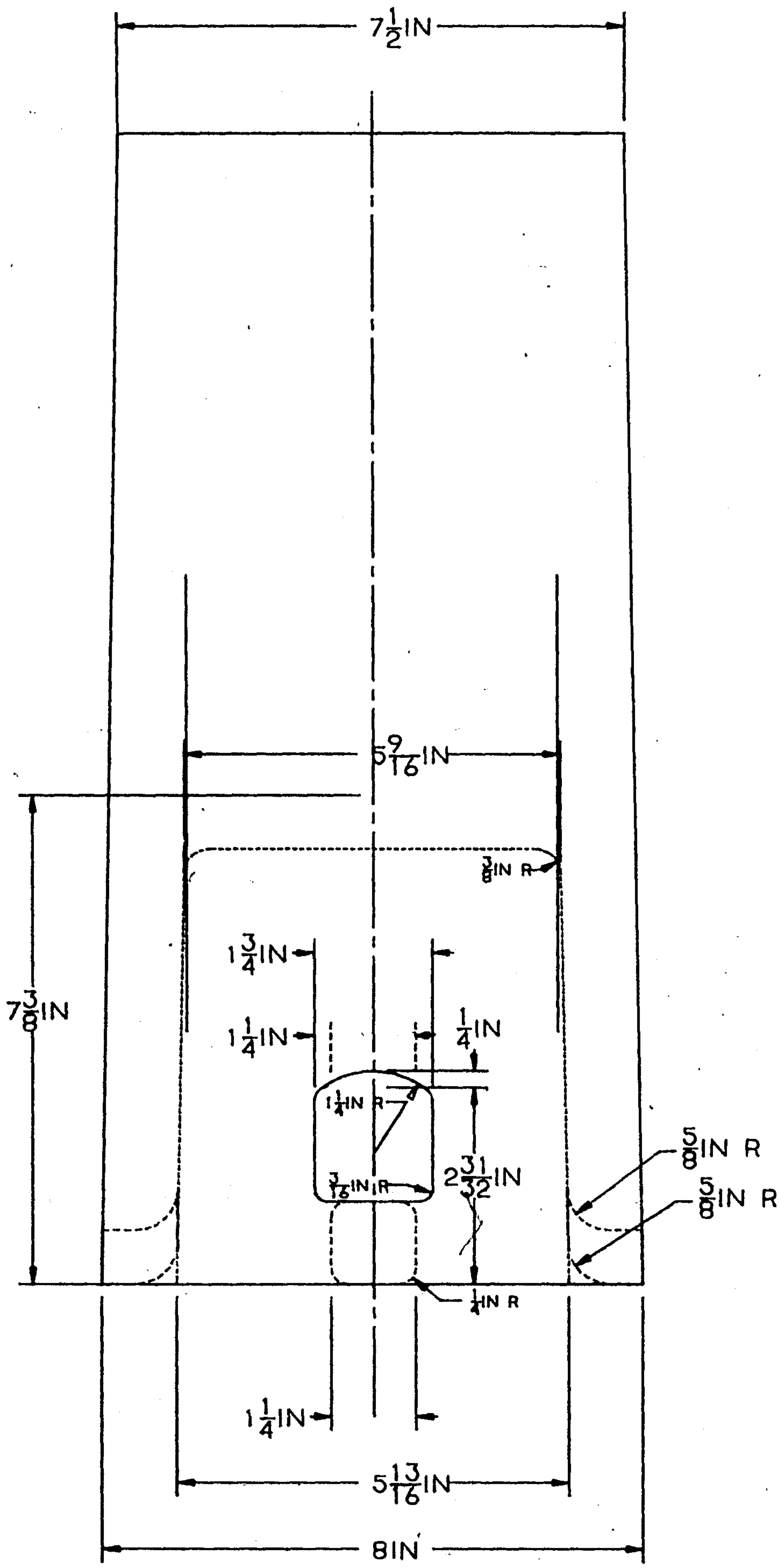

Figure 8-5: Right View with Dimensioning.

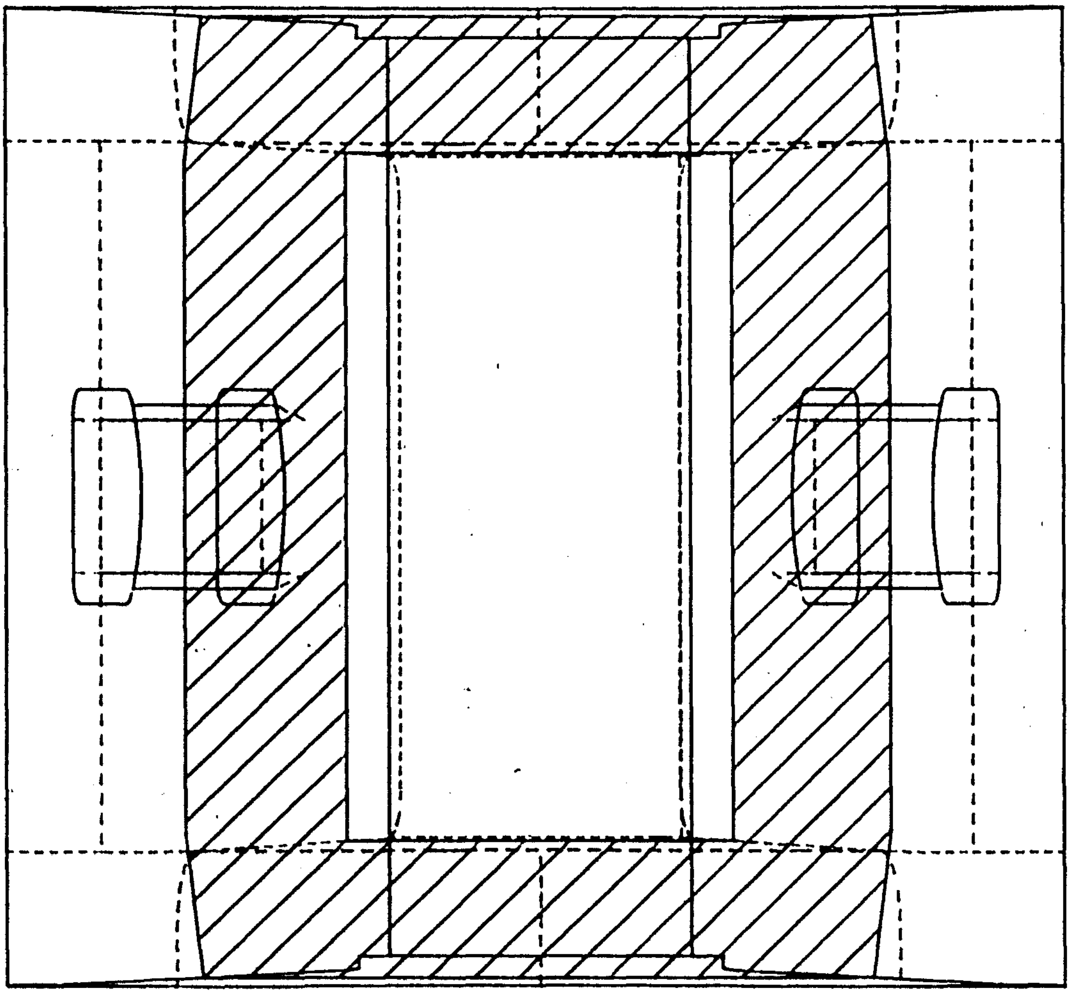

Figure 8-6: Top View with Sectioning.

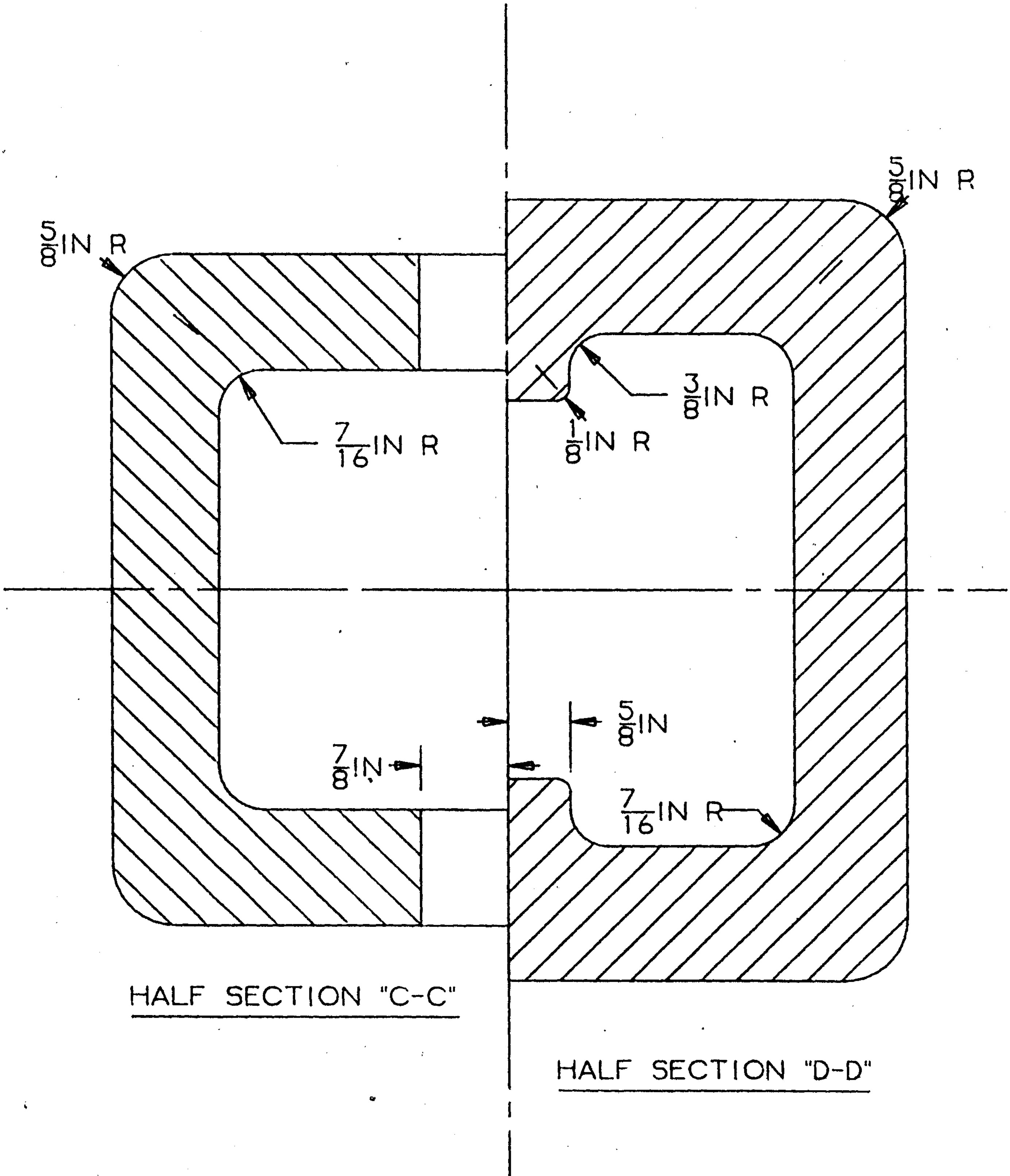

Figure 8-7: Cross Section Views.

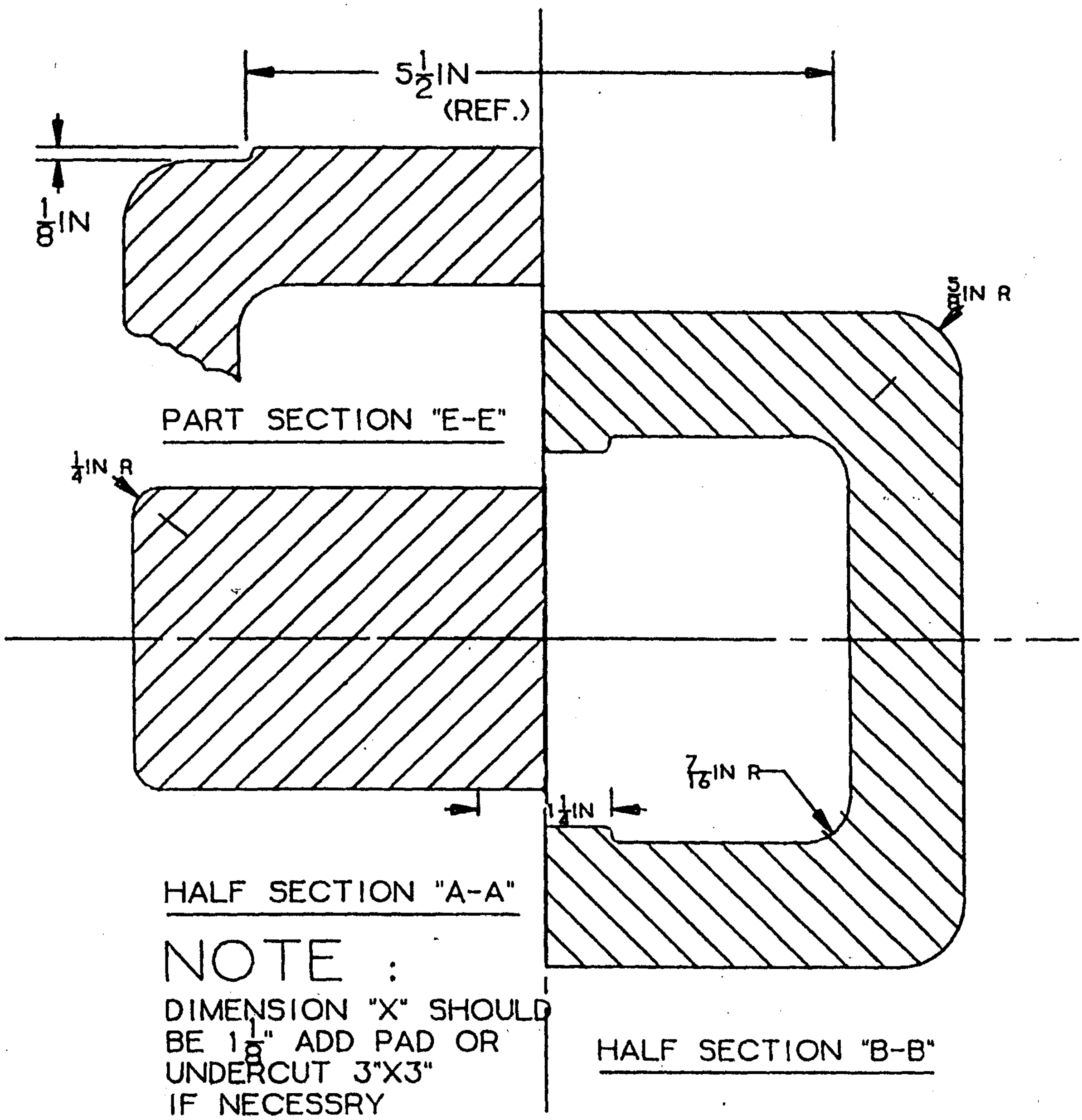

Figure 8-8: Cross Section Views.

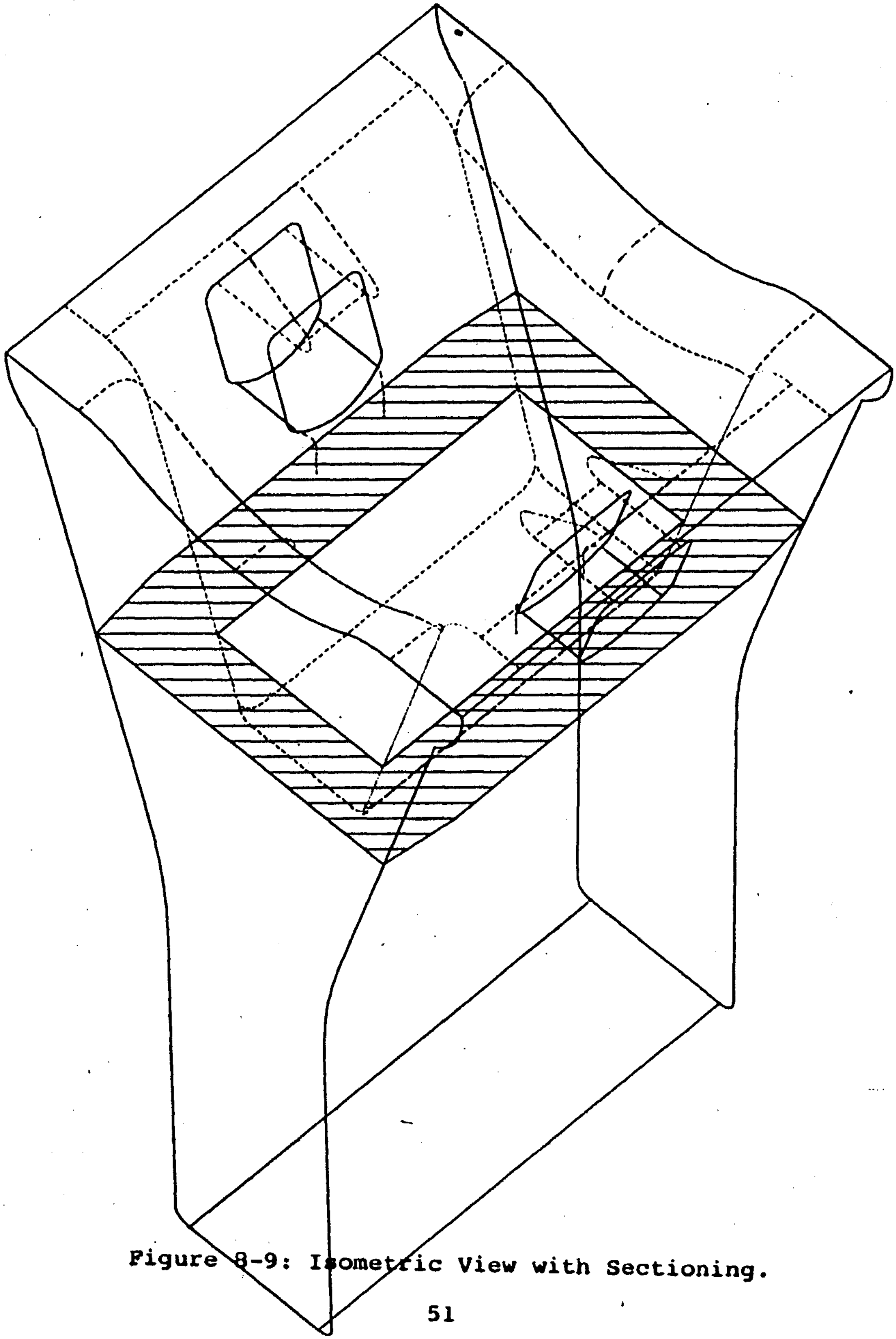

Figure 8-9: Isometric View with Sectioning.

Vita

John Jung-Chung Chen was born on March 15, 1945 in Taiwan, The Republic of China, where he received his pre-collegiate eduction. He received a B.S. degree in Mechanical Engineering from National Cheng-Kung University in 1969.

He served in the Chinese Air Force as a mechanical engineer for a year, Tong-Yuan Machinery Company as a manufacturing engineer for a year, and Ekman Company as a project director for seven years. After eight years of service in industry, he decided to continue his education with graduate study in the United States, and enrolled at Lehigh University in the Department of Industrial Engineering.