Micro-based CAD: A Production Tool for Manufacturing Engineering

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1. Introduction

This paper presents two case studies to illustrate how low cost, microcomputer-based CAD can be a viable production tool for engineering and manufacturing disciplines. The first case study concerns an engineering/manufacturing company before and after the introduction of CAD. The second study documents how micro-based CAD performs sixty to seventy percent of the 2D drafting needs formerly addressed by more costly mini-based systems, with no sacrifice in performance.

In the fast growing CAD industry, a new micro-based CAD system is introduced each week. Evaluating these many systems, especially the software, can be a source of frustration and confusion. For example, after watching a CAD demonstration, it is often difficult to determine if you have seen most of the system's capability or only a very small portion of the overall software. Since not all micro-based CAD systems can produce the successful results given in the two case studies and since they exhibit a wide range of performance levels, from "full-featured" to electronic toys, hardware and software considerations are also presented to show how common pitfalls of evaluating system performance can be avoided.

2. A Case Study of Electro Controls

Electro Controls, located in Salt Lake City, Utah, is a privately owned company founded in 1947. It makes automatic lighting control systems for television studios and theatres. More recently, the company has begun selling its control systems to owners of major hotels and office buildings who need lights in certain areas to turn on/off or to dim on schedule.

Each control system is assembled from standard components to match a specific lighting plan for a particular building. Each job requires a custom set of installation drawings so that the electricians installing the equipment know how to hang the cabinets and how to connect the wires. A set of roughly 100 standard drawings that contain modular components are referenced to produce a design customized to each client's requirements. After the engineering stage is complete, the designs are turned over to manufacturing engineers.

2.1. Engineering the Old Way

Prior to installing a micro-based CAD system, Electro Controls employed an engineering staff that consisted of six systems designers and six draftsmen. The design proceeded according to the following steps.

1. A previous drawing which most closely resembled the current design requirements was selected from the standard drawing file.
2. A blue print of this drawing was made and then red-lined (or edited) by the systems engineer.
3. The edited drawing was given to a draftsman to produce an ink on mylar sheet.
4. A blueprint of this drawing was made for checking purposes. The drafting was checked as well as the actual design.
5. The systems designers sent any changes back to draftsmen to update the ink on mylar sheet.
6. Another blueprint of the revised drawing was made and sent to the customer to review and correct.
7. Minor changes were issued by the systems designers who, in turn, submitted the corrected drawing again to the draftsmen.
8. Another blueprint was made which was checked again by the systems designers. Final changes were performed by the draftsman and the drawings were then issued as a final to the customer.
9. Manufacturing received the design drawings and used them as the basis for generating punch details for the control panel.
10. A silk screen was developed to label the operations on the front of the control panel.

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2.2. Engineering the New Way

Over two years ago, Electro Controls installed a networked, six station, micro-based CAD system. The system hardware/software cost for all six stations totaled about $150,000 (or $25,000 per networked workstation at 1984 prices). Each workstation contained the following: 68000-dedicated graphics processor, NEC 7220 graphics generator, another host processor for I/O, stylus and tablet (with menu), joystick for dynamic pan and zoom, one Megabyte of high-speed memory where the drawing remains resident during the work session, a dot-matrix printer for a fast plot, dual raster screens — one for menu display, separate high resolution (1024×796), multiple intensity (colour option), and a shared 20 Megabyte (expandable to 80 Megabyte) fixed disk where drawings are initially retrieved and stored.

Without the aid of draftsmen, the six systems designers used CAD workstations where they complete the same job that previously took six to eight weeks in about half the time. An average of 300 to 400 drawings are produced each month. According to Dale Gilchrist, Vice President of Engineering, the productivity gain of 4:1 (reduction in staff by one-half and increase in productivity by a factor of roughly two) has had a major impact on marketing. The quick turnaround time in combination with higher quality drawings, has allowed the company to accept jobs from clients requiring as little as three days completion time.

The 100 standard drawings now reside on floppy disk masters along with 30 libraries which contain over 1,000 symbols or details. The standardized engineering and manufacturing production sequence is given below.

1. The floppy disk which contains the drawings that most closely represent the new design is copied into the CAD system.
2. The systems designers make the necessary modifications to the drawings by interactively editing their drawings at their graphics workstations. The drawings are concurrently checked by the designers while they are being viewed on the graphics screen, thereby eliminating the need for blueprints.
3. The drawings are plotted ink on mylar and checked. Drafting conventions require little attention since all lettering, notes, and dimensions are consistently rendered.
4. The drawings are numbered and sent to the customer for review. Any changes or client corrections are returned to the systems designers for minor design changes which are performed at the CAD workstation. The final drawing is electronically plotted using ink on mylar.
5. In manufacturing, punch details are applied to the drawing. They are placed on a separate level so that they can be turned off later for clients.
6. A legend is prepared on still another level which is also plotted ink on mylar. This drawing is used to shoot a silk screen which is transferred to the control panel.

According to Tim Hansen, Systems Designer of Electro Controls, dimensioning the drawing had previously presented the biggest problem for draftsmen. Designers with little drafting experience can dimension components with the consistency and precision of skilled draftsmen through use of the ANSI dimensioning capability of the micro CAD system.

The transition from the drafting board to the CAD system was an easy one because of the workstation's ability to

1. instantly zoom in and out at the push of a button, and
2. move around (or pan) to different locations on the drawing through use of the joystick.

A low-cost, off-line plotter station could be used to generate the final plots without consuming valuable workstation time.

On the low end of the productivity scale, creating a schematic from scratch requires about the same drafting time using CAD as it did manually. (Of course, the CAD drawing has a more appealing consistency.) At the high end of the scale, entire proposal drawings can be quickly generated by filling in the blanks of the title block of standard drawings and adding production or function notes.

3. A Second Case Study: Mini vs. Micro CAD Systems

Due to increases in overall performance of microcomputer systems, the principle distinction between mini- and micro-based systems is price. Progressive management at Lawrence Livermore National Laboratory (L.L.N.L.) under the guidance of Fred Norton, CAD consultant, have realized that the role for the mini-based workstations in the $100,000 and higher range is 3D applications, complex, high-precision design functions, and other speciality applications. It was interesting to note their confirmation of Dataquest statistics which report CAD systems are utilized sixty to seventy percent of the time for 2D applications — only thirty to forty percent of the time for 3D and other applications.[1]

The mechanical engineering divisions of many companies found that creating 2D drawings on mini-based systems (typically costing $120,000 per workstation) was not cost effective. In many cases drafters and designers using such costly CAD workstations reported that even after one year of experience, they had achieved only the same productivity levels as previously attained using manual drafting techniques. The low productivity was attributed to the fact that the mini-based systems required mastery of a complex instruction set — more suitable to 3D modelling and design. Input of the same 2D drawings on micro CAD workstation at L.L.N.L. realized better than 1:1 productivity ratios after only a two month trial period and has contained to rise.

After gaining additional expertise in operating the CAD system, designers and drafters often recognize areas of drafting which are repetitive and which could be automated. The use of high-level language and micro-based system allows the programming of not only various graphic constructions, but also designing software to determine flange ratings, compute tube wall thickness, and solve other engineering problems. A program was written to construct a torsional test specimen based on the input of the minimum specimen diameter. This construction now requires only fifteen minutes instead of four hours that CAD operators previously took prior to the implementation of the program.[2]

4. Micro-based CAD Hardware Technology

The advent of the 68000 microprocessor is largely responsible for the technology breakthrough. Migration of software from BASIC and FORTRAN to Pascal (and other higher-level languages) accounts for the easier maintenance, transportability, and greater capability afforded by modern micro-based systems.[3]

The bar chart in figure 1 shows benchmarks of various processors against the VAX 11/780 running Pascal. It is interesting to note that a dedicated graphics processor based on 68000 architecture operating at 12.5 Megahertz yields a system whose performance far exceeds that of the existing VAX and is approximately equal to improved VAX systems of the future. It also shows performance of the 68000, 8086, and IAPX432 ar various clock rates and wait states.[4]

5. Software Evaluation: A Means to Distinguish One Micro-Based CAD System from Another

On the surface, it may be difficult to distinguish the superiority of one micro-based CAD system over another. To the experienced user, all CAD systems allow the creation of graphic primitives such as lines, arcs, circles, ellipses, text, and combination of these called groups or symbols. Furthermore, all CAD systems provide the capability to move, copy, delete, and edit objects on the drawing. So the question might rightly be asked, "What actually does distinguish one CAD system

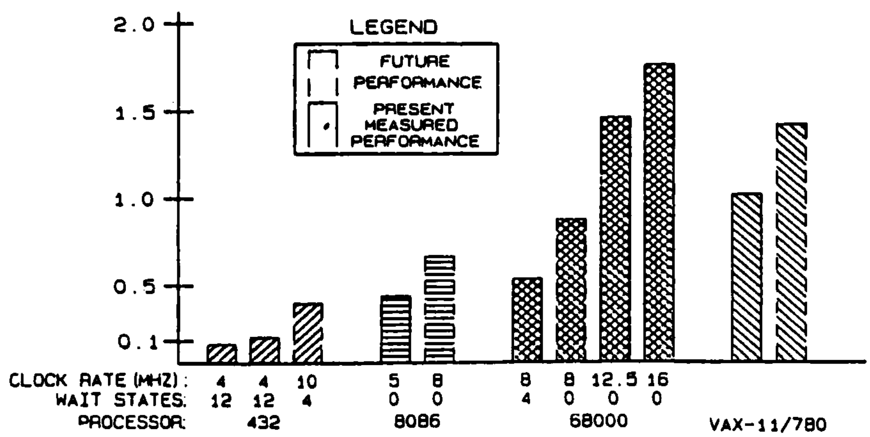


Figure 1. Performance Comparison of Processors

from another when highest productivity is the measure of effectiveness?"

To answer this question one may reason that the fewer CAD functions offered by the software, the faster the learning curve. It is true that operation of some micro-based CAD systems can be mastered in a matter of a few days. The CAD operator quickly recognizes, however, the severe limitations of such systems. Many elementary, time consuming graphic operations are found necessary to perform some of the simplest constructions. To illustrate this, consider the construction of a chamfered corner for example. Without the option to construct a chamfer directly, it may be necessary to perform a manual calculation, create additional lines, and finally edit the line segments. Ask yourself what steps would be required to convert the square corner shown in figure 2 to the chamfered corner shown in figure 3. Ideally, the operator would simply enter the 1/4" (or 2.5") and 30-degree parameters and pick the two lines.

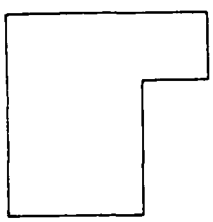


Figure 2. Original Object

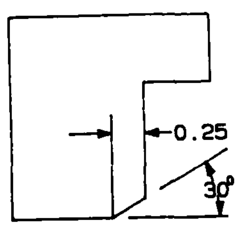


Figure 3. Object with Chamfer

As another example, consider the placement of multiple lines of notes on the drawing. Does the system require that the operator individually place each string of text in a paragraph, or can the spacing between lines be specified so that all the operator need do is indicate the location of the first text line with subsequent text strings automatically located at the desired spacing. Better still, can a file of text which has been previously entered and edited via a word processor be referenced and converted to text on the drawing? Suppose further, it is desired to centre three lines of text inside a rectangle. Does the system software require that the operator manually move the text strings to their centred position, or does the software support the automatic centering of a specified number of text lines inside a given object boundary?

As a final example, consider the external walls shown as double-lines in figure 4. Can the

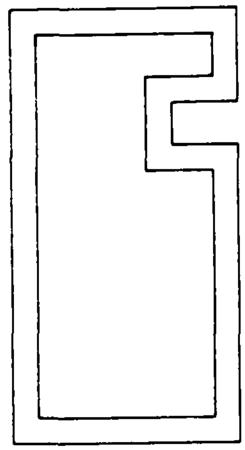


Figure 4. Exterior Walls

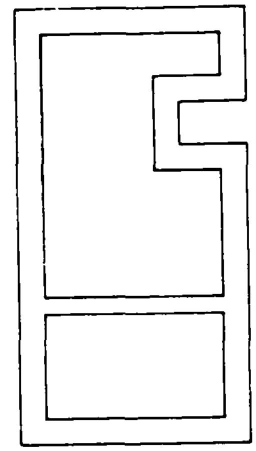


Figure 5. Added interior Walls

interior wall shown in figure 5 be added simply by picking the two endpoints? Can the interior wall be automatically gapped? Furthermore, can doors and windows of specified widths be inserted automatically into these walls at their desired locations?

From these few examples we see that the subtle nuances of CAD software contribute to great productivity gains of one system over another. CAD vendors have long recognized that the more options available to the user, the greater the productivity gains in the long run — despite the fact that the initial learning curve and the mastery of extensive software options may take longer than those systems offering only basic create and edit options.

Today, micro-based CAD systems, priced under $30,000, rival many of the larger $130,000 mini-based systems in terms of both number of software options and speed performance. Table 1 provides a check list of micro-based CAD software functions. These functions represent a concensus of experienced CAD operators generating thousands of mechanical, architectural, electrical, electronic and process drawings in a service bureau environment using mini-based workstations over a period of several years. Currently, state-of-art micro CAD systems respond in seconds to any operator selected function.

6. Conclusion

A properly selected micro-based CAD system can be an effective production tool for engineering disciplines. In comparison to manual techniques, CAD offers a reduction in the manufacturing cycle

TABLE 1. CHECK LIST OF CAD SOFTWARE FUNCTIONS

1. COORDINATE INPUT

1.1 ___ KEY IN ABSOLUTE COORDINATES OF THE FORM (X,Y), WHERE X AND Y ARE EXPRESSED AS DECIMAL NUMBERS.
1.2 ___ KEY IN ABSOLUTE COORDINATES OF THE FORM (5'3-5/16",2'2-3/8"), WHERE THE COORDINATES ARE EXPRESSED IN FEET, INCHES, AND FRACTINAL INCHES.
1.3 ___ KEY IN POLAR COORDINATES OF THE FORM DISTANCE,ANGLE WHERE ANGLE IS EXPRESSED AS A DECIMAL NUMBER OF DEGREES.
1.4 ___ KEY IN POLAR COORDINATES OF THE FORM DISTANCE,XXDYYMZZS, WHERE THE ANGLE IS EXPRESSED IN DEGREES, MINUTES, AND SECONDS.
1.5 ___ KEY IN RELATIVE COORDINATES OF THE FORM [X,Y], WHERE X AND Y ARE EXPRESSED AS DECIMAL NUMBERS.
1.6 ___ KEY IN RELATIVE COORDINATES OF THE FORM [5'3-5/16",2'2-3/8"], WHERE THE COORDINATES ARE EXPRESSED IN FEET, INCHES, AND FRACTIONAL INCHES.
1.7 ___ ALLOW KEYED IN COORDINATES TO BE TERMINATED WITH A RETURN INSTEAD OF KEYING IN THE CLOSING),], OR .
1.8 ___ THE SPECIFICATION OF X OR Y VALUES OF 0.0 IS OPTIONAL. THEREFORE (,5) SPECIFIES THE COORDINATE (0,5); OR (5,) SPECIFIES THE COORDINATE (5,0).
1.9 ___ COORDINATE INPUT FROM STYLUS PICK ON A TABLET.
1.10 ___ COORDINATE INPUT FROM STYLUS ON A DIGITIZER.

2. STYLUS INPUT MODES

2.1 ___ GRID PICK.
2.2 ___ FREE PICK.
2.3 ___ OBJECT SNAP.
___ 2.3.1 INTERSECTION OF TWO ARCS (OR CIRCLES).
___ 2.3.2 INTERSECTION OF ARC (OR CIRCLE) AND LINE.
___ 2.3.3 INTERSECTION OF TWO LINES.
___ 2.3.4 ENDPOINT OF ARC.
___ 2.3.5 ENDPOINT OF CIRCLE.
___ 2.3.6 CLOSEST POINT ON LINE.
___ 2.3.7 QUADRANT POINT OF CIRCLE.
___ 2.3.8 CLOSEST POINT ON ARC OR CIRCLE.
___ 2.3.9 FREE PICK IF NO OBJECT IS FOUND.
2.4 ___ AXIS LOCK.
2.5 ___ NON-AXIS LOCK.

3. OBJECT ATTRIBUTES

3.1 ___ LEVEL (0-255).
3.2 ___ PEN NO. (0-15) FOR COLOR OR PEN THICKNESS OF PLOTTED OBJECTS.
3.3 ___ INTENSITY (0-3) OR COLOR (0-7).

4. BUILT-IN FUNCTIONS

4.1 ___ TOGGLE GRIDS ON/OFF ANY TIME.
4.2 ___ CHANGE GRID SPACING ANY TIME.
4.3 ___ CHANGE OBJECT LEVEL ANY TIME.
4.4 ___ CHANGE OBJECT PEN NUMBER ANY TIME.
4.5 ___ CHANGE OBJECT INTENSITY (COLOR) ANY TIME.
4.6 ___ CHANGE TO GRID PICK ANY TIME.
4.7 ___ CHANGE TO FREE PICK ANY TIME.
4.8 ___ CHANGE TO OBJECT SNAP ANY TIME.
4.9 ___ CHANGE TO AXIS LOCK ANY TIME.
4.10 ☐ CHANGE TO NON-AXIS LOCK ANY TIME.
4.11 ___ REJECT OR UNDO MOST RECENT ACTION ANY TIME.
4.12 ___ PAN TO A DESIRED LOCATION ON THE DRAWING.
4.13 ___ ZOOM IN/OUT TO THE DESIRED DEGREE OF MAGNIFICATION.
4.14 ___ ZOOM IN TO A DESIRED LOCATION BY PICKING A WINDOW.
4.15 ___ DISPLAY A FULL VIEW OF THE DRAWING.
4.16 ___ REDRAW CURRENTLY DISPLAYED WINDOW.

5. DRAWING PRARMETERS

5.1 ___ ACTIVATE BY NAME.
5.2 ___ ACTIVATE BY NUMBER.
5.3 ___ SPECIFY DRAWING UNITS.
___ 5.3.1 MM (MILLIMETERS)
___ 5.3.2 CM (CENTIMETERS)
___ 5.3.3 M (METERS)
___ 5.3.4 KM (KILOMETERS)
___ 5.3.5 IN (INCHES)
___ 5.3.6 FT (FEET)
___ 5.3.7 YD (YARDS)
___ 5.3.8 MI (MILES)
5.4 ___ SPECIFY DRAWING SCALE.
___ 5.4.1 FULL SCALE
___ 5.4.2 KEY IN DESIRED DRAWING SCALE.
5.5 ___ SPECIFY DRAWING SIZE.
___ 5.5.1 A-SIZE (11 X 8.5 INCHES)
___ 5.5.2 B-SIZE (17 X 11 INCHES)
___ 5.5.3 C-SIZE (22 X 17 INCHES)
___ 5.5.4 D-SIZE (34 X 22 INCHES)
___ 5.5.5 E-SIZE (44 X 34 INCHES)
___ 5.5.6 SPECIFY OTHER IMPERIAL DRAWING SIZE
___ 5.5.7 A4-SIZE (29.7 X 21 CM)
___ 5.5.8 A3-SIZE (42 X 29.7 CM)
___ 5.5.9 A2-SIZE (59.4 X 42 CM)
___ 5.5.10 A1-SIZE (84.1 X 59.4 CM)
___ 5.5.11 A0-SIZE (118.9 X 84.1 CM)
___ 5.5.12 SPECIFY OTHER METRIC DRAWING SIZE
5.6 ___ ORIGIN OF DRAWING IN CENTER
5.7 ___ ORIGIN OF DRAWING IN LOWER LEFT CORNER OF DRAWING.

6.0 DRAWING MANAGEMENT

6.1 ___ TRANSFER SINGLE DRAWINGS TO FLOPPY DISK.
6.2 ___ TRANSFER SINGLE DRAWINGS TO FIXED DISK.
6.3 ___ TRANSFER MULTIPLE DRAWINGS SIMULTANEOUSLY TO FIXED DISK.
6.4 ___ TRANSFER MULTIPLE DRAWINGS TO VHS VIDEO CASSETTE.
6.5 ___ DELETE DRAWING.
6.6 ___ DELETE LIBRARY.
6.7 ___ COPY DRAWING.
6.8 ___ COPY LIBRARY.
6.9 ___ RENAME DRAWING.
6.10 ___ RENAME LIBRARY.
6.11 ___ CHANGE DRAWING TYPE FROM WORKING TO STANDARD.
6.12 ___ CHANGE LIBRARY TYPE FROM WORKING TO STANDARD.
6.13 ___ CREATE LIBRARY.
6.14 ___ OPTION TO SAVE CURRENTLY ACTIVE DRAWING UNDER A SPECIFIED FILE NAME.

7. TEXT OPERATIONS

7.1 ___ SPECIFY CHARACTER HEIGHT.
7.2 ___ SPECIFY CHARACTER WIDTH.
7.3 ___ SPECIFY SPACING BETWEEN CHARACTERS.
7.4 ___ SPECIFY TEXT ANGLE.
7.5 ___ SPECIFY TEXT SIZE (SETS BOTH HEIGHT AND WIDTH THE SAME).
7.6 ___ SPECIFY TEXT PEN NUMBER.
7.7 ___ SPECIFY TEXT LEVEL.
7.8 ___ ITALICS FONT.
7.9 ___ OPTION TO DRAG TO DESIRED LOCATION.
7.10 ___ OPTION TO UNDERLINE TEXT.
7.10.1 ___ OPTION FOR DOUBLE UNDERLINE.
7.11 ___ OPTION TO EXAMINE EXISTING TEXT PARAMETERS
___ 7.11.1 ANGLE
___ 7.11.2 PEN NUMBER
___ 7.11.3 LEVEL
___ 7.11.4 INTENSITY
___ 7.11.5 FONT TYPE (NORMAL OR ITALICIZED)
___ 7.11.6 CHARACTERS IN STRING

7.12 ___ ABILITY TO EDIT TEXT STRING
7.13 ___ CHOICE OF STANDARD SIZES
___ 7.13.1 0.1000 INCH
___ 7.13.2 0.1250 INCH
___ 7.13.3 0.1875 INCH
___ 7.13.4 0.2500 INCH
___ 7.13.5 0.3750 INCH
7.14 ___ CHOICE OF STANDARD ANGLE
___ 7.14.1 0-DEGREES
___ 7.14.2 90-DEGREES
7.15 ___ TYPEWRITER OPTION WITH AUTOMATIC CARRIAGE RETURN.
7.16 ___ OPTION TO REPEAT CURRENT LINE A SPECIFIED NUMBER OF TIMES.
7.17 ___ OPTION TO SKIP A SPECIFIED NUMBER OF ROWS.
7.18 ___ SPACING BETWEEN TEXT LINES.
7.19 ___ RIGHT JUSTIFICATION.
7.20 ___ LEFT JUSTIFICATION.
7.21 ___ CENTER JUSTIFICATION.
7.22 ___ SPECIFY MARGIN FOR MAXIMUM NUMBER OF CHARACTERS PER LINE.
7.22 ___ CENTER 1 OR MORE LINES OF TEXT INSIDE ANY OBJECT.

8. LINE OPERATIONS

8.1 ___ SOLID LINES.
8.2 ___ LONG DASHED LINES.
8.3 ___ SHORT DASHED LINES.
8.4 ___ CENTER LINES.
8.5 ___ PHANTOM LINES.
8.6 ___ FENCE LINES.
8.7 ___ PNEUMATIC LINES.
8.8 ___ HYDRAULIC LINES.
8.9 ___ CAPILLARY LINES.
8.10 ___ RAILROAD LINES.
8.11 ___ MULTI-SEGMENT SOLID LINES.
8.12 ___ MULTI-SEGMENT SPECIAL LINES.
8.13 ☐ SNAP VERTEX TO CENTER OF LINE SEGMENT.
8.14 ___ SNAP VERTEX TO CENTER OF CIRCLE.
8.15 ___ SNAP VERTEX TO MIDPOINT OF ARC.
8.16 ___ MULTI-SEGMENT LINES WITH INVISIBLE LINE SEGMENTS (GAPS).
8.17 ___ ABILITY TO CHANGE DASH AND GAP LENGTHS.
8.18 ___ RECTANGLE WITH TWO DIAGONALLY OPPOSITE CORNERS.
8.19 ___ RECTANGLES ALIGNED TO A SPECIFIED ANGLE.

9. ARC OPERATIONS

9.1 ___ SOLID ARCS.
9.2 ___ DASHED ARCS.
9.3 ___ CENTER ARCS.
9.4 ___ PHANTOM ARCS.
9.5 ___ 3-POINT ARCS.
9.6 ___ ARC GIVEN START/CENTER/END.
9.7 ___ ARC GIVEN START/END/RADIUS.
9.8 ☐ ARC GIVEN START/END/INCLUDED ANGLE.
9.9 ___ ARC GIVEN START/CENTER/CHORD.
9.10 ___ ARC GIVEN START/CENTER/INCLUDED ANGLE.
9.11 ___ SPECIFY ARC DIRECTION AS CLOCKWISE OR COUNTER-CLOCKWISE.
9.12 ___ MARK THE CENTER OF THE ARC.
9.13 ___ PLACE ORTHOGONAL CENTER LINES ON ARC CENTER.

10. CIRCLE OPERATIONS

10.1 ___ CIRCLE GIVEN CENTER AND RADIUS.
10.2 ___ CIRCLE GIVEN CENTER AND DIAMETER.
10.3 ___ CONCENTRIC CIRCLES.
10.4 ___ MARK CENTER OF CIRCLE.
10.5 ___ PLACE ORTHOGONAL CENTER LINES ON CIRCLE CENTER.

11. FILLETS

11.1 ___ FILLET BETWEEN TWO LINES.
___ 11.1.1 NO TRIM OF INTERSECTION.
___ 11.1.2 TRIM LINE ENDPOINTS BEYOND FILLET.
___ 11.1.3 TRIM LINE ENDPOINTS BEFORE FILLET.
11.2 ___ FILLET BETWEEN TWO ARCS (OR CIRLCES).
11.3 ___ FILLET BETWEEN A LINE AND AN ARC (OR CIRLCE).
11.4 ___ SPECIFY FILLET RADIUS.
11.5 ___ OBTAIN COMPLEMENT ARC TO FILLET.

12. CHAMFERS

12.1 ___ CHAMFER GIVEN ANGLE AND DISTANCE RELATIVE TO 1ST LINE.
12.2 ___ CHAMFER GIVEN TWO DISTANCES (ANGLE IS COMPUTED).
12.3 ___ DEFAULT CHAMFER ANGLE OF 45-DEGREES.

13. FLOW LINES

THESE ARE LINES THAT CONTAIN ARROWHEADS AT SPECIFIED LOCATIONS ALONG THE LINE.

13.1 ___ ABILITY TO SPECIFY ARROW AT LINE ENDPOINT.
13.2 ___ ABILITY TO SPECIFY ARROW AT CENTER OF LINE.
13.3 ___ ABILITY TO SPECIFY ARROW AT A SPECIFIED LOCATION ON LINE.
13.4 ___ ABILITY TO CREATE A LINE WITH DIMENSION ARROWS.
13.5 ___ OPTION FOR SOLID ARROW.
13.6 ___ OPTION FOR OPEN ARROW.
13.7 ___ OPTION TO CHANGE PEN NUMBER OF ARROW.
13.8 ___ OPTION TO CHANGE ARROW LENGTH.
13.9 ___ OPTION TO CHANGE ARROW LENGTH-TO-WIDTH RATIO.
13.10 ___ OPTION FOR DASHED LINE WITH ARROW.

14. CONSTRUCTION LINES

14.1 ___ LINE TO TANGENT ARC GIVEN ARC END POINT.
14.2 ___ LINE TO COMPLEMENT OF TANGENT ARC.
14.3 ___ ARC TO TANGENT ARC.
14.4 ___ LINE TO TANGENT ARC GIVEN RADIUS/ENDPOINT.
14.5 ___ CONSTRUCTION LINE TANGENT TO TWO ARCS (OR CIRCLES).
14.6 ___ CONSTRUCTION LINE TANGENT TO ARC (OR CIRCLE).
14.7 ___ CONSTRUCTION LINE AT SPECIFIED ANGLE.
14.8 ___ CONSTRUCTION LINE AT ANGLE PERPENDICULAR TO SPECIFIED ANGLE.
14.9 ___ HORIZONTAL CONSTRUCTION LINES.
14.10 ___ VERTICAL CONSTRUCTION LINES.
14.11 ___ CONSTRUCTION LINE BETWEEN TWO GIVEN POINTS.
14.12 ___ CONSTRUCTION LINES SPANNING SELECTED WINDOW.
14.13 ___ CONSTRUCTION LINES SPANNING THE ENTIRE DRAWING.
14.14 ___ TURN OFF DISPLAY OF ALL CONSTRUCTION LINES.
14.15 ___ TURN ON DISPLAY OF ALL CONSTRUCTION LINES.
14.16 ___ DELETE ALL CONSTRUCTION LINES FROM DRAWING.
14.17 ___ CONSTRUCTION LINES FROM AN ESTABLISHED BASE POINT.
14.18 ___ SOLID CONSTRUCTION LINES.
14.19 ___ DASHED CONSTRUCTION LINES.
14.20 ___ PHANTOM CONSTRUCTION LINES.
14.21 ___ CONSTRUCTION LINES AT A SPECIFIED OFFSET FROM ANOTHER LINE.
14.22 ___ CONSTRUCTION LINES REPEATED A SPECIFIED NUMBER OF TIMES.

15. CURVE OPERATIONS

15.1 ___ SELECT SPECIFIED RESOLUTION.
15.2 ___ ENTER DESIRED RESOLUTION.
15.3 ___ RETRIEVE DATA FROM FILE.
___ 15.3.1 SPECIFY X-OFFSET TO BE APPLIED TO DATA.
___ 15.3.2 SPECIFY Y-OFFSET TO BE APPLIED TO DATA.
___ 15.3.3 SPECIFY SCALE TO BE APPLIED TO DATA.
15.4 ___ EVALUATE Y-VALUES ON CURVE GIVEN SPECIFIED X-VALUES.

15.5 — PRINT VERTEX POINTS COMPRISING CURVE.
15.6 — PRINT PARAMETERS USED IN EVALUATING Y-VALUES ON CURVE.
15.7 — MOVE VERTEX POINT OF CURVE.
15.8 — DELETE VERTEX POINT OF CURVE.
15.9 — INSERT VERTEX POINT INTO CURVE.

16. GENERAL EDIT OPERATIONS

16.1 — MOVE INDIVIDUAL OBJECT BY DRAGGING.
16.2 — MOVE INDIVIDUAL OBJECT BY A SPECIFIED INCREMENT.
16.3 — MOVE OBJECTS WITHIN A RECTANGLE.
16.4 — COPY INDIVIDUAL OBJECT AND DRAG TO DESIRED LOCATION.
16.5 — COPY INDIVIDUAL OBJECT TO A SPECIFIED INCREMENTAL LOCATION.
16.6 — COPY OBJECTS WITHIN A RECTANGLE.
16.7 — COPY OBJECTS WITHIN A RECTANGLE A SPECIFIED NUMBER OF TIMES.
16.8 — DELETE INDIVIDUAL OBJECTS.
16.9 — DELETE OBJECTS WITHIN A WINDOW.
— 16.9.1 DELETE ONLY POINTS
— 16.9.2 DELETE ONLY LINES
— 16.9.3 DELETE ONLY ARCS
— 16.9.4 DELETE ONLY TEXT
— 16.9.5 DELETE ONLY CIRCLES
— 16.9.6 DELETE ONLY GROUPS
16.10 — ALIGN OBJECTS HORIZONTALLY.
16.11 — ALIGN OBJECTS VERTICALLY.
16.12 — RIGHT JUSTIFY TEXT TO A SPECIFIED LOCATION.
16.13 — LEFT JUSTIFY TEXT TO A SPECIFIED LOCATION.
16.14 — CENTER JUSTIFY TEXT A SPECIFIED LOCATION.
16.15 — ROTATE OBJECT TO A SPECIFIED ANGLE.
16.16 — ROTATE OBJECT A SPECIFIED NUMBER OF DEGREES.
16.17 — COPY OBJECT A SPECIFIED NUMBER OF TIMES, ROTATING EACH COPY BY THE SPECIFIED ANGLE.
16.17 — SCALE OBJECT IN BOTH X AND Y-DIRECTIONS.
16.18 — SCALE OBJECT IN THE X-DIRECTION ONLY.
16.19 — SCALE OBJECT IN THE Y-DIRECTION ONLY.
16.20 — MIRROR OBJECT ABOUT THE X-AXIS.
— 16.21 MIRROR OBJECT ABOUT THE Y-AXIS.
— 16.22 MOVE ORIGIN OF OBJECT.

17. ARC EDIT OPERATIONS

17.1 — CHANGE RADIUS.
17.2 — CHANGE DIRECTION.
17.3 — CHANGE INCLUDED ANGLE.
17.4 — GAP ARC.
17.5 — REFLECT ARC.
17.6 — CHANGE ARC END POINT.
17.7 — CHANGE ARC CENTER POINT.
17.8 — ROTATE ARC A SPECIFIED ANGLE.
17.9 — COMPLEMENT ARC.
17.10 — EDIT ENDPOINT OF ARC TO THE POINT WHERE THE ARC INTERSECTS ANOTHER GIVEN OBJECT.

18. LINE EDIT OPERATIONS

18.1 — MOVE VERTEX.
18.2 — REMOVE VERTEX.
18.3 — INSERT VERTEX.
18.4 — EXTEND LINE.
18.5 — EXTEND LINE TO THE POINT AT WHICH THE LINE INTERSECTS ANOTHER GIVEN OBJECT.
18.6 — MOVE VERTEX OF A NON-ORTHOGONAL LINE SO THAT THE LINE BECOMES ORIENTED ALONG THE X OR Y AXES.
18.7 — MOVE LINE SEGMENT.
18.8 — ERASE LINE SEGMENT.
18.9 — UNERASE A LINE SEGMENT (TO UNDO A GAPPED LINE).
18.10 — GAP A LINE SEGMENT.
18.11 — SET THE LENGTH OF A LINE

19. ANSI DIMENSIONING AND TOLERANCES

19.1 — CONSTRUCT FEATURE CONTROL SYMBOLS ACCORDING TO ANSI STANDARDS.
— 19.1.1 DIAMETER.
— 19.1.2 SYMMETRY.
— 19.1.3 FLATNESS.
— 19.1.4 PARALLELISM.
— 19.1.5 STRAIGHTNESS.
— 19.1.6 PROFILE LINE.
— 19.1.7 PROFILE SURFACE.
— 19.1.8 MMC (MAXIMUM MATERIAL CONDITION).
— 19.1.9 CONCENTRICTY.
— 19.1.10 ROUNDNESS.
— 19.1.11 POSITION.
— 19.1.12 PROJECTED TOLERANCE.
— 19.1.13 RUNOUT.
— 19.1.14 PERPENDICULARITY.
— 19.1.15 ANGULARITY.
— 19.1.16 CYLINDRICITY.
— 19.1.17 REGARDLESS OF FEATURE SIZE.
— 19.1.18 PLUS/MINUS SIGN.
— 19.1.19 SLASH.
19.2 — SPECIFY BOX SIZE.
19.3 — KEY IN DESIRED TEXT STRINGS.
19.4 — OBTAIN DOUBLE HIGH SYMBOLS.
19.5 — CONTINUE SYMBOLS ON THE NEXT LINE.

20. DETAIL CALL-OUTS

CIRCLES/ELLIPSES CONTAINING CENTERED NUMBERS OR CHARACTERS WITH LEADER LINES THAT POINT TO DESIGNATED OBJECTS.

20.1 — SPECIFY TEXT SIZE.
20.2 — CONSTRUCT CIRCLE.
20.3 — CONSTRUCT ELLIPSE.
20.4 — OPTION FOR LEADERLINE.
— 20.4.1 1-VERTEX LEADER LINE.
— 20.4.2 2-VERTEX LEADER LINE.
20.5 — SPECIFY STARTING VALUE.
20.6 — SPECIFY AUTOMATIC INCREMENTAL VALUE.
20.7 — DEFAULT SYMBOL SIZE TO CONTAIN CENTERED TEXT.
20.8 — SPECIFY ARROW LENGTH.

21. FASTENERS

21.1 — SPECIFY FASTENER TYPE
— 21.1.1 SQUARE BOLT HEAD.
— 21.1.2 HEX FLAT FACE BOLT.
— 21.1.3 HEX FLANGE BOLT.
— 21.1.4 FLAT COUNTERSINK HEAD.
— 21.1.5 HEX CAP BOLT.
— 21.1.6 HEX SOCKET CAP.
— 21.1.7 LOW HEAD CAP.
— 21.1.8 BUTTON HEAD CAP.
— 21.1.9 ROUND HEAD CAP.
— 21.1.10 ROUND HEAD SQUARE NECK.
— 21.1.11 ROUND MACHINE HEAD.
— 21.1.12 FLAT COUNTERSINK MACHINE HEAD.
— 21.1.13 OVAL COUNTERSINK MACHINE HEAD.
— 21.1.14 PAN HEAD MACHINE.
— 21.1.15 FILLISTER HEAD.
— 21.1.16 TRUSS HEAD.
21.2 — SPECIFY HEAD TYPE.
— 21.2.1 STANDARD SQUARE NUT.
— 21.2.2 HEXAGONAL DOUBLE CHAMFER.
— 21.2.3 HEXAGONAL JAM NUT.
— 21.2.4 SQUARE MACHINE NUT.
— 21.2.5 HEXAGONAL FLAT FACE NUT.
— 21.2.6 DOUBLE CHAMFER MACHINE NUT.
— 21.2.7 HEAVY HEX JAM NUT.
— 21.2.8 HEX FLANGE NUT.
21.3 — SPECIFY TYPE OF SOCEKET SET SCREW.
— 21.3.1 FLAT POINT SOCKET SET SCREW.
— 21.3.2 OVAL POINT SOCKET SET SCREW.
— 21.3.3 CONE POINT SOCKET SET SCREW.
— 21.3.4 HALF DOG POINT SOCKET SET SCREW.
21.4 — SPECIFY THREAD DIAMETER.

21.5 — SPECIFY THREADS PER INCH (OR PITCH FOR METRIC FASTENERS).
21.6 — SPECIFY FASTENER LENGTH.
21.7 ☐ SPECIFY THREAD LENGTH.
21.8 — SPECIFY ANGLE OR ORIENTATION OF FASTENER.
21.9 — OPTION TO OBTAIN CENTER LINES THROUGH FASTENER.
21.10 — OPTION FOR SCHEMATIC THREADS.
21.11 — OPTION FOR TRUE THREADS.
21.12 — OPTION FOR METRIC INPUT.
21.13 — OPTION FOR IMPERIAL INPUT.
21.14 — OPTION FOR SIDE VIEW.
21.15 — OPTION FOR END VIEW.
21.16 — SELECTION OF STANDARD THREADS.
— 21.16.1 NATIONAL FINE.
— 21.16.2 NATIONAL COARSE.
21.17 — OPTIONAL WASHER ON FASTENER.
— 21.17.1 TYPE A PLAIN WASHERS: NARROW AND WIDE.
— 21.17.2 TYPE B PLAIN WASHERS: NARROW, REGULAR AND WIDE.
— 21.17.3 HELICAL SPRING LOCK WASHERS: NAR., REG., WIDE.
21.18 — ABILITY TO CHANGE OR ADD FASTENER TYPES.

22. POLYGON OPERATIONS

22.1 — FULL ELLIPSE.
22.2 — HALF ELLIPSE.
22.3 — QUARTER ELLIPSE.
22.4 — GAP ELLIPSE.
22.5 — SPECIFY RESOLUTION.
22.6 — INSCRIBED POLYGON.
22.7 — CIRCUMSCRIBED POLYGON.
22.8 — SPECIFY NUMBER OF SIDES COMPRISING POLYGON.
22.9 — MARK CENTER OF ELLIPSE OR POLYGON.
22.10 — PARALLELOGRAM.
22.11 — GAP ELLIPSE OR POLYGON BOUNDARY

23. ANSI WELD SYMBOLS

23.1 — SQUARE GROOVE.
23.2 — V-GROOVE.
23.3 — BEVEL GROOVE.
23.4 — U-GROOVE.
23.5 — J-GROOVE.
23.6 — FLARE V-GROOVE.
23.7 — FLARE BEVEL WELD.
23.8 — FILLET WELD.
23.9 — PLUG WELD.
23.10 — SPOT WELD.
23.11 — SEAM WELD.
23.12 — STAGGERED FILLET.
23.13 — BACKING.
23.14 — MELT THROUGH.
23.15 — SURFACING.
23.16 — FLANGE EDGE.
23.17 — FLANGE CORNER.
23.18 ☐ FLUSH CONTOUR.
23.19 — CONVEX CONTOUR.
23.20 — CONCAVE CONTOUR.
23.21 — FINISH SYMBOL.
23.22 — SPECIFY ARROW TYPE.
23.23 — SPECIFY TEXT SIZE.
23.24 — SPECIFY WELD NOTES.

24. SYMBOL OR GROUP OPERATIONS

24.1 — CREATE GROUP BY PICKING INDIVIDUAL PRIMITIVE OBJECTS OR OTHER GROUPS.
24.2 — CREATE GROUP BY SELECTING ALL OBJECTS WITHIN A SPECIFIED WINDOW.
24.3 — ALLOW A MAXIMUM OF 255 GROUP MEMBERS ON EACH LEVEL; ALLOW UP TO 10 LEVELS OF GROUP NESTING.
24.4 — FILE GROUPS INTO DRAWING LIBRARY.
24.5 — RETRIVE GROUPS FROM DRAWING LIBRARY.
24.6 — FILE GROUPS INTO MASTER LIBRARY WHERE THEY CAN BE ACCESSED BY ALL DRAWINGS.
24.7 — RETRIEVE GROUPS FROM MASTER LIBRARY.
24.8 — RENAME GROUPS IN DRAWING OR MASTER LIBRARIES.
24.9 — DELETE GROUPS FROM DRAWING OR MASTER LIBRARIES.
24.10 — PACK MASTER LIBRARIES.
24.11 — INSERT GROUP INTO LINE.
— 24.11.1 MIRROR GROUP ABOUT INSERTED LINE.
— 24.11.2 MIRROR GROUP ABOUT LINE WHICH IS PERPENDICULAR TO INSERTED LINE.
24.12 — PLACE GROUP AT END OF LINE.
24.13 — RETRIEVE GROUP BY NUMBER.
24.14 — RETRIEVE GROUP BY NAME.

25. GROUP EDIT OPERATIONS

25.1 — MOVE GROUP ORIGIN.
25.2 — UN-NEST TOP LEVEL GROUP ONLY.
25.3 — UN-NEST ALL LEVELS IN GROUP.

26. MENU SET-UP OPERATIONS

26.1 — SET UP COMMAND MENU.
26.2 — TAKE DOWN COMMAND MENU.
26.3 — SET UP GROUP MENU.
26.4 — TAKE DOWN GROUP MENU.

27. CROSSHATCH OPERATIONS

27.1 — MANUALLY PICK BOUNDARY TO BE CROSSHATCHED.
27.2 — AUTOMATICALLY TRACE BOUNDARY TO BE CROSSHATCHED.
27.3 — ALLOW SELECTION OF MULTIPLE BOUNDARIES TO ACCOMMODATE HOLES.
27.4 — SPECIFY SPACING BETWEEN SUCCESSIVE LINES.
27.5 — SPECIFY OFFSET FROM START POSITION.
27.6 — SPECIFY ANGLE.
27.7 ☐ SPECIFY PATTERN TYPE.

28. AREA/PERIMETER CALCULATIONS

28.1 — MANUALLY PICK POLYGON.
28.2 — AUTOMATICALLY TRACE BOUNDARY.
28.3 — ACCUMULATE AREAS OF MULTIPLE BOUNDARIES.
28.4 — SUBTRACT AREAS OF HOLES OR INNER BOUNDARIES.
28.5 — PRINT OUT GEOMETRY DATA OF SELECTED OBJECTS.

29. ACCESS GEOMETRY DATA

29.1 — RETURN OBJECT TYPE.
29.2 — RETURN LINE PARAMETERS.
— 29.2.1 LINE SEGMENT NUMBER.
— 29.2.2 START POINT COORDINATES.
— 29.2.3 END POINT COORDINATES.
— 29.2.4 LENGTH.
— 29.2.5 ANGLE RELATIVE TO THE +X AXIS.
29.3 — RETURN ARC PARAMETERS.
— 29.3.1 START POINT.
— 29.3.2 END POINT.
— 29.3.3 CENTER POINT.
— 29.3.4 RADIUS.
— 29.3.5 INCLUDED ANGLE.
— 29.3.6 ARC LENGTH.
29.4 — RETURN POINT PARAMETERS.
— 29.4.1 X-COORDINATE.
— 29.4.2 Y-COORDINATE.

30. DRAWING DEFAULT OPERATIONS

30.1 — CHANGE SPACING OF MAJOR GRIDS.
30.2 — CHANGE SPACING OF MINOR GRIDS.
30.3 — SPECIFY INCREMENT FOR MAJOR GRIDS.
30.4 — CHANGE SENSITIVITY OF STYLUS PICK BY ENLARGING OR DECREASING THE SIZE OF THE HIT WINDOW.
30.5 — SET ALL LEVELS ON.
30.6 — SET ALL LEVELS OFF.
30.7 — SET A SPECIFIED LEVEL ON.
30.8 — SET A SPECIFIED LEVEL OFF.
30.9 — SET A RANGE OF LEVELS ON.
30.10 — SET A RANGE OF LEVELS OFF.
30.11 — INSPECT DRAWING HEIGHT.
30.12 — INSPECT DRAWING WIDTH.
30.13 — INSPECT DRAWING SCALE.

30.14 __ INSPECT DRAWING UNITS.
30.15 __ INSPECT DRAWING ORIGIN LOCATION.
30.16 __ INSPECT DRAWING MEMORY UTILIZATION (AS A PERCENTAGE OF FULL CAPACITY).
30.17 __ INSPECT CURRENTLY ACTIVE LEVEL.
30.18 __ INSPECT CURRENTLY ACTIVE PEN NUMBER.
30.19 __ INSPECT CURRENTLY ACTIVE INTENSITY (OR COLOR).
30.20 __ INSPECT CURRENTLY ACTIVE SYLUS INPUT MODE (FREE PICK, GRID PICK, OR OBJECT SNAP).
30.21 __ INSPECT CURRENTLY ACTIVE AXIS LOCK OR NON-AXIS LOCK STATUS.

31. TEXT EDIT OPERATIONS

31.1 __ SPECIFY TEXT TO BE EDITED.
31.2 __ SPECIFY JUSTIFICATION FOR EDITED TEXT.
__ 31.2.1 LEFT JUSTIFICATION.
__ 31.2.2 CENTER JUSTIFICATION.
__ 31.2.3 RIGHT JUSTIFICATION.
31.3 __ SPECIFY EXISTING CHARACTER OR SUBSTRING TO BE REPLACED BY NEW CHARACTER OR SUBSTRING.
31.4 __ SPECIFY OPTION TO TRUNCATE TO THE END OF THE TEXT STRING.
31.5 __ PROVIDE OPTION FOR DUPLICATING EDIT ON OTHER TEXT STRINGS.
31.6 __ ALLOW TEXT STRING TO BE RETYPED.

32. OBJECT RETRIEVE/EDIT OPERATIONS

32.1 __ RETRIEVE PEN NUMBER.
32.2 __ RETRIEVE LEVEL.
32.3 __ RETRIEVE LINE STYLE.
32.4 __ RETRIEVE KIND ATTRIBUTE (USED FOR CUSTOM PROGRAMS).
32.5 __ RETRIEVE INTENSITY (OR COLOR).
32.6 __ RETRIVE A GROUP MEMBERS ATTRIBUTES.
32.7 __ RETRIEVE A TOP LEVEL GROUP'S ATTRIBUTES.
32.8 __ EDIT SPECIFIED OBJECTS IN A RECTANGLE.
__ 32.8.1 POINTS.
__ 32.8.2 LINES.
__ 32.8.3 ARCS.
__ 32.8.4 TEXT.
__ 32.8.5 CIRCLES.
__ 32.8.6 GROUPS.
32.9 __ EDIT TOP LEVEL GROUP.
32.10 __ EDIT GROUP MEMBER.
32.11 __ EDIT ALL MEMBERS IN GROUP.
32.12 __ EDIT PEN NUMBER.
32.13 __ EDIT LEVEL.
32.14 __ EDIT LINE STYLE.
32.15 __ EDIT KIND ATTRIBUTE.
32.16 __ EDIT INTENSITY (OR COLOR).

33. PROPERTY OPERATIONS

PROPERTIES ARE DESCRIPTIVE OR TEXT INFORMATION WHICH IS ASSOCIATED WITH GRAPHIC OBJECTS ON THE DRAWING.

33.1 __ DEFINE PROPERTY FORMAT.
33.2 __ SPECIFY MAXIMUM NUMBER OF CHARACTERS/PROPERTY.
33.3 __ SPECIFY NUMBER OF FIELDS OR REPORT COLUMNS.
33.4 __ SPECIFY REPORT TITLES.
33.5 __ SPECIFY REPORT DATE OR REVISION NUMBER.
33.6 __ INDICATE WHETHER FIELDS ARE NUMERIC OR ALPHANUMERIC.
33.7 __ EXAMINE PROPERTY OF A SPECIFIED OBJECT.
33.8 __ ASSIGN PROPERTY TO A SPECIFIED OBJECT.
__ 33.8.1 SPECIFY CHANGE TO ALL FIELDS.
__ 33.8.2 SPECIFY CHANGE TO SELECTED FIELDS.
33.9 __ COPY A SPECIFIED PROPERTY AS AN INDEPENDENT RECORD.
33.10 __ COPY A SPECIFIED PROPERTY AS ASSOCIATED WITH ANOTHER EXISTING PROPERTY RECORD.
33.11 __ REMOVE A PROPERTY FROM A SPECIFIED OBJECT.
33.12 __ DISPLAY OBJECTS WITH UNASSIGNED PROPERTIES.
33.13 __ PRINT ALL PROPERTIES IN THE DATA BASE.
33.14 __ PRINT A PROPERTY REPORT OF ALL GRAPHIC OBJECTS ON DRAWING.
33.15 __ SPECIFY THE NAME OF THE PROPERTY FILE.
33.16 __ SPECIFY WHICH FIELD IS TO BE SORTED.
33.17 __ AUTOMATICALLY ACCUMULATE QUANTITIES OF IDENTICAL ITEMS.

34. MECHANICAL DIMENSIONS

34.1 __ SPECIFY TEXT SIZE FOR LABELING DIMENSION VALUE.
34.2 __ CHOOSE STANDARD TEXT SIZES.
__ 34.2.1 0.08 INCH TEXT.
__ 34.2.2 0.10 INCH TEXT.
__ 34.2.3 0.125 INCH TEXT.
34.3 __ LINEAR DIMENSIONS.
34.4 __ ANGULAR DIMENSIONS.
34.5 __ RADIAL DIMENSIONS.
34.6 __ OPTION FOR HANDLING DIMENSION TEXT WHICH IS TOO LARGE TO BE CONTAINED WITHIN THE DIMENSIONED DISTANCE.
34.7 __ OPTION TO HANDLE TOLERANCES.
34.8 __ OPTION TO HANDLE DIMENSION LIMITS.
34.9 __ OPTION TO KEY IN NOTE.
34.10 __ OPTION TO OFFSET THE DIMENSION TEXT BY A SPECIFIED AMOUNT.
34.11 __ OPTION TO OFFSET THE DIMENSION TEXT BASED ON A PICKED POINT.
34.12 __ VERTICAL DIMENSION ANGLE.
34.13 __ HORIZONTAL DIMENSION ANGLE.
34.14 __ NON-ORTHOGONAL DIMENSION ANGLE.
34.15 __ OPTION TO CHANGE THE ENDPOINTS OF THE OBJECT TO BE DIMENSIONED.
34.16 __ OPTION TO CHANGE THE VALUE OF THE DIMENSIONED LENGTH.
34.17 __ OPTION TO USE A COMMA (FOR EUROPEAN) OR DECIMAL POINT (FOR IMPERIAL) DECIMAL NUMBERS.
34.18 __ OPTION TO EXPRESS DIMENSION VALUES IN FEET, INCHES, AND FRACTIONAL INCHES.
34.19 __ OPTION TO SPECIFY NUMBER OF DECIMAL PLACES SHOWN ON DIMENSION VALUE.
34.20 __ OPTION TO APPLY A SCALE FACTOR TO THE DIMENSIONED DISTANCE.
34.21 __ OPTION TO HANDLE STAGGERED DIMENSIONS.
34.22 __ SELECT SIDE OF OBJECT WHERE DIMENSIONED TEXT IS TO BE PLACED.
34.23 __ OBJECT TO DIMENSION OBJECTS FROM A SELECTED REFERENCE POINT.
34.24 __ OPTION TO EXPRESS DIMENSION VALUE IN METRIC AND/OR IMPERIAL UNITS OF MEASURE.
34.25 __ OPTION TO CHANGE THE TYPE OR SHAPE OF THE DIMENSION ARROW.

35. LINE WIDEN OPERATIONS

35.1 __ WIDEN FROM CENTER LINE.
35.2 ☐ WIDEN TO GIVEN SIDE OF LINE.
35.3 __ OPTION TO DELETE OR SAVE REFERENCE LINE TO BE WIDENED.
35.4 __ SPECIFY WIDTH.
35.5 __ HANDLE BOUNDARIES CONSISTING OF LINES AND/OR ARCS.

36. DRILL HOLE OPERATIONS

36.1 __ SPECIFY DRILL HOLE DIAMETER.
36.2 __ SPECIFY HOLE DEPTH.
36.3 __ SPECIFY DRILL ANGLE.
36.4 __ SPECIFY THREAD DIAMETER.
36.5 __ SPECIFY THREAD PER INCH.
36.6 __ OPTION FOR THRU HOLE.
36.7 __ SPECIFY CHAMFER DIAMETER.
36.8 __ SPECIFY CHAMFER ANGLE.

36.9 — SPECIFY CHAMFTER DEPTH.
36.10 — SPECIFY SIDE AND/OR END VIEW.
36.11 — SPECIFY PERIMETER VIEW.
36.12 — SPECIFY ORIENTATION.
36.13 □ SPECIFY METRIC OR IMPERIAL THREADS.
36.14 — SPECIFY TRUE OR SCHEMATIC THREAD REPRESENTATION.

37. SPRING OPERATIONS

37.1 — COMPRESSION SPRING.
37.2 — EXTENSION SPRING.
37.3 — SECTION VIEW.
37.4 — SCHEMATIC VIEW.
37.5 — SIMPLIFIED VIEW.
37.6 — SPECIFY LENGTH.
37.7 — SPECIFY INSIDE DIAMETER.
37.8 — SPECIFY OUTSIDE DIAMETER.
37.9 — SPECIFY WIRE DIAMETER.
37.10 — SPECIFY NUMBER OF COILS.
37.11 — AUTOMATICALLY COMPUTER NUMBER OF COILS FOR EXTENSION SPRINGS.
37.12 — SPECIFY ORIENTATION.
37.13 — OPTION TO SHOW CENTER LINE.

38. CUT & PASTE OPERATIONS

38.1 — CUT ALL OBJECTS THAT INTERSECT A GIVEN RECTANGLE AND GROUP THE OBJECTS FOR SUBSEQUENT ENLARGEMENT FOR DETAILS.
38.1 — OPTION TO SAVE ORIGINAL OBJECTS INSIDE RECTANGLE.

39. CUSTOM-TAILORED TASKS

39.1 — A MEANS FOR ADDING CUSTOM TASKS TO THE MENU.
39.2 — A HIGH-LEVEL PROGRAMMING AID WHICH MAKES GEOMETRY ACCESS AND RETRIEVAL TRANSPARENT TO THE USER.
39.3 — A PROGRAMMER'S GUIDE WHICH DETAILS HOW TO WRITE CUSTOM TASKS.

40. PLOT OPERATIONS

40.1 — SET PEN TABLE.
40.2 — SPECIFY PLOT SCALE.
40.3 — OPTION TO PICK WINDOW.
40.4 — OPTION TO FRAME WINDOW.
40.5 — OPTION TO CLIP WINDOW.
40.6 — OPTION TO ADJUST WINDOW.
40.7 — SELECT DESIRED PLOTTER.

41. FAST PLOT OPERATIONS

41.1 — SELECT DESIRED MATRIX PRINTER.
41.2 — SELECT DRAWING WINDOW TO BE PLOTTED.

42. DRAWING PACK

42.1 — OPTION TO RECOVER STORAGE OCCUPIED BY PREVIOUSLY DELETED OBJECTS.

43. SYMBOL LIBRARIES

43.1 — ARCHITECTURAL.
43.2 — LANDSCAPE.
43.3 — FACILITIES PLANNING.
43.4 □ PIPING & INSTRUMENTATION.
43.5 — PETRO-CHEMICAL.
43.6 — ELECTRICAL.
43.7 — ELECTRONICS.
43.8 — MINING & METALLURGY.
43.9 — ABILITY TO ADD CUSTOM SYMBOL (OR GROUP) LIBRARIES.

44. LANDSCAPE ARCHITECTURE

44.1 — FREE-HAND SKETCH.
44.2 — SKETCH USING BRUSH PATTERN.
— 44.2.1 SOLID CIRCULAR BRUSH OF SPECIFIED DIAMETER.
— 44.2.2 SOLID RECTANGULAR BRUSH OF SPECIFIED HEIGHT AND WIDTH.
— 44.2.3 PICK DESIRED BRUSH PATTERN.

45. WALL CONSTRUCTION

45.1 — CONSTRUCT DOULBE LINE WALLS.
— 45.1.1 WIDEN WALL TO THE LEFT.
— 45.1.2 WIDEN WALL FROM THE CENTER.
— 45.1.3 WIDEN WALL TO THE RIGHT.
45.2 — AUTOMATIC CORNER AND INTERSECTION CLEAN-UP.
45.3 — PICK STARTING REFERENCE POINT.

46. DOOR/WINDOW CONSTRUCTION

46.1 — SPECIFY WIDTH OF DOOR/WINDOW.
46.2 — OPTION FOR DOUBLE DOOR.
46.3 — OPTION FOR SLIDING DOOR/WINDOW.
46.4 — PICK STARTING REFERENCE POINT.
46.5 □ AUTOMATIC GAPPING OF DOUBLE LINE WALL.

47. FACILITIES PLANNING

47.1 — SPECIFY SCALE OF SYMBOL.
47.2 — SPECIFY ANGLE OF SYMBOL ROTATION.
47.3 — SPECIFY DESIRED STANDARD SYMBOL.
— 47.3.1 CLUB CHAIR.
— 47.3.2 WING CHAIR.
— 47.3.3 ARM CHAIR.
— 47.3.4 LARGE SOFA.
— 47.3.5 SMALL SOFA.
— 47.3.6 END TABLE.
— 47.3.7 FOOTSTOOL.
— 47.3.8 TV CONSOLE.
— 47.3.9 PORTABLE TV.
— 47.3.10 CHINA CABINET.
— 47.3.11 FIREPLACE.
— 47.3.12 COFFEE TABLE.
— 47.3.13 SMALL DESK.
— 47.3.14 LARGE DESK.
— 47.3.15 DINING TABLES.
— 47.3.16 TWIN BED.
— 47.3.17 FULL BED.
— 47.3.18 QUEEN BED.
— 47.3.19 KING BED.
— 47.3.20 WARDROBE CLOSET.
— 47.3.21 CHEST.
— 47.3.22 DRESSING TABLE.
— 47.3.23 NIGHT STAND.
— 47.3.24 TRIPPLE DRESSER.
— 47.3.25 DOUBLE DRESSER.
— 47.3.26 CHAIR.
— 47.3.27 VANITY.
— 47.3.28 BENCH.
— 47.3.29 BATHTUB.
— 47.3.30 WATER CLOSET.
— 47.3.31 LAVATORY.
— 47.3.32 SHOWER.
— 47.3.33 FREEZER.
— 47.3.34 REFRIGERATOR.
— 47.3.35 REFRIG./FREEZER.
— 47.3.36 SINK.
— 47.3.37 OVEN.
— 47.3.38 WASHER.
— 47.3.39 DRYER.
— 47.3.40 STOVE.

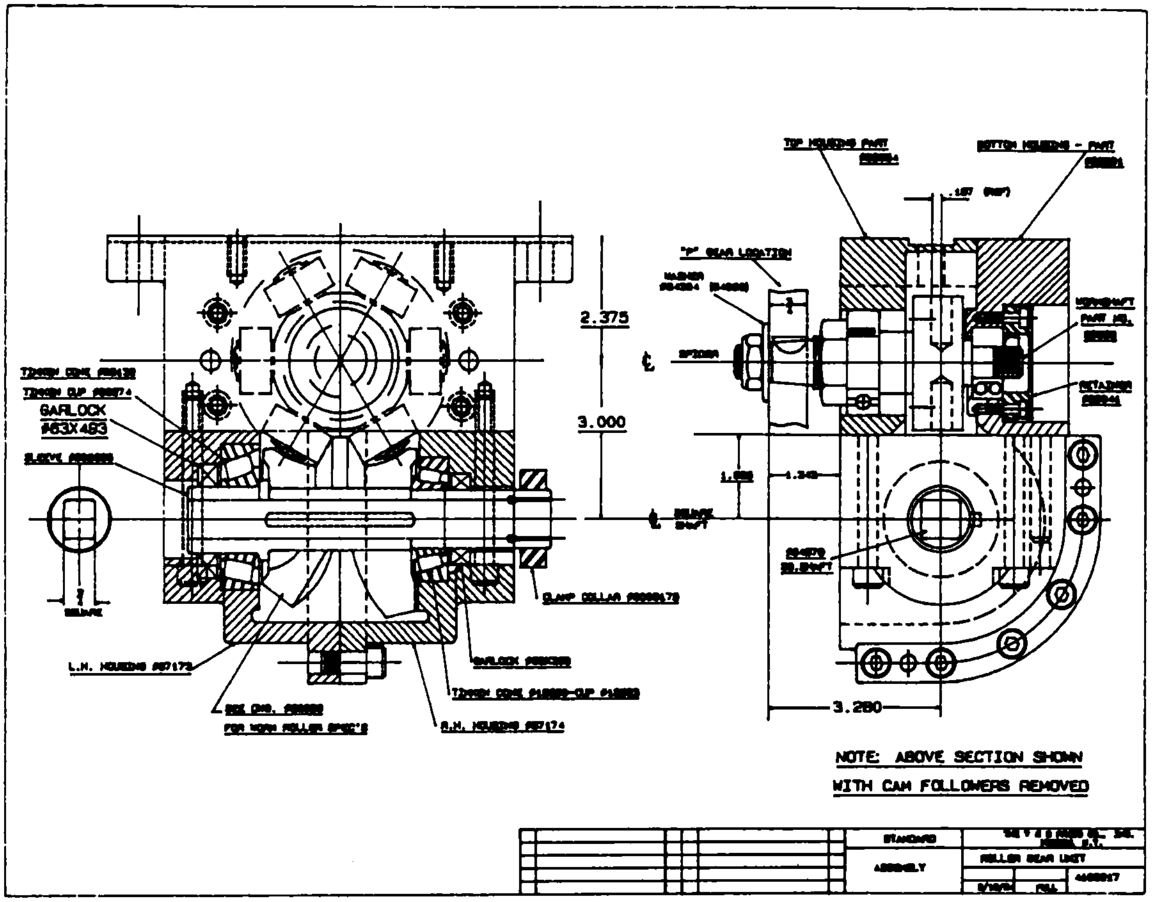
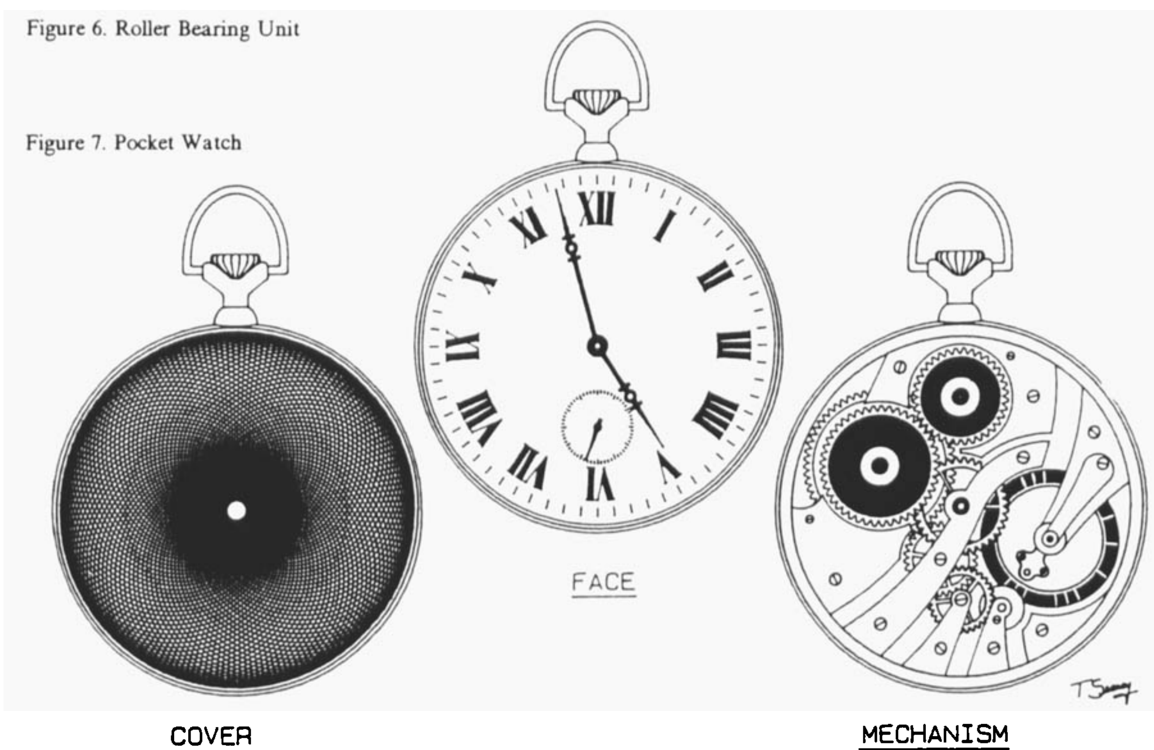


Figure 6. Roller Bearing Unit

Figure 7. Pocket Watch



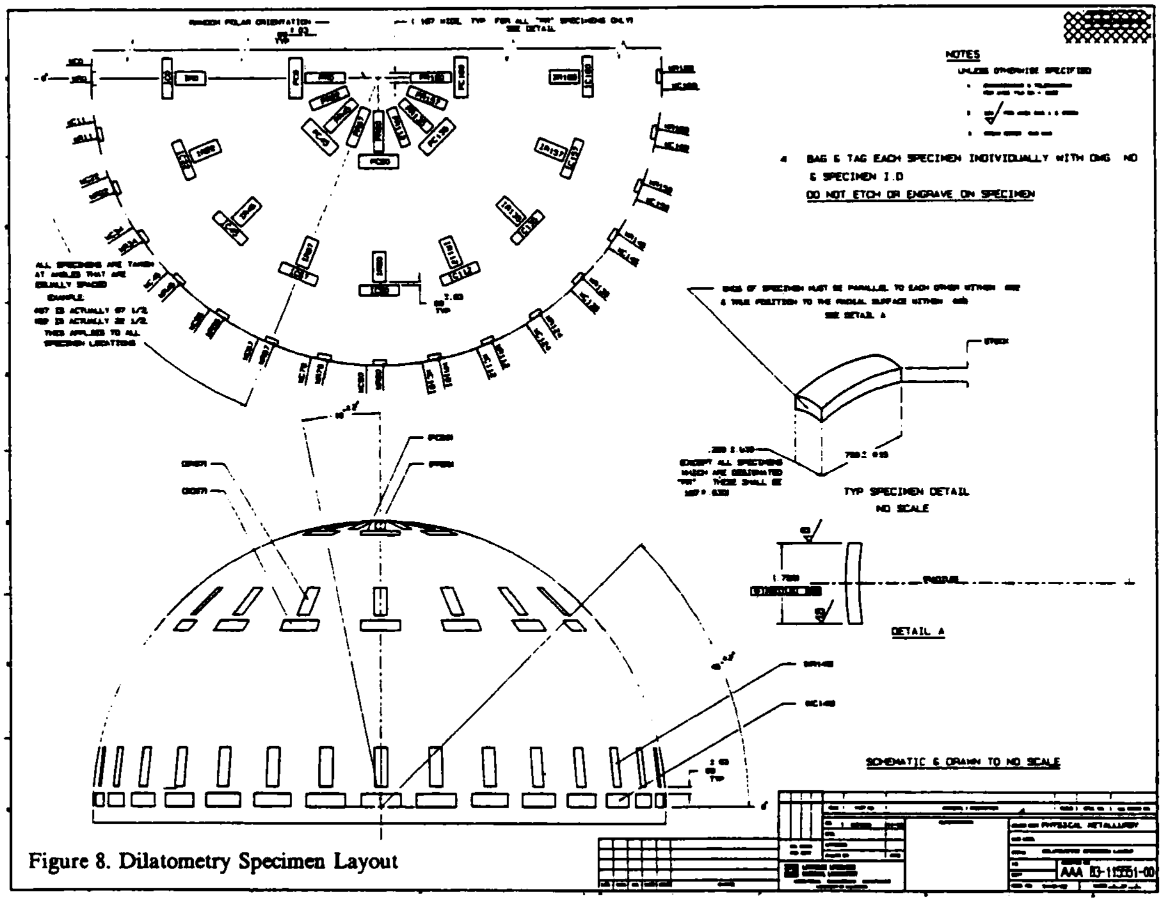


Figure 8. Dilatometry Specimen Layout

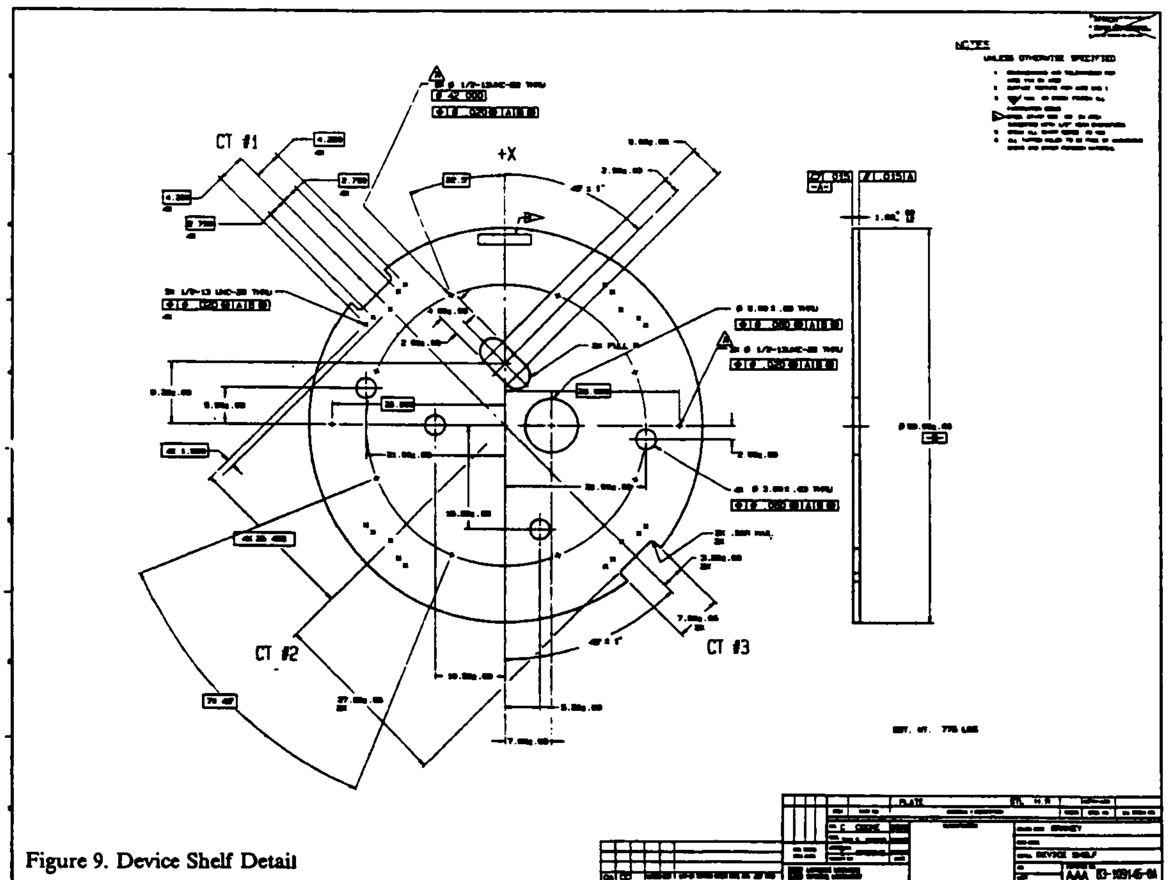


Figure 9. Device Shelf Detail

and a reduction in the manufacturing cycle and a reduction of costly field errors due to consistency. Through use of a common data base of standards, micro-based CAD allows the cost effective creation of production drawings which can be rapidly changed or edited in a consistent format.

A full-featured CAD system should be upgradable, networkable, and expandable through use of a high-level graphics programming language. State-of-the-art micro CAD systems perform most graphic manipulations (even on complex objects) in less than three seconds are more cost effective for the input of 2D drawings than the higher priced mini-based systems. Furthermore, since each workstation in the networked micro system incorporates distributed processing, degradation is not as apparent as mini workstations that are networked to a single central processing unit (CPU).

In CAD Environments, benchmarks can be misleading since computer graphics involves a human-machine interface. Even if identical drawings are used for benchmarks, a control test is difficult to achieve due to differences in an operator's

(a) learning curve,

(b) ability to effectively use available commands,

(c) prior CAD experience,

(d) exposure to the specific type of drawing,

(e) familiarity with the drawing symbols,

(f) initial preparation of symbol libraries,

(h) skill in establishing production techniques prior to generating the drawing,

as well as other factors. More important, however, is an evaluation of the CAD software, the ease of use, documentation, support and maintenance. Usually, the more comprehensive the CAD software, the greater the productivity potential — regardless of the claimed "horsepower".

If the CAD system is to be used in a specific application area such as mechanical design, determine whether or not programs are available for ANSI dimensioning, geometric tolerancing, the construction of weld symbols, fasteners, springs, etc.[5] For architectural applications, the ability to draw free-hand for landscapes and renderings is useful[6] Also programs to construct double-line walls and insert doors and windows of various widths provide CAD productivity gains that exceed manual techniques.

Examples of various engineering drawings produced on micro CAD workstations discussed in this paper are shown in Figures 6 through 10.

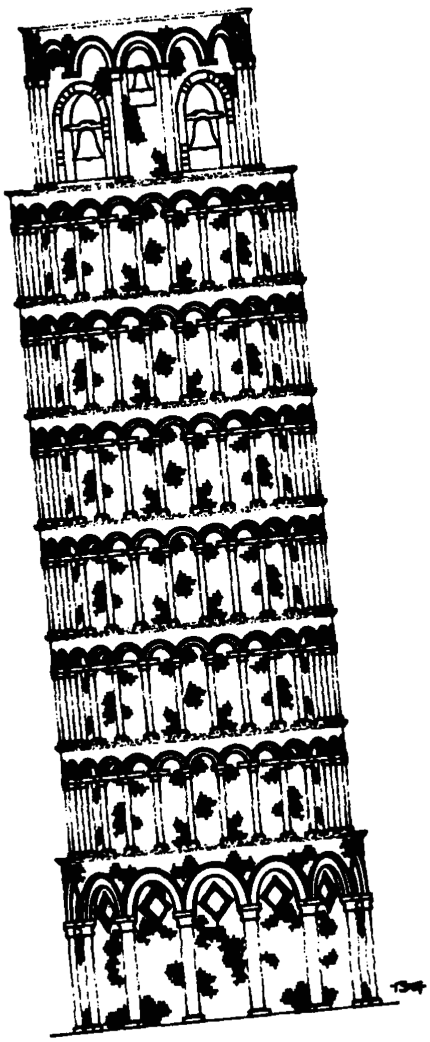


Figure 10. Leaning Tower of Pisa

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5. Dr. Gary S. Goldman, "MDAS: Mechanical Design Application Software," in *copyright 1981 by Cascade Graphics Development*, (1981).

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