3

20030121033

Best Available Copy

National Defence / Défense nationale

AD-A164 408

COMPUTER-AIDED DESIGN OF A RESPIRATOR FACEPIECE MODEL

by

D.J. Hidson

DEFENCE RESEARCH ESTABLISHMENT OTTAWA

REPORT 902

Canada

December 1984
Ottawa

National Defence | Défense nationale

COMPUTER-AIDED DESIGN OF A RESPIRATOR FACEPIECE MODEL

by

D.J. Hidson
Chemical Protection Section
Protective Sciences Division

DEFENCE RESEARCH ESTABLISHMENT OTTAWA
REPORT 302

PCN
13B10

December 1984
Ottawa

ABSTRACT

This paper describes the evaluation and acquisition of CAD/CAM technology required for the design and development of complex sculptured surfaces for molding rubber and elastomeric materials. Benchmark tests incorporating the complex 3-D geometry that such a design project must handle were performed with various systems vendors and a time-sharing system was chosen. Geometry was constructed using bi-parametric cubic patches and cutter paths were plotted over these surfaces. A post-processor has been prepared for a three-axis numerical control milling machine and a cavity cut to vacuum-form a thermoplastic rubber for a prototype.

Keywords: human factors engineering; anthropometric data; CADD (Computer Aided Design and Drafting); French language; numerical control programming;

RÉSUMÉ

Le présent document décrit l'évaluation et l'acquisition de la technologie de conception/gestion automatisée nécessaire à la conception et à la préparation de surface sculptées complexes employées comme moules pour le caoutchouc et les élastomères. Les essais de repérage dans le système complexe à trois dimensions, requis dans le cas d'un tel projet, ont permis d'expérimenter les divers systèmes. Le choix s'est arrêté sur un système à temps partagé. Le motif a été construit à l'aide d'éléments cubiques bi-paramétriques et le tracé du découpage a été dessiné sur ces surfaces. On a préparé un dispositif de post-traitement pouvant s'adapter à une fraiseuse triaxiale à commande numérique, et on a découpé une cavité pour former sous vide un prototype en caoutchouc thermoplastique.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

1.0 INTRODUCTION

For hundreds of years, engineering design has always begun with the drawing board and the scribe. Only very recently has this begun to change with the application of computer-aided design (CAD) techniques to the drafting process and computer-aided manufacturing (CAM) to construction. The combination of these two into CAD/CAM is transforming the face of most engineering projects today.

The process of designing a respirator facepiece has been described in some detail before [1]. Briefly, the designer produces sketches that are given to a model maker or pattern maker who then constructs three-dimensional models in a soft-modelling material. Changes are made until the engineer is satisfied with the shape. A core is then cast off this shape - in plaster. To produce the other part of the mold, the female part, the model is built up with a varying thickness of wax corresponding to the desired thickness of the molded part. This part of the mold as with the core, has to be made out of several pieces of plaster, more or less depending on the complexity of the geometry. When the molds are completed (they are, of course, hand-made) a model may be molded out of a room-temperature vulcanizing rubber (RTV).

For checking geometry and placement of eyepieces, outlet valves, etc, these models are suitable. However, as they are not molded from a rubber, they cannot be assessed for any engineering properties. For changes to be made to the design the whole process has to be repeated and a new mold made. This is tedious and time consuming.

To remove the design process from this circle a new approach was taken. Computer-aided design and manufacturing systems were investigated [1] in depth and a recommendation for acquisition was made. This paper describes the installation and operation of the McDonnell Douglas CADD (Computer-Aided Design and Drafting) system on a time-sharing basis at DREO. Also, the design of a respirator facepiece, is described and the numerical control N/C machining required to produce a three-dimensional model ready for vacuum-forming a thermoplastic rubber is described.

2.0 THE MCAUTO CAD/CAM SYSTEM

2.1 Operating Environment

CADD operates on the central computer complex at McDonnell Douglas Automation Company (MCAUTO) in St. Louis, Missouri. It is a time sharing system and is accessed from DREO via a dedicated, high speed communication line, transferring data at 9600 baud. All computing is done at MCAUTO in St. Louis: there is no local intelligence (see reference [1]). The hardware at the DREO workstation consists of the following items:

- Tektronix 4014-1 storage tube with Data Communication Interface

- Hard copy unit 4631, also Tektronix

- Graphics Tablet 4953, stylus and controller with interactive buffer.

- Calcomp 960 plotter with 907 controller

- Infotron Supermux 480 multiplexer

- Dataroute modem for the 9600 baud digital service between Ottawa and St. Louis.

2.2 Hardware

As there were some extensive modifications to various items, a more detailed description of the hardware is included.

2.2.1 The Tektronix 4014-1 Storage Tube

This is a standard off-the-shelf item, but has been considerably modified by MCAUTO engineers to accommodate a certain amount of refresh display. This is demanded by the method of interaction of the operator with CADD through the function light buttons (FLBs) which execute certain CADD operations.

The refresh part of the display is operated through an Interactive Buffer circuit board (CM 018-0120-00) which is described in detail in reference [2]. Briefly, this device provides local, fast-access storage for 4014/4015 computer display terminals. The Buffer has a capacity of 1023 ASCII characters. Data may be entered into the Buffer from the keyboard, an interfaced computer or from any attached peripheral such as a graphics tablet. Data is entered sequentially starting at location zero. "The buffer" is the terminology used for the storage area from location zero up to and including the last data character entered. Refresh display is enabled by means of the continuous dumping of the buffer to the terminal screen using the write-thru feature of the terminal.

All characters and ASCII codes except BS (backspace) and CR (carriage return) may be stored in the buffer allowing the intermixture of alphanumerics graphics and control functions. A degree of editing is possible with 'delete character' (BS) from the end of the buffer only and 'clean buffer' (ESC = ϕ, Reset) but CADD does not require the user to interact with the buffer in any way from the keyboard. The interactive buffer is contained on a single circuit board which plugs into the terminal minibus.

2.2.2 The Supermux 480 Multiplexer

The Supermux 480 is a statistical time division multiplexer (STDM). It operates on a slightly different principle from conventional time division multiplexers (TDM).

For TDM, the concept is to accept low speed data inputs from a variety of sources and interleave, or multiplex, these varied inputs into a high-speed, fixed format, Mux Link signal to a remote TDM. At the far end, the signal is demultiplexed and transformed back to low-speed outputs and routed to the output channels. The synchronization between the TDMs is maintained by means of a control character, the SYNC character. Fixed time slots follow the SYNC character and each channel is assigned a fixed time slot (see Fig. 1). The slots contain data characters when the channel is active or fill characters when the channel is inactive.

In statistical time division multiplexing more channels are connected to the multiplexer than there are character time slots available on the Link. If the channel activity exceeds the ability of the Mux Link to handle it, data is temporarily stored in 16 Kbyte RAM buffer and is sent over the link as the activity level drops. The manner in which a data field is fitted into a frame is shown in Fig. 2.

The frame size is variable and is a function of the channel activity: periods of low activity using shorter frames and periods of high activity using longer frames. Because the frame length is a variable, data characters are directed to the proper channel by means of channel address characters embedded within the frame.

When in operational mode, the status of the system is displayed on fourteen front panel light-emitting diodes (LEDs):

- Mux ready - lit up where unit operating correctly and powered up.

- Channel active - lit up when both Transmit and Receive Data Signals are both in a marking condition.

- Inbound error - lit up when local unit has received an inbound frame with an error or no frames at all.

- Outbound error - lit up when remote unit has received an error and seeks retransmission of data.

- Buffer overload - lit up when local buffer reaches 80% capacity and goes off when buffer data volume falls to 60% capacity.

- Link loop - lit up when the local unit is receiving its own Link frame or the local unit is in test mode.

- Line check - Usually off. Flashes when local or remote unit is in test mode.

The terminal is connected to the computer facility in St. Louis in a modem-mux/mux-modem configuration which is shown schematically in Figs. 3 and 4. Further details of the SM480, its operation and test, may be found in reference [3].

2.2.3 Modification to the TEK 4014 Terminal

DREO uses two accounts on the MCAUTO TSO System: one on the IBM 370 service which may be accessed on the 9600-baud line or a 1200-baud dial-up line for the Calcomp plotter; and another on the MCAUTO CYBER service which is accessed through DATAPAC and TYMNET also on a 1200-baud dial-up line.

When the 1200 baud line was used, it was found that there were many character errors appearing on the terminal. The communication network between Ottawa and St. Louis was examined and found to be error-free. The

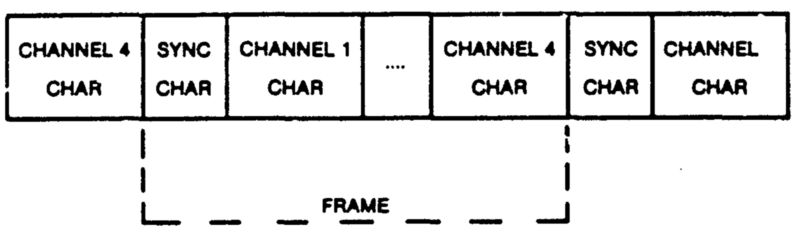

Figure 1: Schematic of Time Division Multiplexer.

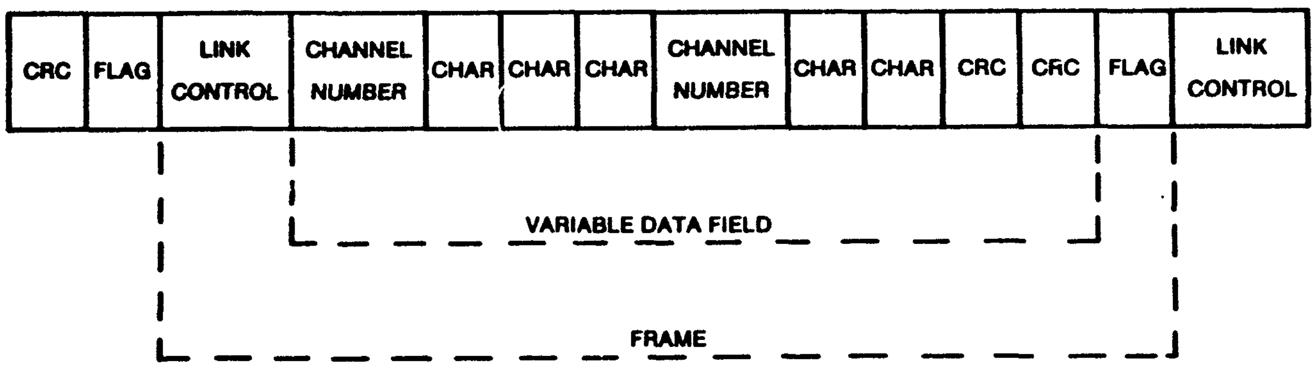

Figure 2: Schematic of Statistical Time Division Multiplexer.

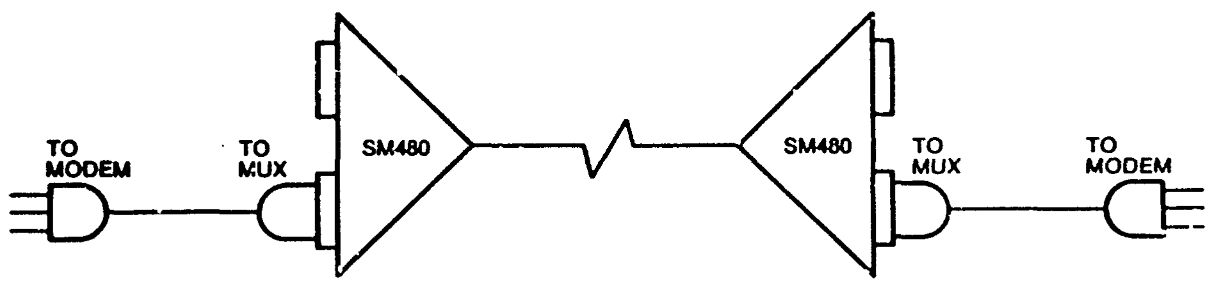

Figure 3: Work Station/Host Computer Link-Up.

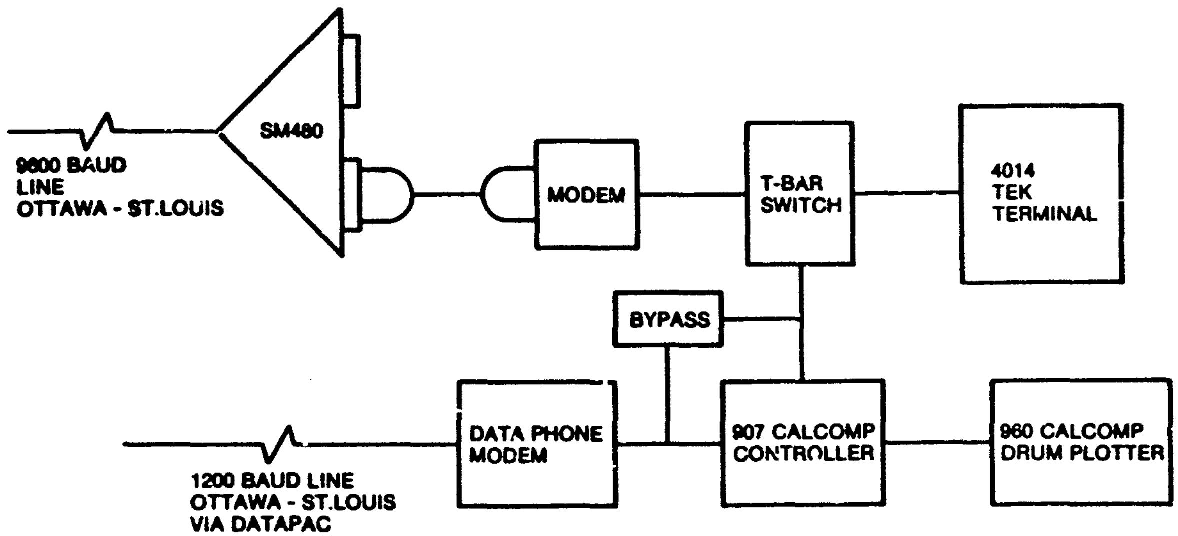

Figure 4: CADD Workstation Layout at DREO.

signal was checked at each junction of the line at DREO. The problem was found to be with the clock strap option on the data communication interface. There are two positions for this available: X1 and X16. When used, the X1 option creates a unique relationship between the communcations clock and the transferred data. The RDATA and TDATA lines must change states on the positive going edge of the clock. Data should be sampled on the negative going edge. It was found that the X16 multiplier was suitable for the high-speed line and the X1 multiplier for the low-speed line. A toggle switch was mounted on front of the TEK close to the ON-OFF switch. Two positions are labelled 1200 baud and 9600 baud.

2.3 Interaction with CADD

CADD operates in the computer complex of McDonnell Douglas Automation Company in St. Louis, Missouri. Design engineers may access CADD from a variety of terminals: IBM, Evans and Sutherland Picture Systems and Tektronix 4014. Only the Tektronix 4014 will be discussed in detail here.

The terminal consists of a storage-type graphics display tube, an alphanumeric keyboard and an attached graphics tablet and electronic stylus. The engineer may create three-dimensional designs in any or all of the following ways:

- Enter alphanumeric information (x, y, z coordinate points) from the keyboard.

- Use the digitizing tablet and stylus to pick entities (points, lines, conics, cubics etc) for the function light displays (or function keys) which invoke specific routines that execute construction commands for arcs, lines, conics, cubics, surfaces etc.

- Digitize two-dimensional data points into a CADD model by detecting points with the stylus from a drawing placed on the graphics tablet.

An engineer is usually concerned with creating a geometric representation of a physical object. When a drawing board is being used this representation is in the form of a two-dimensional line drawing showing the orthographic views of the object or model, that is, plan, elevation and side view. This method may be used in CADD. However, CADD's three-dimensional geometric capabilities allow the designer to work in 3-D directly, creating a line drawing, or wire-frame model, which may be viewed in its entirety from any angle while construction takes place in any plane. A third option is for a completely surfaced model in which all points are defined by their x-, y- and z- coordinates. Once one of these forms has been created, it may be used to construct the other two.

CADD is currently being accessed by DREO using MCAUTO's Time-sharing Option MVS/TSO, which is an interactive, user-oriented system. CADD operates on the IBM 370 system and with nine of these computers in the St. Louis facility a rapid response for the user is guaranteed.

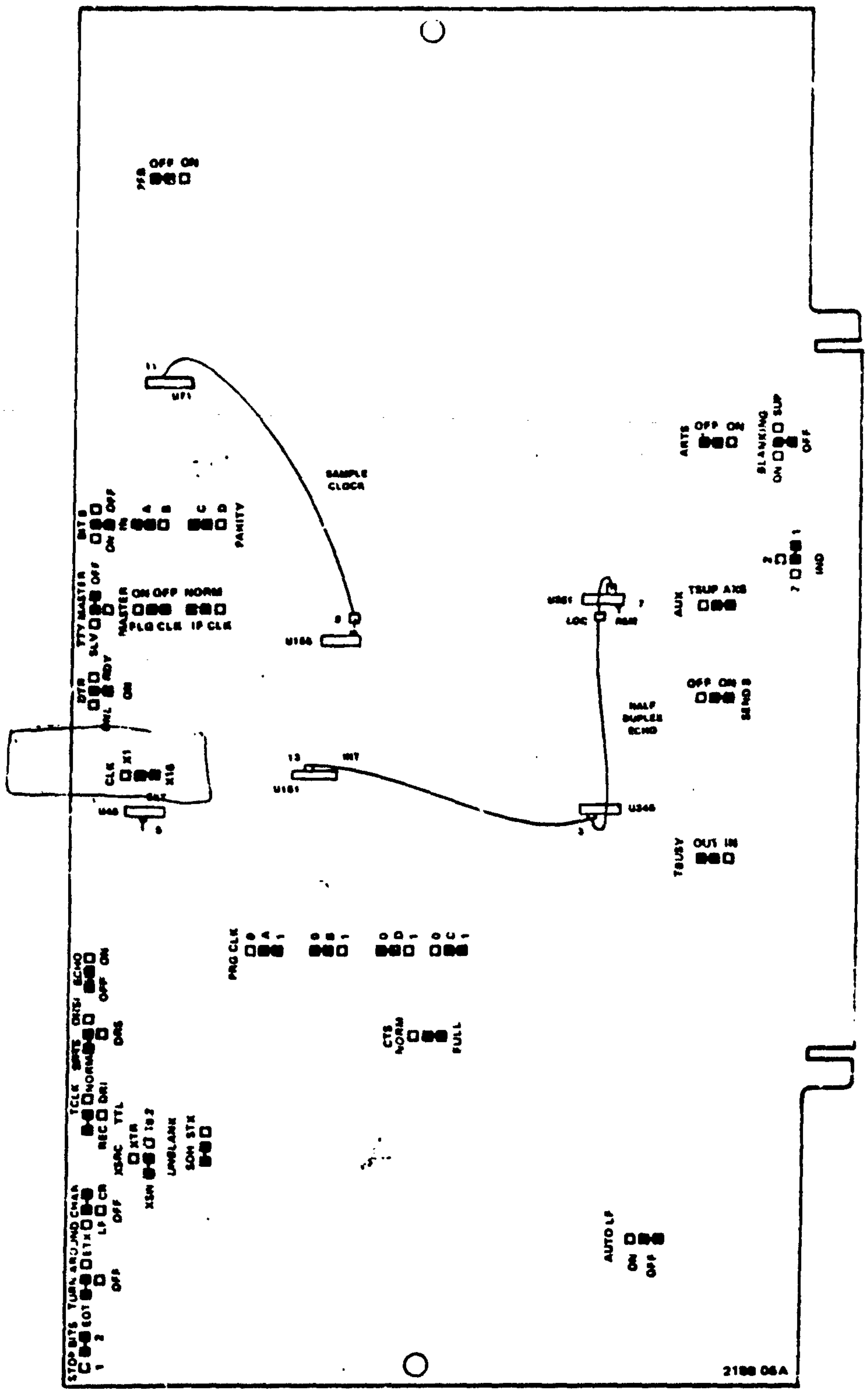

Figure 5: Circuit Board Showing Clock Options.

3.0 CREATION OF A CADD MODEL

When the user is seated at the terminal and logged-on to CADD, the screen will appear as in Fig. 6.

In top right-hand corner of the screen is the Function Light Display showing each function key enclosed in a square. At the bottom of the screen, in refresh mode, are the Function Light Buttons. These handle the operations that deal with the whole model, for example, scaling, viewing from different angles, changing the type of display and filing the model in the CADD Database Management System (CDBMS). The function light button, MENU, will display a menu of less frequently used operations and is shown in Fig. 7.

The engineer can use various function keys in the function light display to construct the CADD model. The following is a brief description of these:

DELP: Delete Points - All standalone points are deleted from the model; others are erased.

BDPL: Bounded Plane - A plane may be constructed with an arbitrary perimeter.

PLN: Plane - This creates an infinite plane which may be used for construction viewing or sectioning. It is represented by a triangle with an asterisk at the center.

PTCH: Patch Surface - Creates a three-dimensional parametric cubic surface by one of a variety of methods.

TR/R: Translate/Rotate - This allows any entity to be translated, rotated and ratioed along or about any axis. Surfaces of revolution can also be generated.

DISP: Display Points - This will dipslay the end points of all entities (arcs, lines, etc) or the end points of those entities picked before DISP.

PROJ: Project - Allows the projection of any number of picked entities on to any number of picked parametric ruled surfaces or parametric cubic patches (PRS or PTCH respectively) or on to an unbounded plane of the designer's choosing.

PRS: Parametric Ruled Surface - Creates a three-dimensional parametric ruled surface between two mixed entity strings.

DEPH: Depth - This allows the designer to assign a depth valve to a constuction plane and move entities any distance above and below the construction plane.

SPHR: Sphere - Creates a sphere.

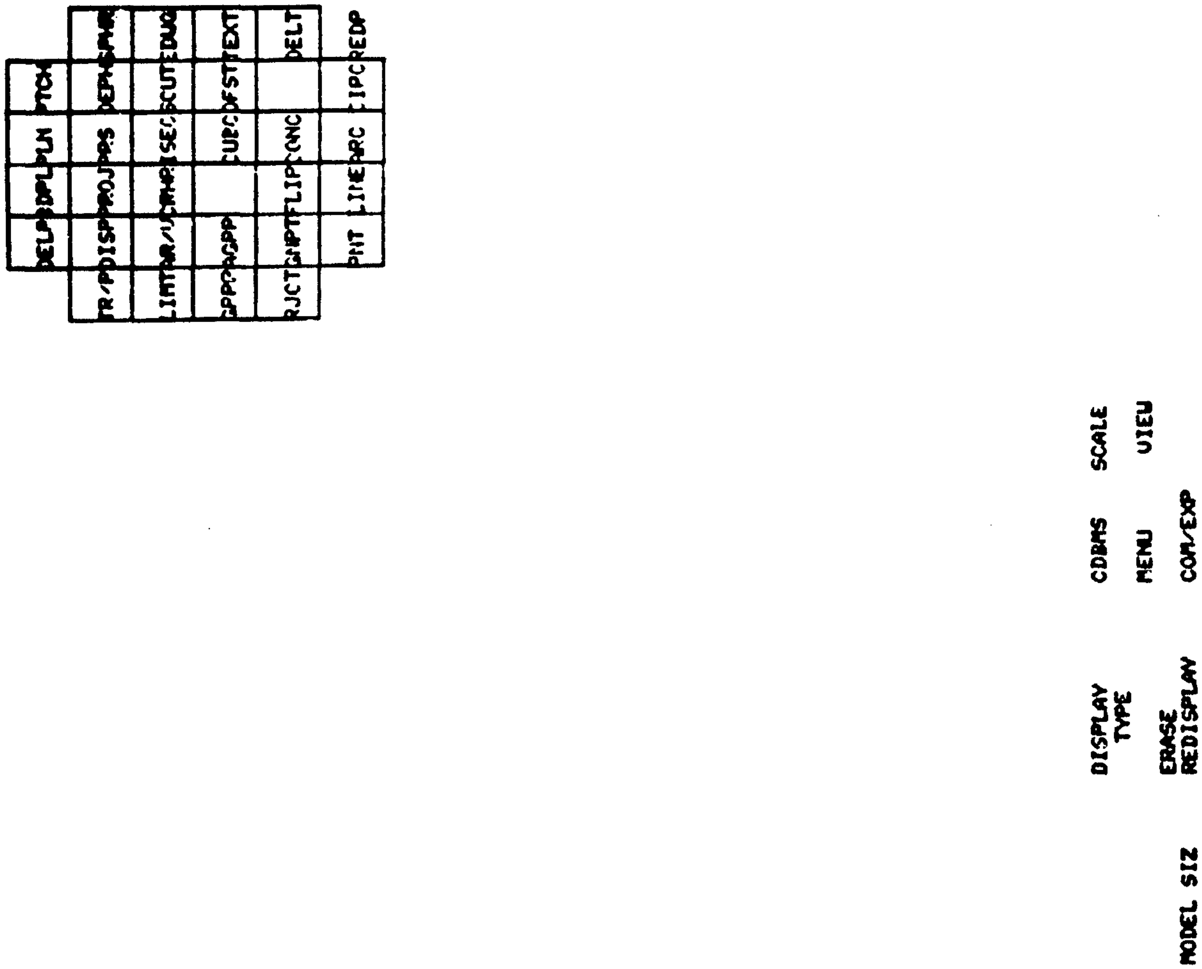

Figure 6: Screen Display for Gperator.

1.TERMINATE GRAPHICS SESSION	19.RETURN TO MONITOR
2.DELETE DRAWING	20.SCRATCH HARDCOPY ORDER
3.DELETE BY ENTITY TYPE	21.BATCH JOB STATUS - HARDCOPY
4.ERASE / REDISPLAY BY TYPE	22.TRANSFER TO ANOTHER MODULE
5.CREATE/UPDATE PART DRAWING	23.
6.PICTURE PLANE	24.DIGITIZE(TEKTRONIX ONLY)
7.DIMENSION LIGHT BUTTONS ON/OFF	25.TAPERED WING
8.	26.SKEWED AXIS
9.	27.TRIANGULATED FLAT PATTERN
10.ELAPSED SITTING TIME	28.PRINT/PUNCH/DISPLAY/READ PN A
11.MODEL SIZE	29.ZERO DELETE BIT
12.AUTOFILE/DUMP/RECOUP/LOFT	30.FUNCTION LIGHT BUTTON ASSIGNMENT
13.DESK CALCULATOR	31.SPECIAL SYSTEM TRANSFER
14.	32.SCREEN DISPLAY OPTIONS
15.KINEMATICS	33.
16.CHANGE LABEL	34.
17.CHANGE MATRIX	35.
18.HARDCOPY DRAWING	36.

EXIT

Figure 7: Main Menu.

LIMT: Limit - This function will cut off lines, arcs, circles etc by intersecting them with other entities.

AR/V: Area/Volume - Gives the area and moments of area of planar figures and the related properties of volumetric figures.

CRHR: Crosshair - Generates cross hairs at points in space.

ISEC: Intersect - Shows the points and curves resulting from the intersection of any entity by another.

SCUT: Section Cuts - Displays the points and curves generated when a set of entities intersects a specified plane. These sections may be displayed separately.

GPRP: Geometric Properties - This gives the geometric properties of any entity or the relational properties between any two entities.

AGRP: Autogroup - Allows contiguous entities to be grouped together under one identification label for translation, rotation copying etc. Groups so formed may be joined to form higher level groups.

CUBC: Cubic - The cubic function with join a set of points in space into a parametric cubic curve of arbitrary tolerance or a spline curve.

OFST: Offset - Will offset lines, curves, surfaces or entity strings from a specified curve.

TEXT: Text - Allows alphanumeric characters to be displayed and stored in the CADD model.

RJCT: Reject - Negates the last function invoked. If a data stack was formed RJCT will delete the stack from the top down.

GNPT: Generate Point - This function will generate points in the view plane as specified by the stylus position on the tablet.

FLIP: Flip - Will create a mirror image of a set of entities about a line or plane.

CONC: Conic - Allows conic sections (ellipses, parabolas and hyperbolas) to be created from points and lines.

DELT: Delete - Deletes the picked entities from the model and the display. On the Tektronix storage tube this will only show upon picture repaint (REDP).

PNT: Point - Points are constructed by more than 50 methods.

LINE: Lines - creates lines.

ARC: Arc - Generates arcs.

CIRC: Circle - Generates circles.

REDP: Redisplay - Repaints the picture.

The Function Light Buttons at the bottom of the screen display deals with the presentation handling and filing of the model as a whole. This display is in refresh mode:

DISPLAY TYPE: Display Type - This function will change the presentation of lines, cubic, arcs etc from solid lines to dashed, phantom, center lines etc. Also, parametric ruled surfaces, patches, bounded planes and the like can be presented in a variety of ways and forms.

CDBMS: CADD Database Management System - A function that handles filing of the in-core model on disk, retrieving from disk, editing of file descriptions, arranging and merging.

SCALE: Scale - Saves four views or separate scales, changes the scale of the model and allows the model to be displaced relative to the screen center.

MODEL SIZ: Model Size - Displays information of the current CADD model in bytes used and bytes available. This function may be replaced by other function from the Main Menu, such as Picture Planes (PICT PLN).MODEL SIZ is the default option.

ERASE REDISPLAY: Erase/Redisplay - Erases and redisplays picked entities.

MENU: Menu - Returns to Main Menu.

VIEW: View - Allows the engineer to view the orthographic views, the trimetric view and to rotate the model about any axis.

COM/EXP: Compress/Expand - Enables picked parts of the model to be stored in a compressed data format and not displayed on the screen. This the passive mode and has a capacity of 204800 bytes. The active mode (in which the model is displayed) will store 65280 bytes. EXPAND draws the model from passive storage to active and redisplays it.

The main MENU (shown in Fig. 7) will perform a variety of functions such as transferring the operator to modules other than the CADD module, hardcopy drawing preparation and kinematics among other tasks. The numbers with no subsequent commands are for new functions as they become available.

4.0 USING CADD FOR DESIGN

4.1 Pre-CADD Methodology

Two methods of engineering design have been used at DREO for many years: the first, for drawings, the classical drawing board, and second, for 3-D mock-ups, model-making and sculpting.

The nature of model-making and its application to such problems in three-dimensional geometry as models for gas-masks has been dealt with in other DREO publication (DREO Tech Note 82-17) and will not be re-examined or expanded upon here. Suffice it to say that the process of model-making - the plasticine - headform - sculpture combination - is completely analog in its nature. Headforms are sculpted from anthropometric data by a sculptor or artist (an analog concept); a gas mask form is again sculpted from clay or plasticine over this form (again an analog operation) and this shape is copied by means of a duplicating machine into an aluminum or steel model cavity. Dimensional control along this path is extremely difficult: for instance, it has been found that distortions introduced in the sculpting/casting process have produced discrepancies between specified and measured dimensions of more than 5 mm [4].

The application of computer-aided design seeks to eliminate, or at least reduce to a minimum, this class of inaccuracies by the accurate storage of data in digital format. It is not that analog processes are removed, rather, at critical steps where the transfer of data takes place, or a transformation of data takes place, for example, as it would in sculpture to mold, data is digitized at that point and may be transferred without loss of definition. The design of surfaces on the computer may still involve considerable personal judgement and action on the part of the designer, but when those surfaces are defined, they may be transferred between data bases without loss of definition and may be copied directly byte for byte. This is particularly important when we wish to move from geometry to numerical control machining.

The assessment of computer-aided design manufacturing systems (CAD/CAM) suitable for the projects at DREO has been described before in reference [1]. The use of the CADD system in relation to the design of a mask will be described.

4.2 Model Construction With CADD

The initial conditions here refer to the starting point of the design process. Herein, we shall refer specifically to the design of the mask.

The initial conditions for most engineering design are a blank screen and the point, line, circle, etc, function keys. However, to begin a design involving such complex geometries, a digitized periphery, that is the area of mask in contact with the face, was taken from a standard headform (CWS-MIT headform #3) and entered into the database. The origin was taken to be a point directly under the chin in the mid-plane of the face. Points were taken every 0.2 inches vertically (the z-axis being vertical) and the x- and y- coordinates were determined.

The actual area of the C3 mask in contact with the face was determined by mounting a C3 mask on a standard headform and spraying a chalk dust in the interior cavity. The boundary of the contact area was marked on the inside by the chalk dust boundary and on the outside by the mask boundary itself. Points up and down these boundaries were taken every 0.2 inches vertically and entered in the CADD database via the keyboard. Four sets of points were taken across the contact area through the depth of the face. These points were grouped using the function 'autogroup' (AGRP) and the points were formed into patch surfaces using the function 'patch' (PTCH). The initial dataset for each patch was sixteen points (see Fig. 8). The basis dataset for patch surface creation in CADD is varied: any sixteen points or four parametric cubic curves are required. The curves must have contiguous end-points otherwise a "no-connectivity" error will result. These are the types of errors that are easy to make with designing something intuitively, but which must be addressed rigorously and analytically when using a computer, as computers have no intuition.

In constructing a set of contiguous patches it is not possible to generate the patch from sixteen points and have the cubic curves continuous in both path and gradient at the junction of the patches. If the gradients are not matched at the boundaries, surface discontinuities will result. Often these are not critically important, but in the peripheral surface where the mask edge will have to meet the face surface continuity is highly desirable.

This problem was addressed in the following way. Alternate patches were created and intermediate ones created using surface blending techniques. To create a patch that blends two others into a continuous surface, pick the appropriate boundary of one patch and its corresponding patch symbol, the appropriate boundary of the other patch and its patch symbol and the function key PTCH. This will create a patch that blends to the other two with a continuous surface (see Figs. 9 & 10). This patch that has been so created may not match the original point data, but, if the surfaces do not have wildly varying curvatures, the correspondence will be close. Furthermore, the created patch may be modified if required by offsetting points from the surface and defining new parametric cubic curves which may then be made into a new patch. The blending process, however, enables the boundary curves and their gradients to be matched which are the critical conditions for smooth surfaces.

The surface of the headform that seals with the mask was constructed in this manner. Two views of its structure may be seen in Figs. 11 and 12.

Throughout the design work, only the left-hand side of a mask form was constructed as the function key FLIP will mirror any surface or construction about a plane or line. Actually, the design was completed, the tool paths set up and the N/C programming executed all on left-side geometry as the N/C machine itself has a function key for producing mirror images. This cut down computing time and costs.

As the purpose of producing the models is to examine various geometries, the term concept design was used for each change of model. The first concept design was discussed in reference [5] and the second and third concept designs are discussed herein.

To provide a new mask with improved vision requires a larger, better placed eyepiece than the one currently in place on the C3 mask. A periphery for a lens was constructed and positioned (on the computer model) in front of the eye center and at a 40° angle with the vertical axis (see Fig. 13 and 14). The general shape was an arbitrary design allowing the maximum surface area, with a positive curvature boundary, that is commensurate with the sizes and positions of the accessories.

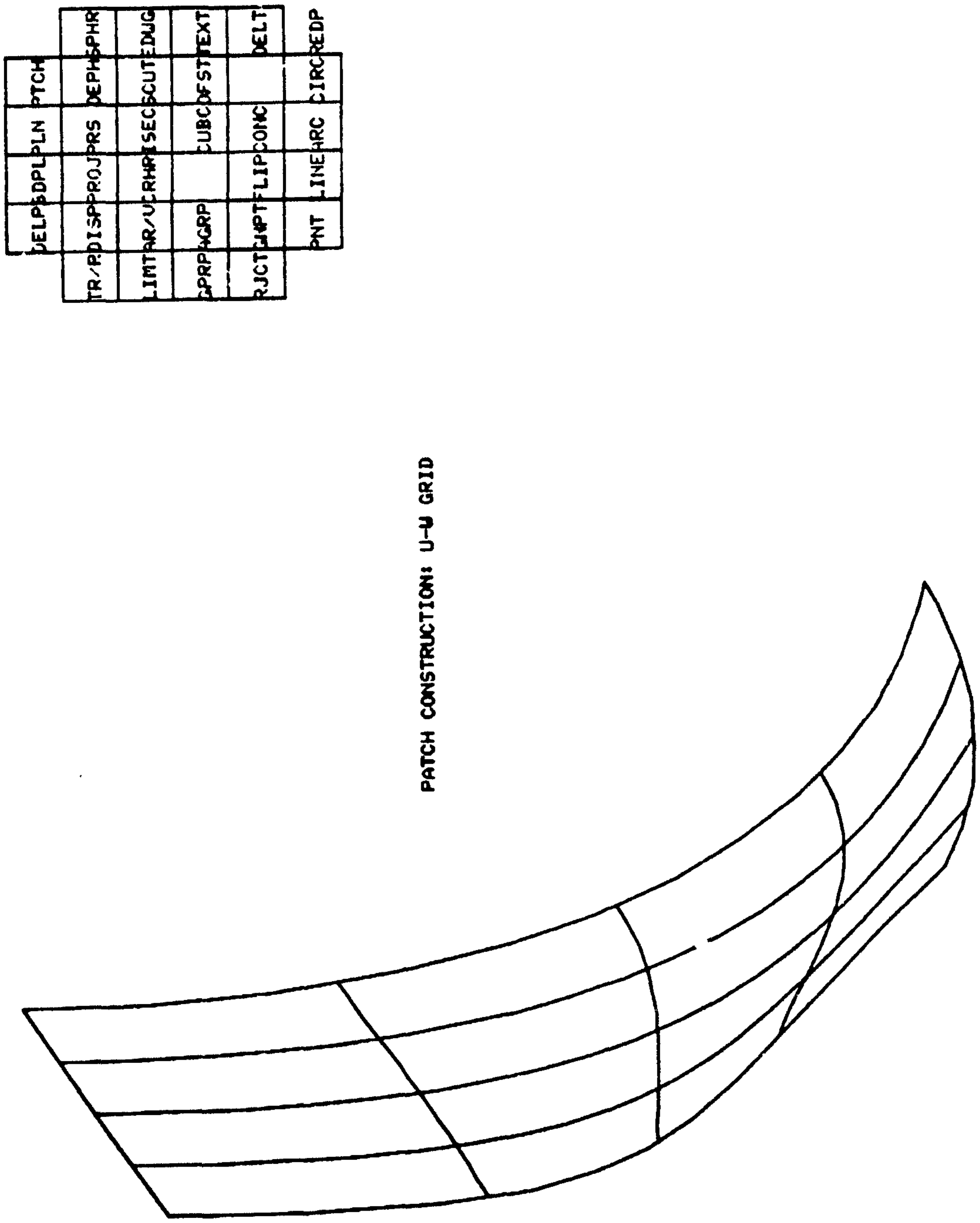

Figure 8: Patch Surface Creation.

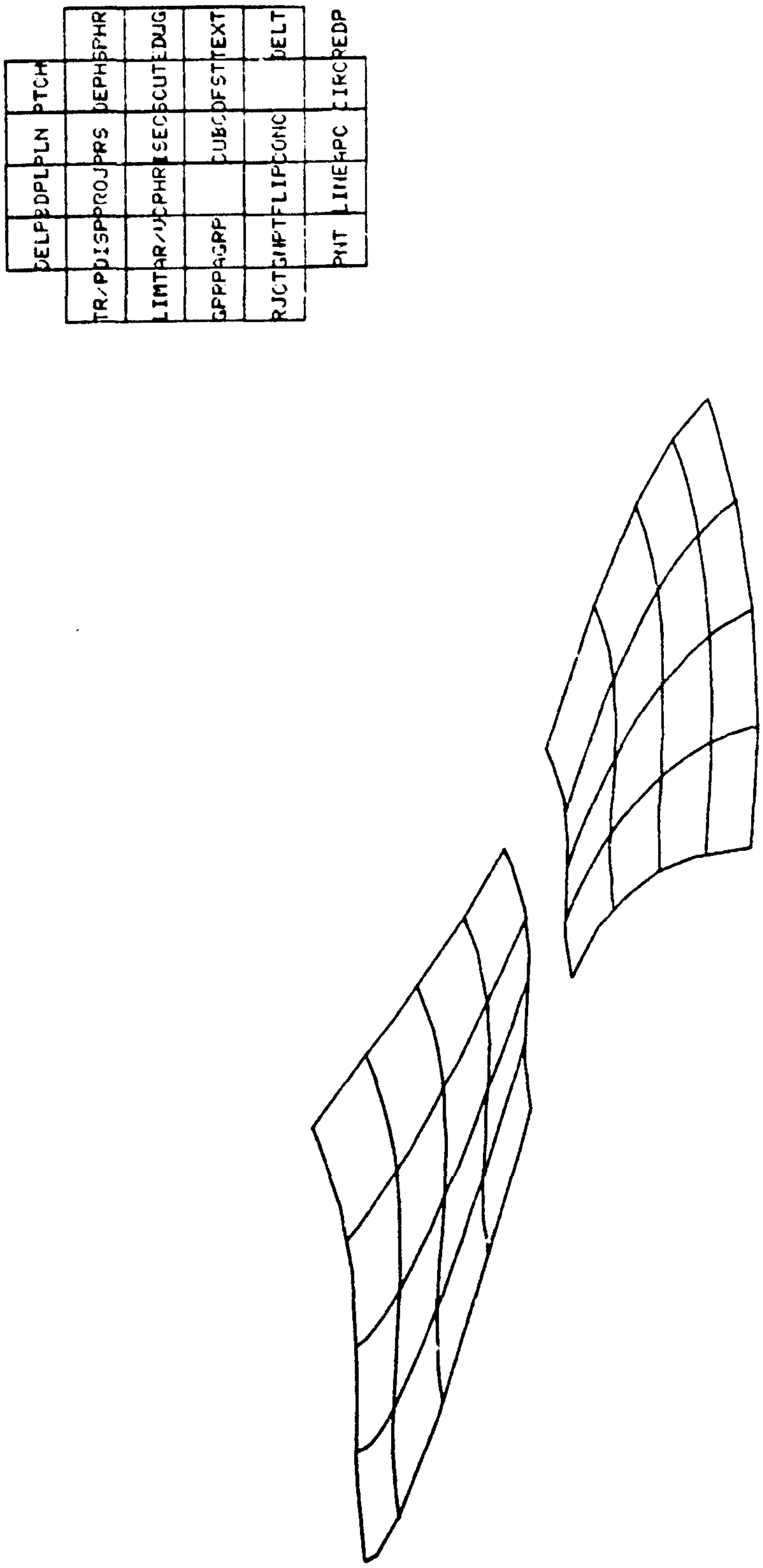

Figure 9: Patch Surfaces - Grid Construction.

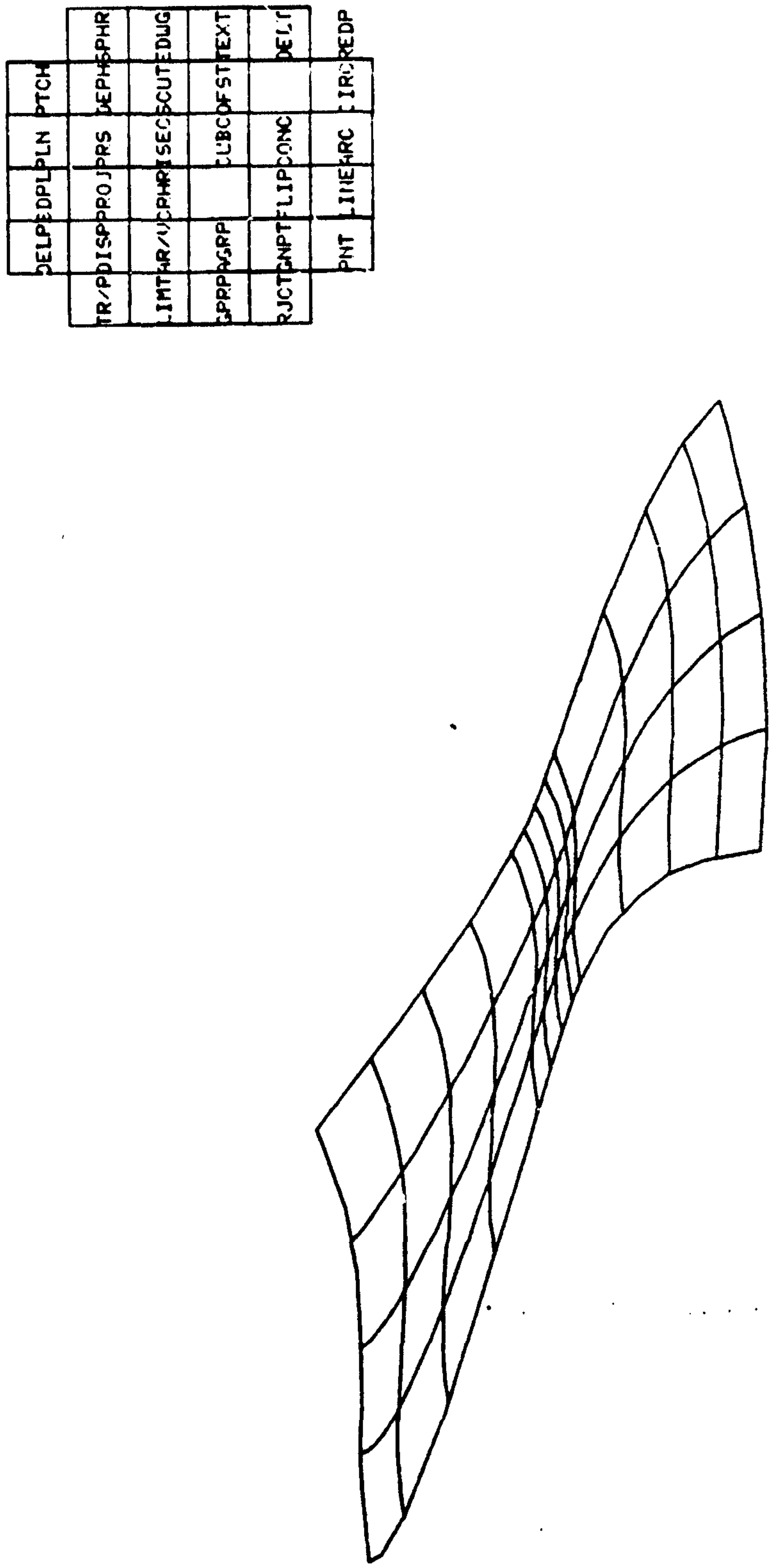

Figure 10: Surface Blending of Patches.

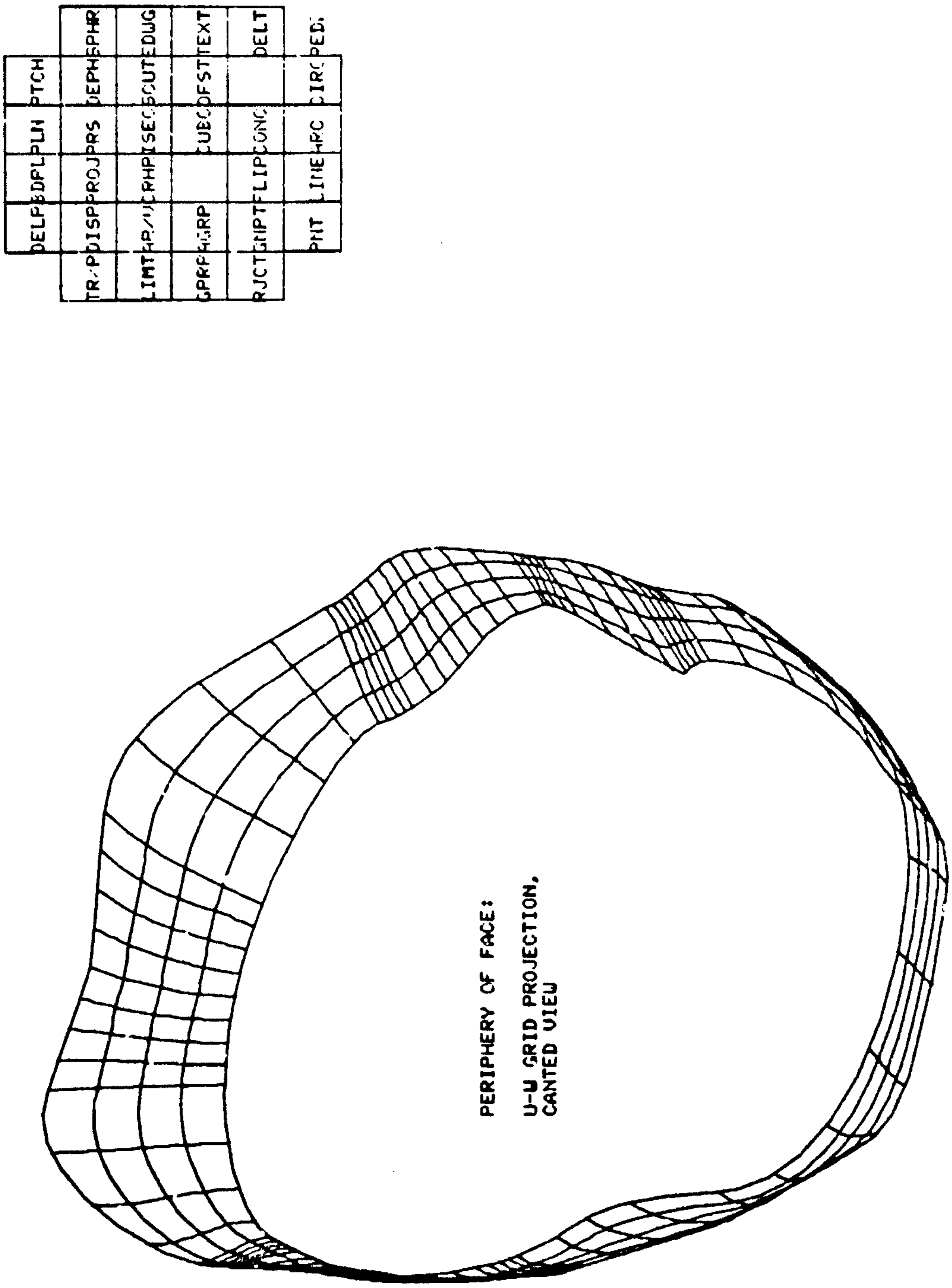

Figure 11: Periphery of Face, Patch Surface Construction.

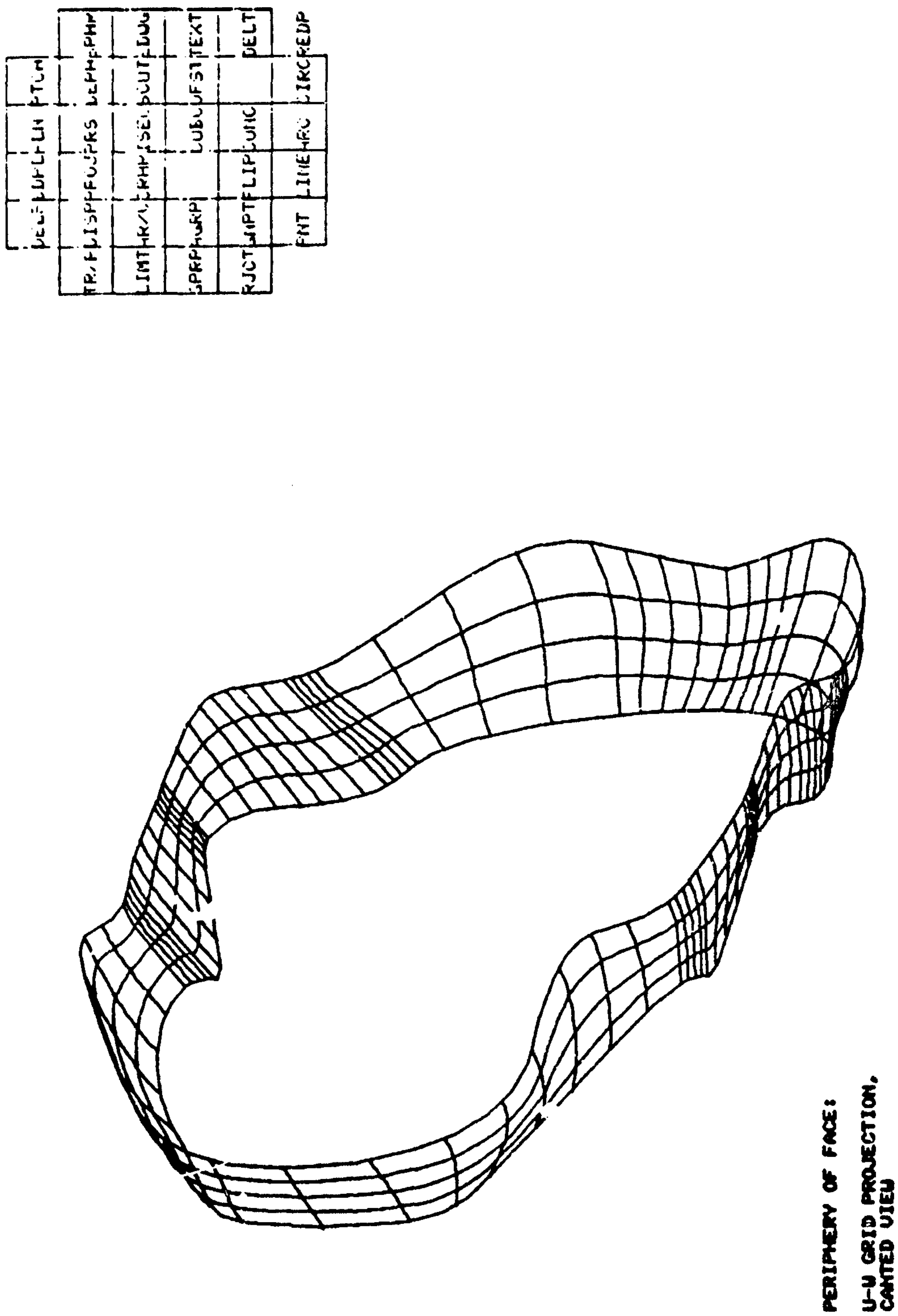

Figure 12: Periphery of Face, Canted View.

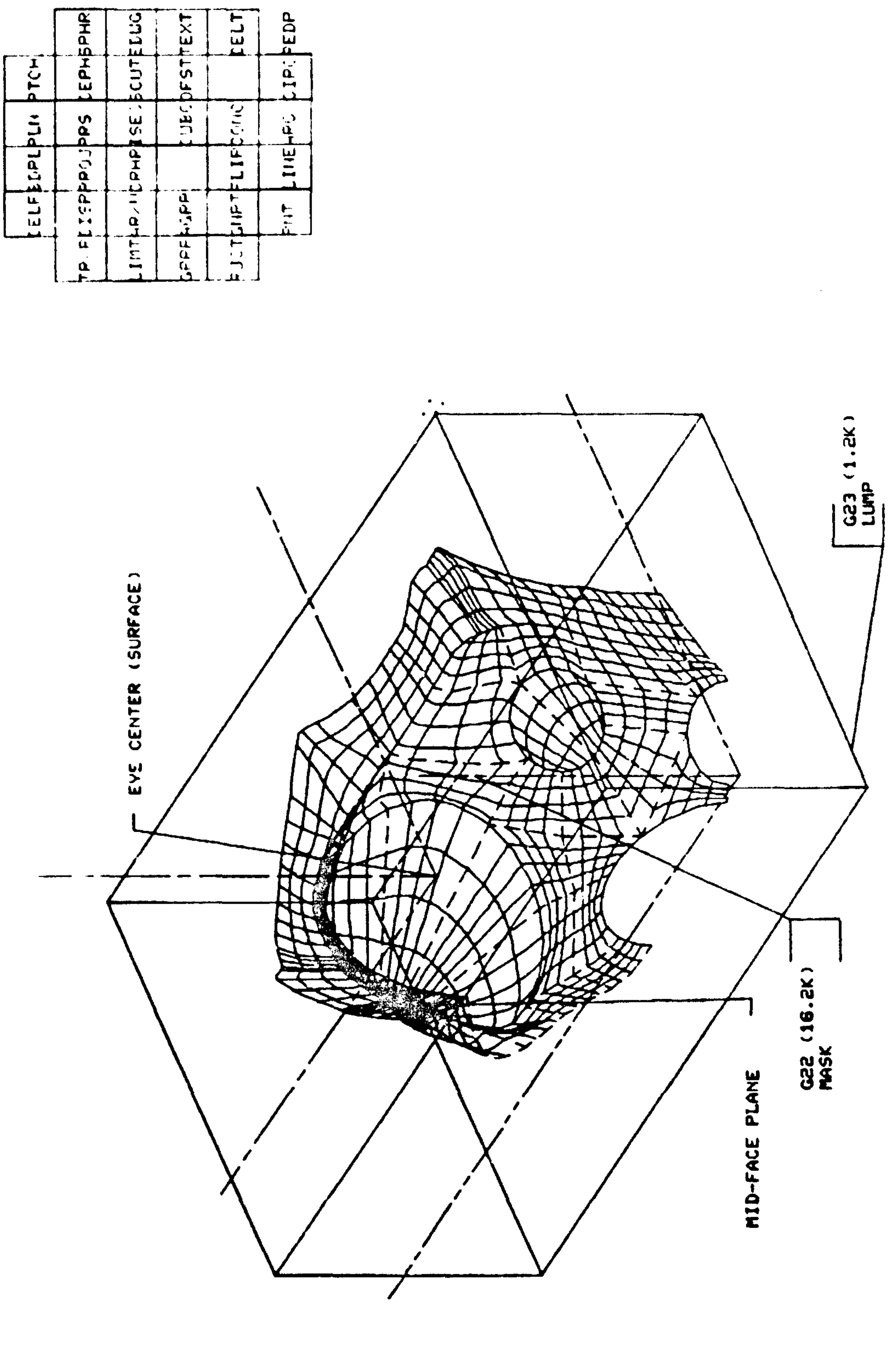

Figure 13: Half-Face Mask Model.

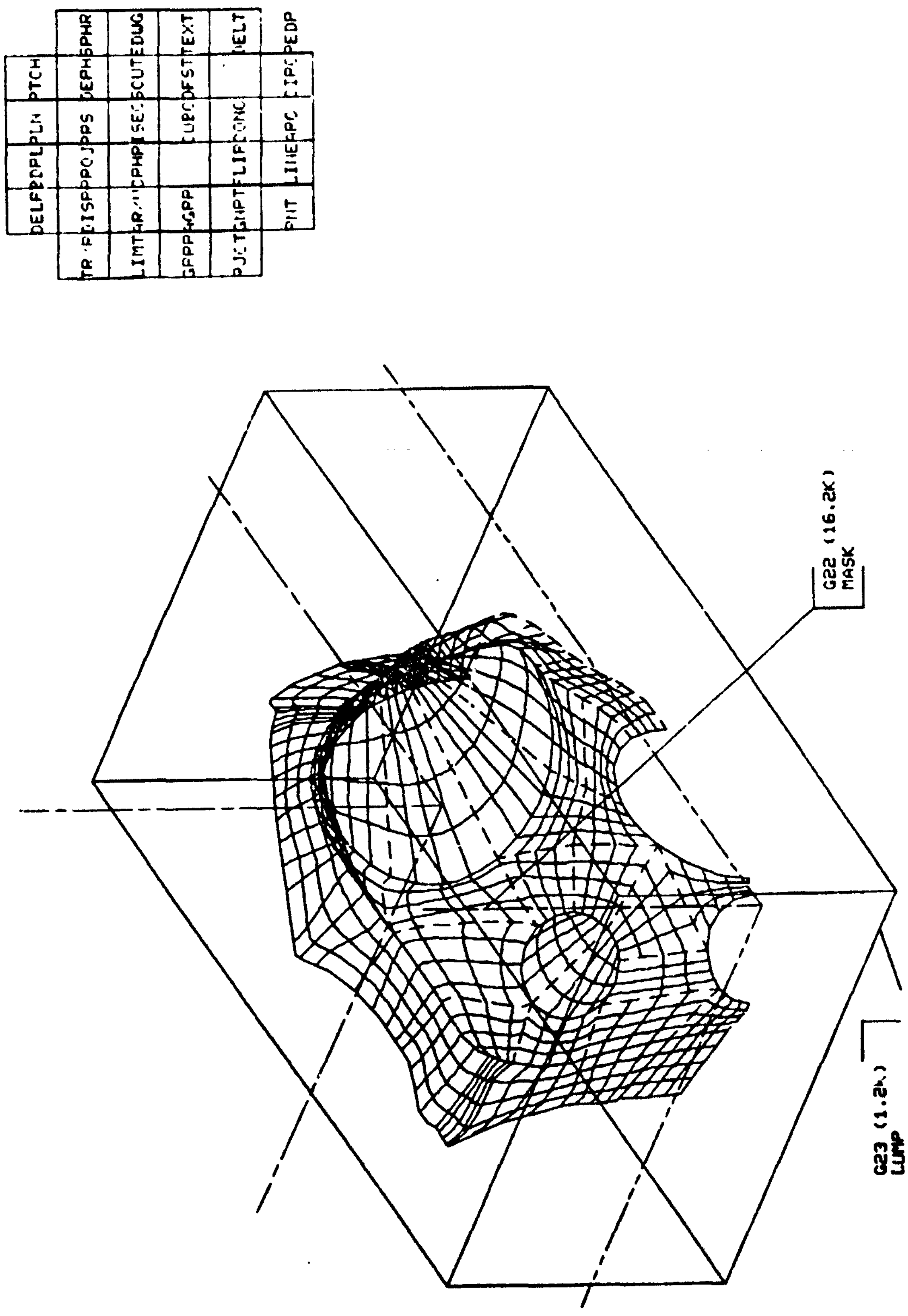

Figure 14: Half-Face Mask Model, Reverse View.

Patch surfaces were constructed to surface the model. The nature of the connections between the surfaces representing the eyepieces and the periphery seal was examined carefully. Some of these surfaces had to meet with surface gradients parallel and some had to meet with gradients normal to one another. Surfaces meeting the eyepiece were parallel to the eyepiece surface and surfaces connecting the periphery to the facepiece were normal (around the top portion of the mask form above the eyepiece). Several different views of the surfaced model, (left-hand side) are shown in Figs. 13 and 14. Some surfaces that were close together were blended with an intervening patch matching the surface gradients at both ends. The data stack for this operation was CUBIC 1, PATCH 1, CUBIC 2, PATCH 2, PTCH operator. These functions are described in detail in Appendix 1.

A third concept design was constructed using the same methods. Here the design criteria demanded a circular eyepiece shape (Figs. 15 and 16). This was positioned in front of the eyecenter and inclined so that the bottom of the shape was slightly further from the face than the top. This was to allow greater space for the nosecup. Surfaces were again constructed to match the peripheral surface and the unchanged parts of the design of the second concept. Upon completion of the modelling, only the parts of the numerical control (N/C) programming pertaining to the new surfaces were changed. These programs were run under the executable CLISTs and a new model was available.

The NC data for this model were post-processed to be run on an Ex-Cello-O 604 three-axis machine with a Bendix A5M Dynapath controller.

5.0 NUMERICAL CONTROL PROGRAMMING

Numerical control, or NC, is really a combination of machining directed by computer programming.

For simple geometry involving lines, circles and arcs and usually 2 ½ D models, a simple program in APT (Automatic Programming of Tools) is sufficient. A program may be used to generate a punched tape that may be fed directly into the memory of an NC machine. More complex geometry may involve circular interpolation. For cutting a model of the mask shape, with complex 3-D geometry, a large number of point-to-point operations must be executed. This means that paths must be plotted over all the surface and computations carried out to generate the large number of point-to-point instructions for the NC machine. CADD is very good at doing this.

First, sets of parametric cubic curves are laid out on the model surfaces. This may be done by one of several ways. One method is to pick out a set of surfaces from the model and intersect these surfaces with a regularly-spaced set of planes. The planes will be placed normal to one of the model axes. The intersections produced will be another set of parametric cubic curves which have to be joined up to produce a set of cutter paths. For a surface with a large number of complex patch surfaces, this can be rather confusing. A second method involves using the patch and cubic functions (PTCH, CUBC). The patch surface is picked followed by the function key cubic (CUBC). Then any number of u- and/or w-curves may be laid out across the patch. Thus, over a set of patches, all the u- or w-

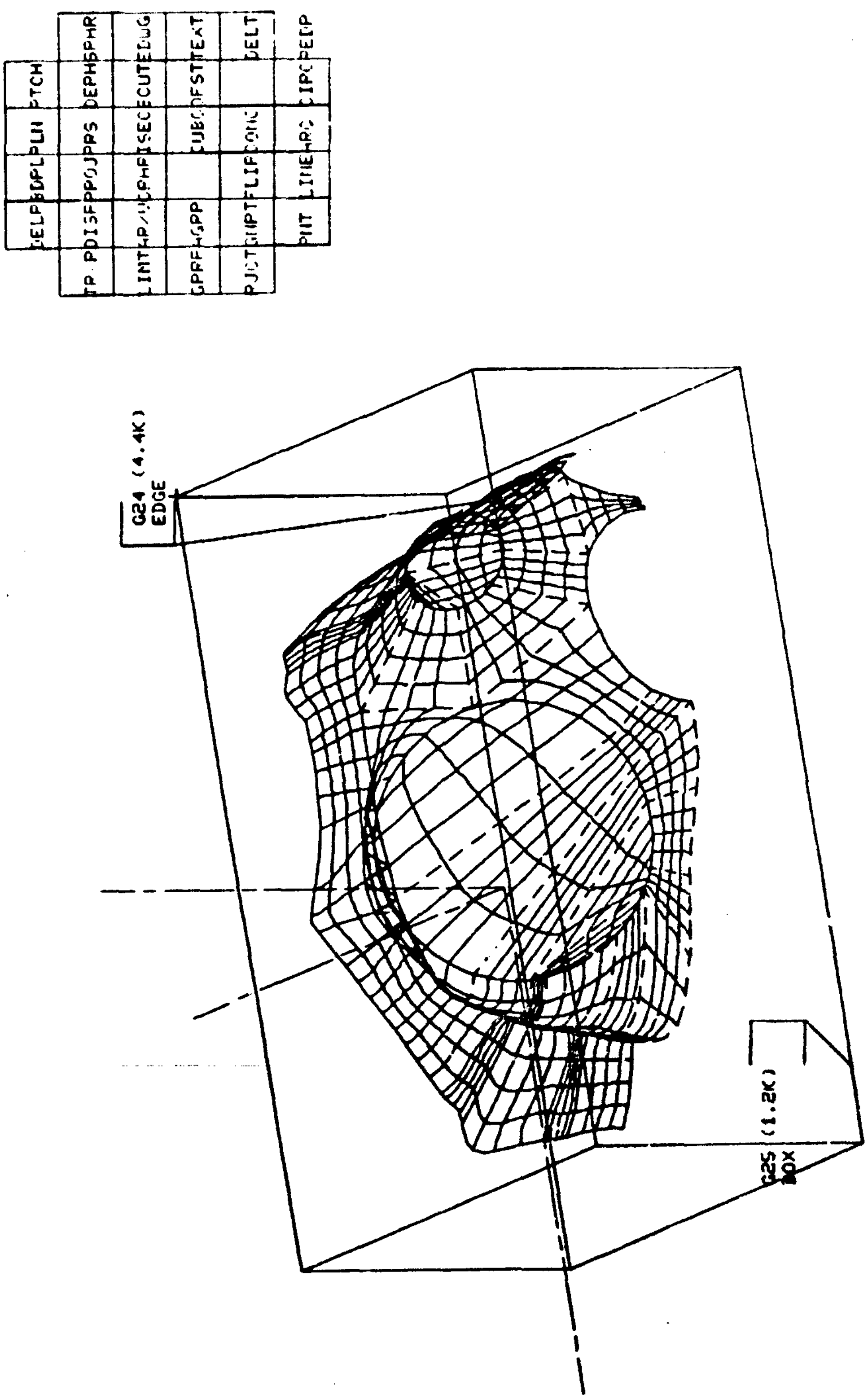

Figure 15: Mask Model, Circular Eyepiece Concept.

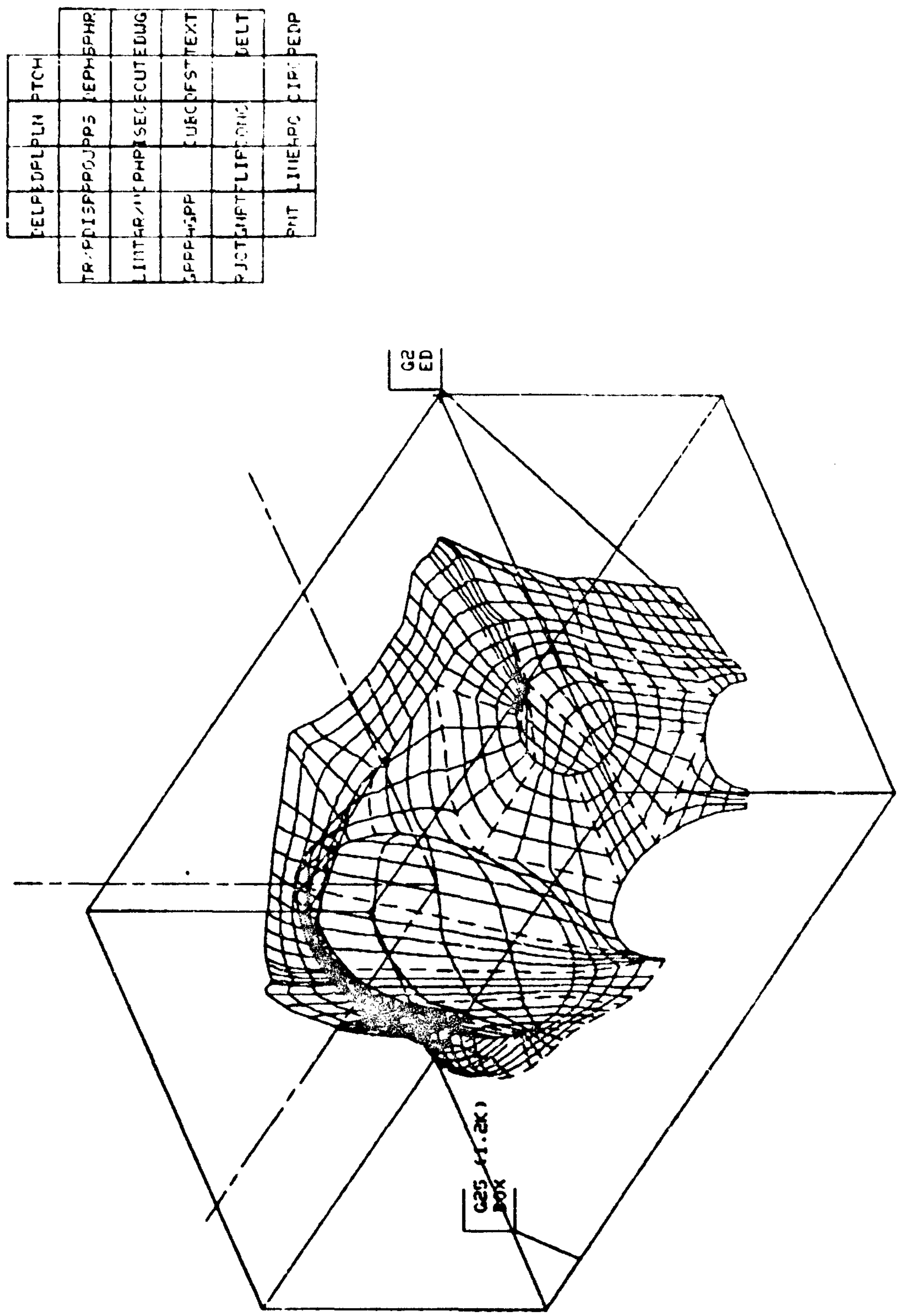

Figure 16: Mask Model, Circular Eyepiece Concept.

curves may be joined up forming a contiguous set (see Figs. 17 and 18). The model was divided up into seven different sets of surfaces for ease of handling. Each set of surfaces was then stored under a different model name. These models were titled RUFCUT, CUTR1 through CUTR6.

To produce NC data, an executable CLIST was built and run. This is a program that runs on the IBM TSO processor and builds up an APT source code using the curves and surfaces in the CADD model. An example, EXMILL2.CLIST, is shown in Figs. 19 through 22. This is an interactive program containing a postprocessor for an Ex-Cell-O 604 3-axis milling machine with a Bendix A5M Dynapath controller. The program may be run without any post-processor information in it, as a check on the cutter paths, but the CL data file will be empty.

Four files are produced by this program: ADVRT.DATA, PRINT.DATA, CLDAT.DATA and PUNCH.DATA. The program contains the statement MODEL/'FILEJX', 'NAME' which calls up the CADD model. The further statement CALL/RESRVE, SEC1, 'GPCMPR', 'G0030', RC, ACR, CR, CLZ, TOL, TF, RF, CF fills in all the argument values determining the characteristics of the cutter and machine for which we are producing data. 'GPCMPR' is the routine that maps the parametric cubics defined in our cutter path definition with the patch surfaces in the CADD model. 'G0030' refers to the group of curves, number 30, in the CADD model that describes the cutter path for a particular set of surfaces. The execution of EXMILL2.CLIST as seen from the terminal is shown in Fig. 23.

The post-processor for the particular NC machine/NC controller combination that is being used is contained in the program. This allows the point-to-point NC data produced by the computations on the cutter paths and surfaces to be ready for the NC machine's memory or for punching on to paper tape. The post-processor describes number field widths, machine characteristics and start up procedures. These procedures vary from machine to machine and controller to controller, but modifications may easily be made to the EXMILLN.CLIST program on IBM TSO. Each CADD model drawing may contain several groups of cutter paths. These may be run together as one program if all the paths are contiguous, or they may be run separately. If run separately, the machine will return the cutter to the clearance plane and set-point after performing the required operations on each individual group.

The model was divided up into seven sets of surfaces and cutter paths for ease of handling. The paths for these are illustrated in Figs. 24 through 30. The model was first cut from a block of machineable wax manufactured by Do-All Ltd. This is a material which allows a high cutting rate and requires no lubricant. It can be used to check programs and the geometry of the part. Chips can be saved, melted down and formed into blocks again for re-use.

NC data was prepared for a Matsuura 3-axis milling machine with a Yasnac controller. A post-processor was written for this machine/controller combination using the MCAUTO UDOIT program guide. This was included in the EXMILL3.CLIST file. When the programming was completed and the NC data produced the PUNCH.DATA files for each of the models was transferred to the MCAUTO CYBER system by means of the CYBER.MOVE.CNTL.CLIST. This was because

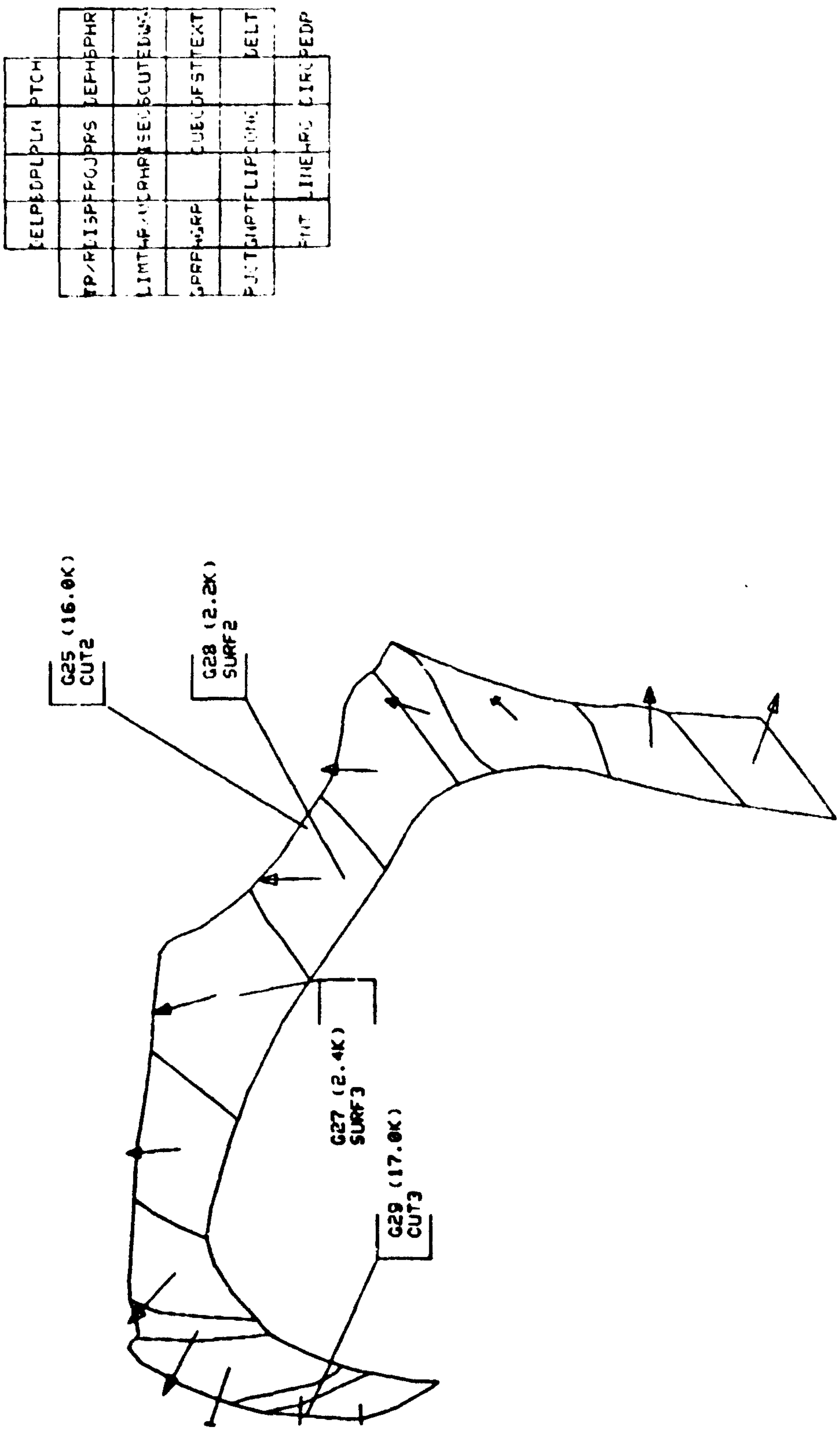

Figure 17: Segmented Patch Construction of Model Surface.

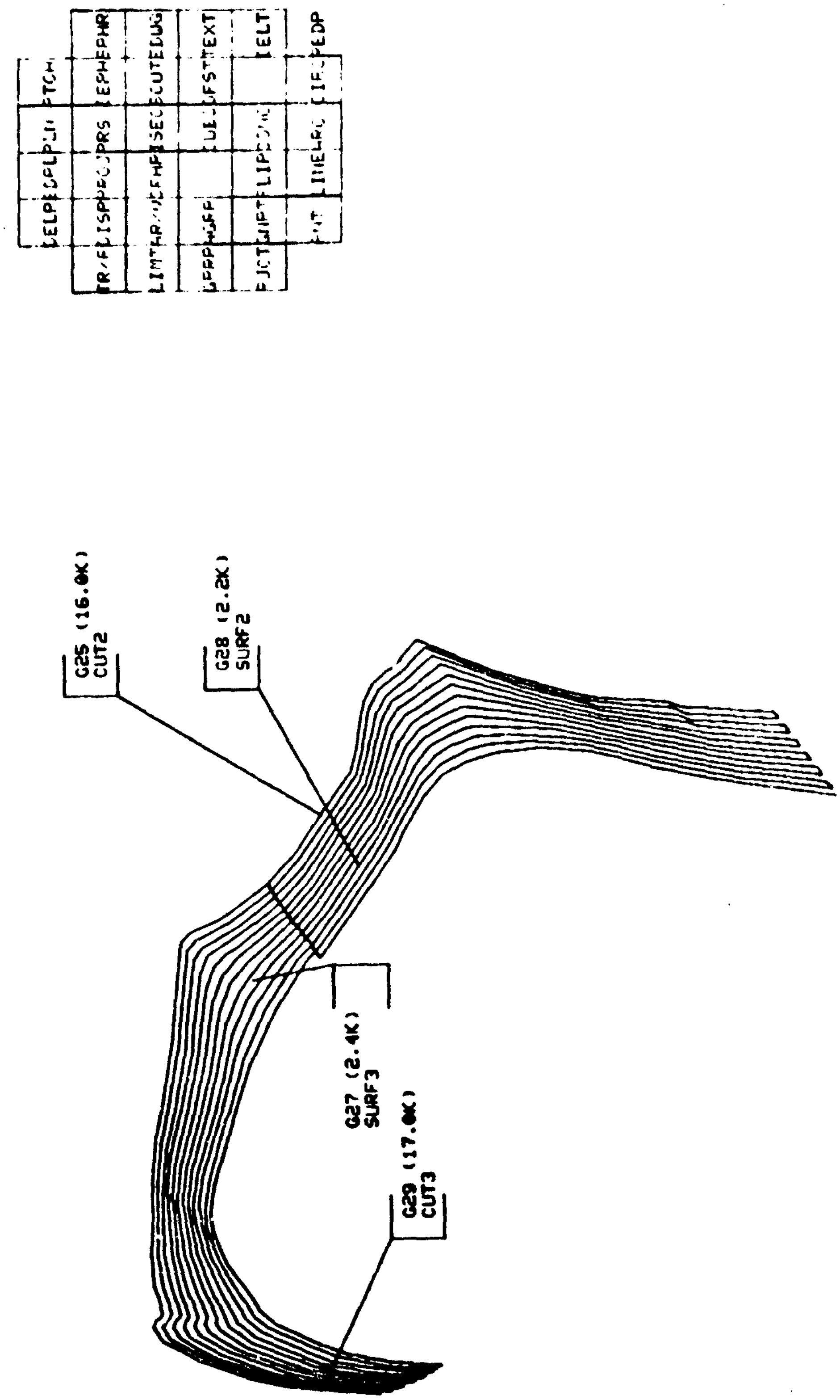

Figure 18: Cutter Paths Plotted Over Patch Surfaces.

```
EXMILL2.CLIST
PROC 0
FREEALL
CONTROL NOLIST
LAB00: WRITENR KEY IN (8) DIGIT (MAX) ID'
READ &ID
IF &ID EQ THEN GOTO LAB00
LAB001: WRITENR KEY IN PROGRAMMER NAME!
READ
IF &SYSDUAL EQ THEN GOTO LAB001
SET &NOM = &STR(&SYSDUAL)
WRITE KEY IN SET POINT'
SET &X = 0
WRITENR X = &X ,KEY IN NEW X'
READ &ANS
IF &STR(&ANS) EQ THEN GOTO LAB01
SET &X = &STR(&ANS)
LAB01: SET &Y = 0
WRITENR Y = &Y ,KEY IN NEW Y'
READ &ANS
IF &STR(&ANS) EQ THEN GOTO LAB02
SET &Y = &STR(&ANS)
LAB02: SET &Z = 1
WRITENR Z = &Z ,KEY IN NEW Z!
READ &ANS
IF &STR(&ANS) EQ THEN GOTO LAB03
SET &Z = &STR(&ANS)
LAB03:  SET &ACR=.5
WRITENR ACR = &ACR --KEY IN NEW ACR'
READ &ANS
IF &STR(&ANS) EQ THEN GOTO LAB04
SET &ACR = &STR(&ANS)
LAB04: SET &CR = &STR(&ACR)
WRITENR CR = &CR --KEY IN NEW CR!
READ &ANS
IF &STR(&ANS) EQ THEN GOTO LAB05
SET &CR = &STR(&ANS)
LAB05: SET &XSMATL=&STR(0)
WRITENR XSMATL = &XSMATL --KEY IN NEW XSMATL!
READ &ANS
IF &STR(&ANS) EQ THEN GOTO LAB06
SET &XSMATL = &STR(&ANS)
LAB06: SET &CLZ = &STR(&Z)
WRITENR CLZ = &CLZ --KEY IN NEW CLZ'
READ &ANS
IF &STR(&ANS) EQ THEN GOTO LAB07
SET &CLZ = &STR(&ANS)
LAB07: SET &TOL = .005
WRITENR TOL = &TOL ,KEY IN NEW TOL'
READ &ANS
IF &STR(&ANS) EQ THEN GOTO LAB08
SET &TOL = &STR(&ANS)
LAB08: SET &CF = 20
WRITENR CF = &CF ,KEY IN NEW CF'
READ &ANS
IF &STR(&ANS) EQ THEN GOTO LAB031
SET &CF = &STR(&ANS)
```

Figure 19: Executable .CLIST for Building N/C Post Processor.

```
LAB081: SET &RPM = 870
WRITENR RPM = &RPM ,KEY IN NEW RPM!
READ &ANS
IF &STR(&ANS) EQ THEN GOTO LAB09
SET &RPM = &STR(&ANS)
LAB09:  WRITE =====> PAUSE TO CLEAN UP DATASETS <=====
FILESTAT &ID..PUNCH.DATA
IF &LASTCC EQ 4 THEN GOTO LAB091
DELETE &ID..PUNCH.DATA
LAB091: FILESTAT &ID..ADVRT.DATA
IF &LASTCC EQ 4 THEN GOTO LAB092
DELETE &ID..ADVRT.DATA
LAB092: FILESTAT &ID..CLDAT.DATA
IF &LASTCC EQ 4 THEN GOTO LAB093
DELETE &ID..CLDAT.DATA
LAB093: FILESTAT &ID..PRINT.DATA
IF &LASTCC EQ 4 THEN GOTO LAB10
DELETE &ID..PRINT.DATA
LAB10: EDIT DUMMY.CNTL CNTL OLD
SET &PARTNO8 = &ID
SET &KNT = &LENGTH(&PARTNO8)
SET &LID = 8 - &KNT
 IF &LID NE 0 THEN SET &PARTNO8 = &PARTNO8&SUBSTR(1:&LID,&STR(         ))
10 //&PARTNO8 JOB X,NAME('ZIMMERMA 30304 Q2132'),MSGCLASS(A),NOTIFY,       X
IN //               REGION(1500),CPU(3),IO(4),LINES(60),CARDS(60),        X
IN //               PROG(0000000)
DATA
IN //* */**********************************************************
IN //* */  MCAUTO  ST LOUIS                                     GPCMPR
IN //* */
IN //* */  PROGRAMMER  &NOM
IN //* */
IN //* */ MCAUTO REP LOU ZIMMERMANN      DEPT K329
IN //* */
IN //* */ MCDONNELL DOUGLAS AUTOMATION COMPANY (MCAUTO)
IN //* */ CADCAM SERVICES DIVISION
IN //* */ BLDG 305  LEV 2W  ROOM 210
IN //* */ TELE (800) 325 1760
IN //* */
IN //* */**********************************************************
IN //*MAIN CLASS=TSOK                                          */
IN //*FORMAT PR,DDNAME=,DEST=MA304                             */
IN //*FORMAT PU,DDNAME=,DEST=MA158                             */
IN // EXEC MDCAPTC,ADV=1,PRJ=MISC
IN //FT02F001 DD DSN=&SYSPPEF..&ID..CLDAT.DATA,UNIT=TSOKDA,
IN //              DCB=(RECFM=F,LRECL=2980,BLKSIZE=2980,DSORG=PS),
IN //              SPACE=(2980,(430,55),RLSE),DISP=(,CATLG)
IN //FT07F001 DD DSN=&SYSPREF..&ID..PUNCH.DATA,UNIT=TSOKDA,
IN //              DCB=(RECFM=FB,LRECL=80,BLKSIZE=1680,DSORG=PS),
IN //              SPACE=(1680,(50,10),RLSE),DISP=(,CATLG)
IN //FT11F001 DD DSN=&SYSPREF..&ID..PRINT.DATA,UNIT=TSOKDA,
IN //              DCB=(RECFM=FB,LRECL=137,BLKSIZE=19043,DSORG=PS),
IN //              SPACE=(19043,(50,50),RLSE),DISP=(,CATLG)
IN //FT15F001 DD DSN=&SYSPREF..&ID..ADVRT.DATA,UNIT=TSOKDA,
IN //              DCB=(RECFM=VA,LRECL=255,BLKSIZE=1680,DSORG=PS),
IN //              SPACE=(1680,(10,10),RLSE),DISP=(,CATLG)
IN //GO.SYSIN DD *
```

Figure 20: Executable .CLIST for Building N/C Post Processor.

```
IN PARTNO &ID  &NOM  DREO
IN $$  &NOM  CAD/CAM DIVISION  DREO
IN $$**********************************************************
IN MACHIN/UDOIT,1      $$NRC EXCELLO MILLING MACHINE
IN INSERTF N240,G2,X-3.4,Y-3.4,Z-3.4,I-3.4,J-3.4,F3.2,S4,T2,M2
IN INSERT %$
IN INSERT N1G70$
IN INSERT N2G90$
IN SEQNO/3
IN LOADTL/1
IN $$**********************************************************
IN PPPRNT
IN FROM/(SETPT=POINT/&X.,&Y.,&Z.)
IN ACR=&ACR
IN CR=&CR
IN XSMATL=&XSMATL
IN CUTTER/(2*(ACR+XSMATL)),(CR+XSMATL)
IN RC=CR+XSMATL
IN CLZ=&CLZ
IN TOL=&TOL
IN TF=150
IN RF=50
IN CF=&CF
IN SPINDL/&RPM,CLW
IN COOLNT/ON
IN FEDRAT/CF
ENDDATA
SET &DRNAM = 0
LAB11: WRITENR KEY IN DRAWING NAME '
READ
SET &ANS = &STR(&SYSDVAL)
READDVAL &PARM1
WRITE &SYSDVAL
IF &STR(&PARM1) EQ THEN GOTO LAB15
IF &STR(&PARM1) = &STR(&DRNAM) THEN GOTO LAB14
SET &DRNAM = &STR(&ANS)
GOTO LAB13
LAB12: IF &LENGTH(&STR(&DRNAM)) = 0 THEN GOTO LAB11
LAB13: DATA
IN MODEL/'FILEJX','&DRNAM.'$$,MODIFY,1
ENDDATA
LAB14: WRITENR KEY IN GROUP NUMBER'
READ &GRPNO
IF &GRPNO EQ THEN GOTO LAB11
IF &GRPNO LT 1 OR &GRPNO GT 9999 OR &DATATYPE(&GRPNO) NE NUM THEN DO
   WRITE  INVALID GROUP NUMBER--TRY AGAIN'
GOTO LAB14
END
ELSE SET &N = 5-&LENGTH(&GRPNO)
SET &GROUP=&SUBSTR(1:&N,G000)&GRPNO
DATA
IN PPRINT PROCESS GROUP '&GROUP.' OF MODEL '&DRNAM.'
IN CALL/RESRVE,SEC1,'GPCMPR','&GROUP.',RC,ACR,CR,CLZ,TOL,TF,RF,CF
IN PPRINT END PROCESS OF GROUP '&GROUP.' OF MODEL '&DRNAM.'
ENDDATA
GOTO LAB14
LAB15: DATA
```

Figure 21: Executable .CLIST for Building N/C Post Processor.

```
01710 IN GOTO/SETPT,TF
01720 IN STOP
01730 IN REWIND
01740 IN PRINT/3,ALL
01750 IN FINI
01760 IN //
01770 ENDDATA
01780 WRITE =====> PAUSE TO SUBMIT &ID <=====
01790 RENUM
01800 SUBMIT
01810 END NOSAVE
01820 END
READY
```

Figure 22: Executable .CLIST for Building N/C Post Processor.

```
READY
EX EXMILL2.CLIST
KEY IN (8) DIGIT (MAX) ID'CT1NRC
KEY IN PROGRAMMER NAME!HIDSON
KEY IN SET POINT'
X = 0 ,KEY IN NEW X!
Y = 0 ,KEY IN NEW Y'
Z = 1 ,KEY IN NEW Z'0.1
ACR = .5 --KEY IN NEW ACR'.25
CR = .25 --KEY IN NEW CR'
XSMATL = 0 --KEY IN NEW XSMATL'
CLZ = 0.1 --KEY IN NEW CLZ'
TOL = .005 ,KEY IN NEW TOL'
CF = 20 ,KEY IN NEW CF'
RPM = 870 ,KEY IN NEW RPM'
=====> PAUSE TO CLEAN UP DATASETS <=====
ENTRY (A) TSOCD70.CT1NRC.PUNCH.DATA DELETED
ENTRY (A) TSOCD70.CT1NRC.ADVRT.DATA DELETED
ENTRY (A) TSOCD70.CT1NRC.CLDAT.DATA DELETED
ENTRY (A) TSOCD70.CT1NRC.PRINT.DATA DELETED
KEY IN DRAWING NAME !CT1NRC
CT1NRC
KEY IN GROUP NUMBER'33
KEY IN GROUP NUMBER'34
KEY IN GROUP NUMBER'35
KEY IN GROUP NUMBER'
KEY IN DRAWING NAME '

=====> PAUSE TO SUBMIT CT1NRC <=====
JOB CT1NRC(JOB01934) SUBMITTED
READY
```

Figure 23: Prompts Displayed by .CLIST.

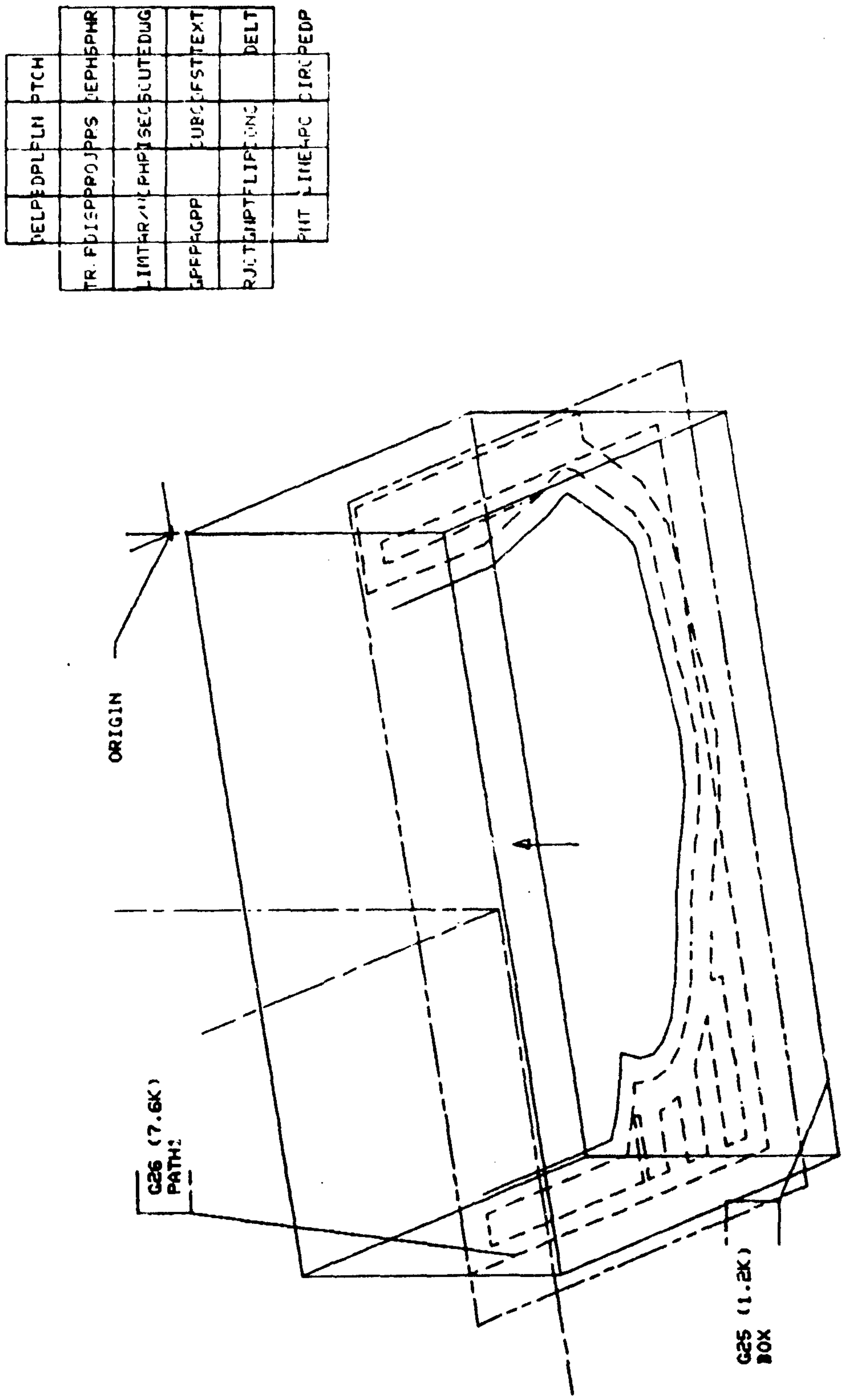

Figure 24: Cutter Path for the Rough Cut.

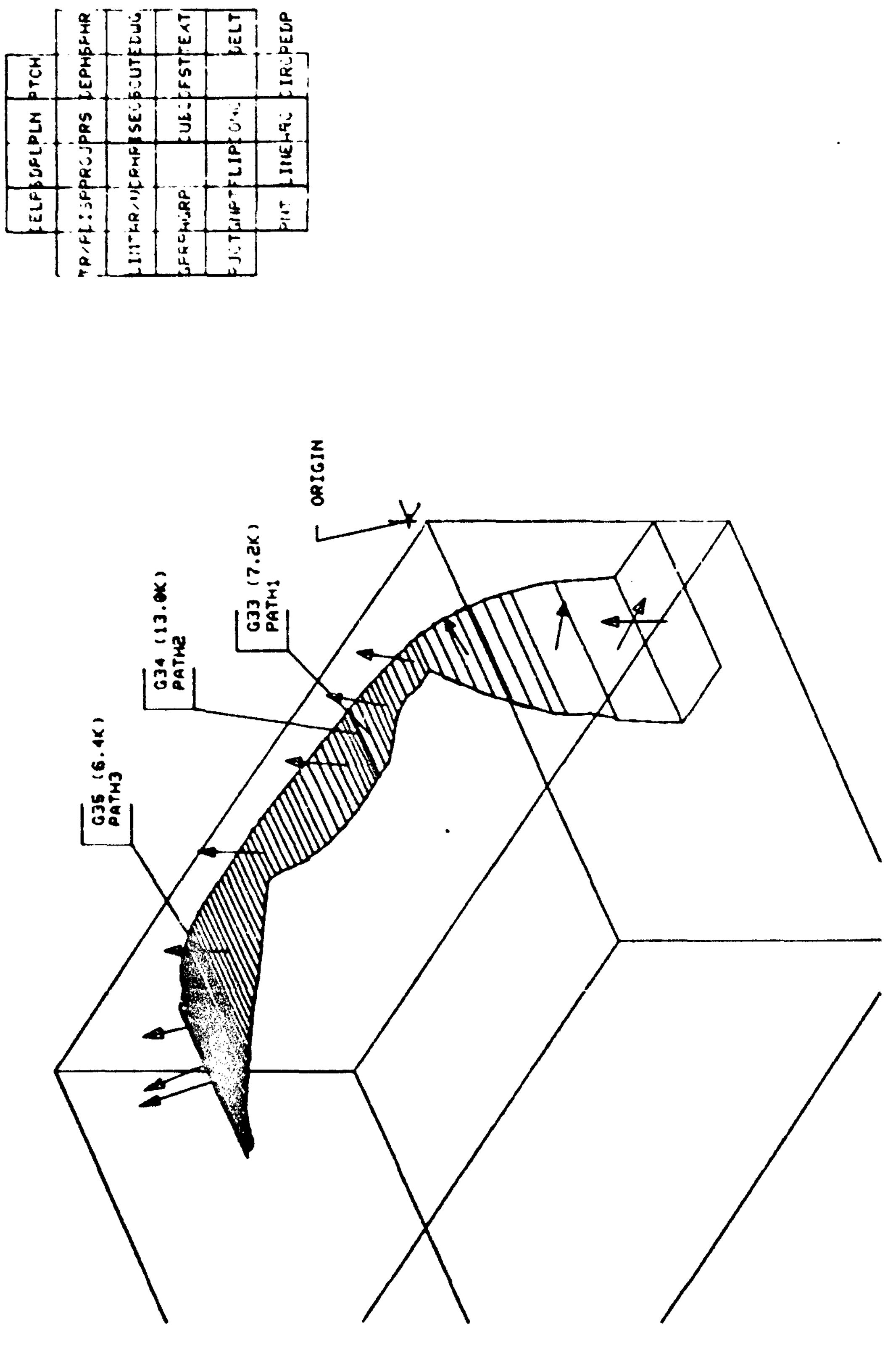

Figure 25: Cutting the Model: Cutter Path One

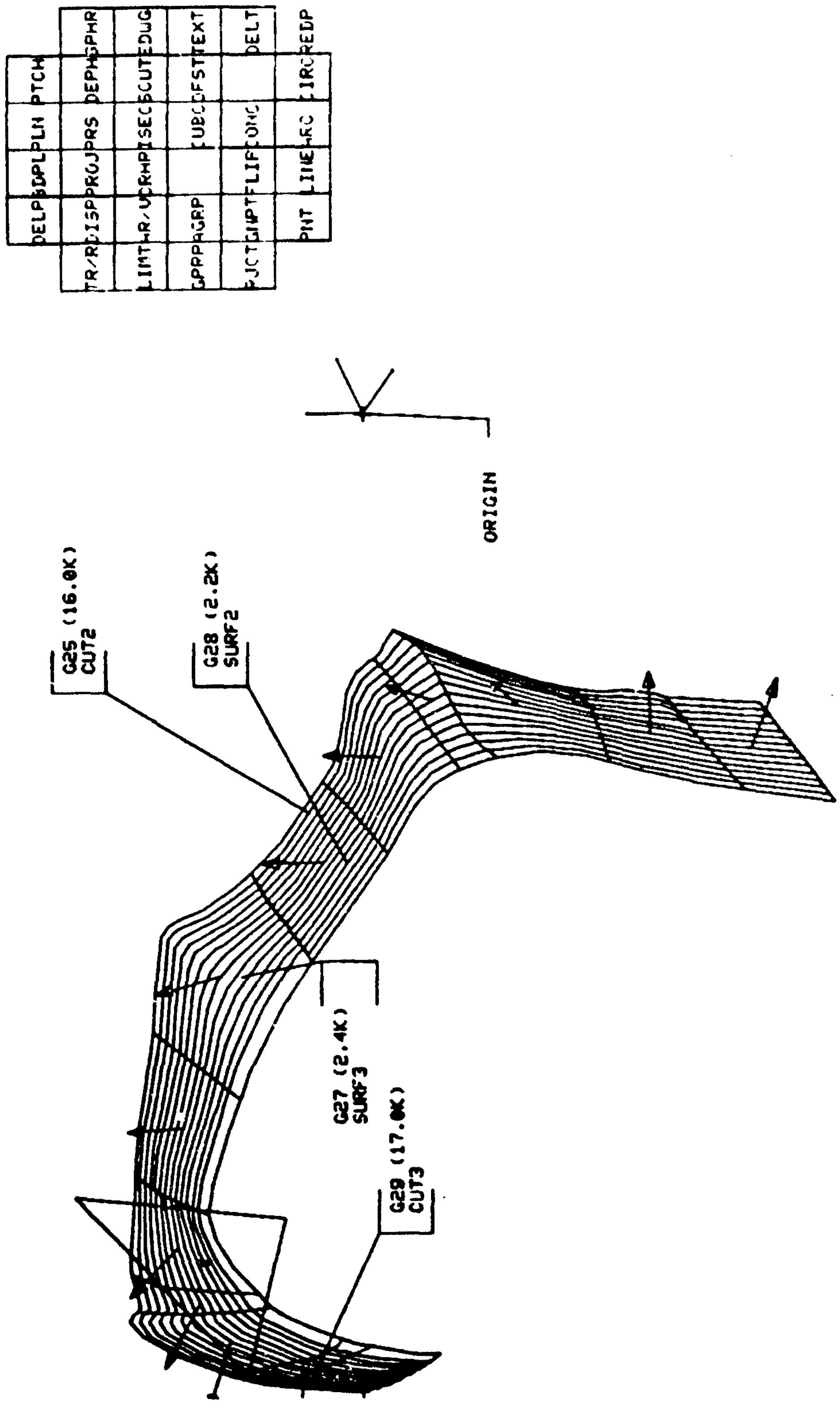

Figure 26: Cutting the Model: Cutter Path Two.

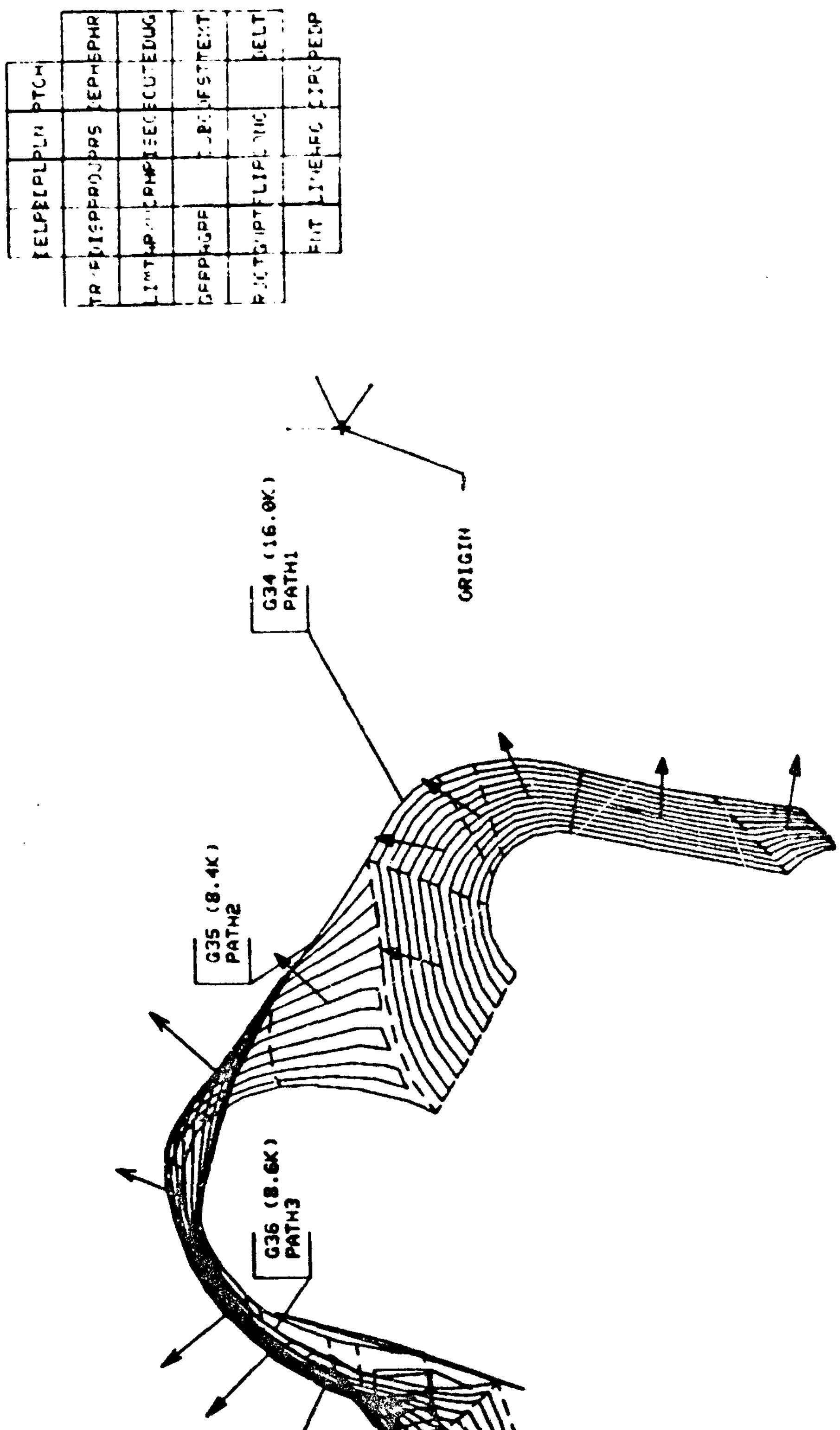

Figure 27: Cutting the Model: Cutter Path Three.

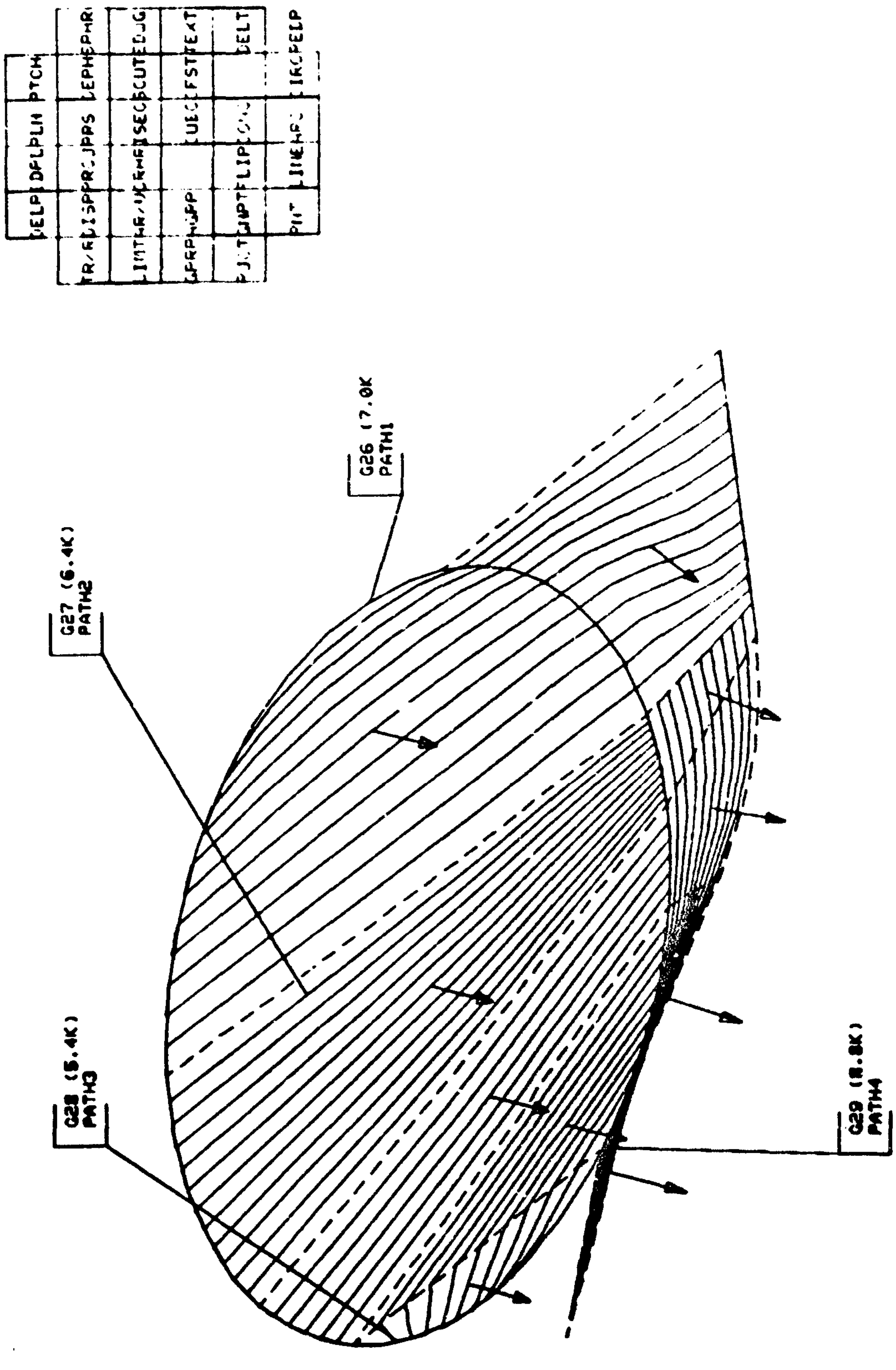

Figure 28: Cutting the Model: Cutter Path Four.

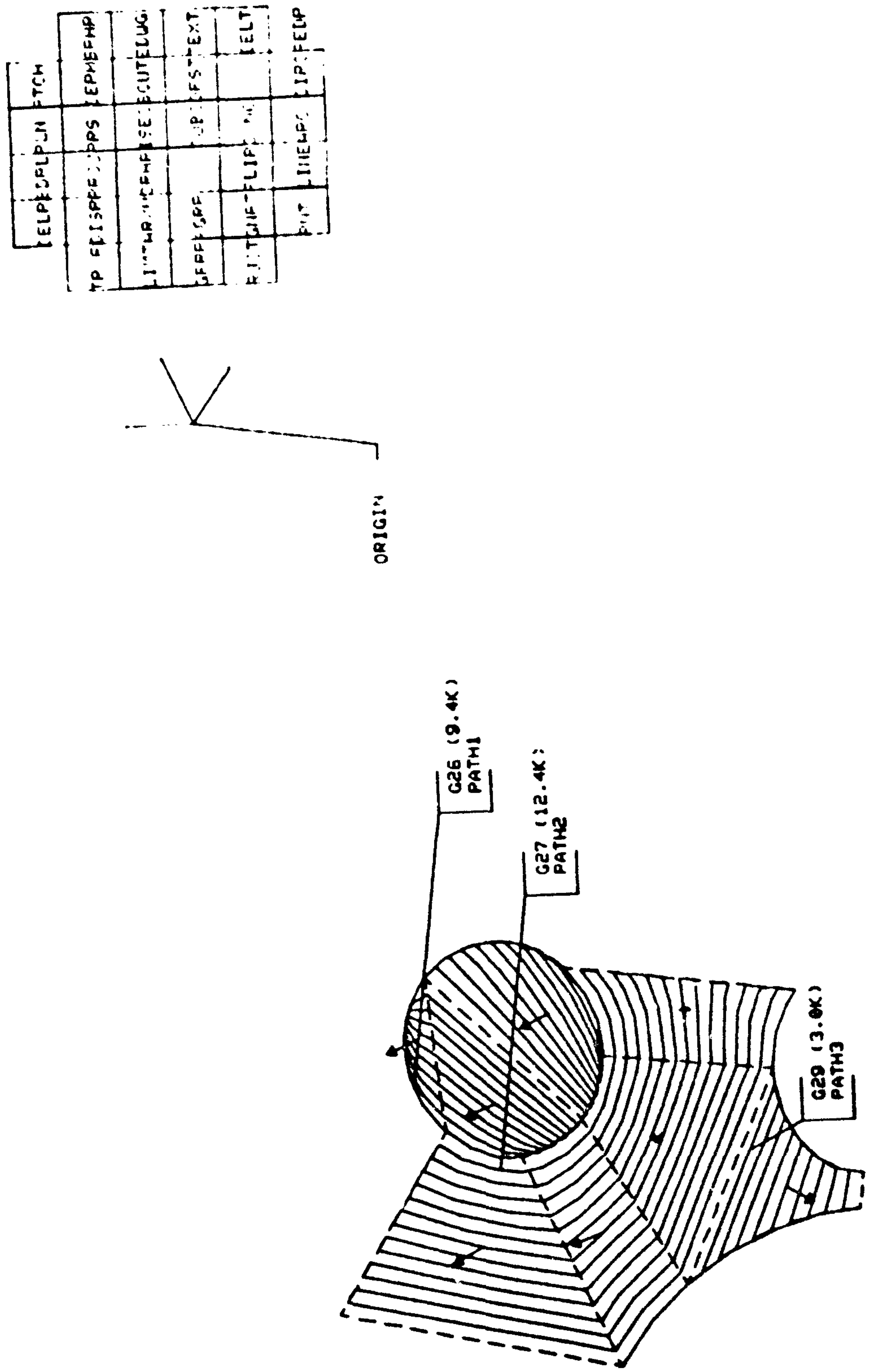

Figure 29: Cutting the Model: Cutter Path Five.

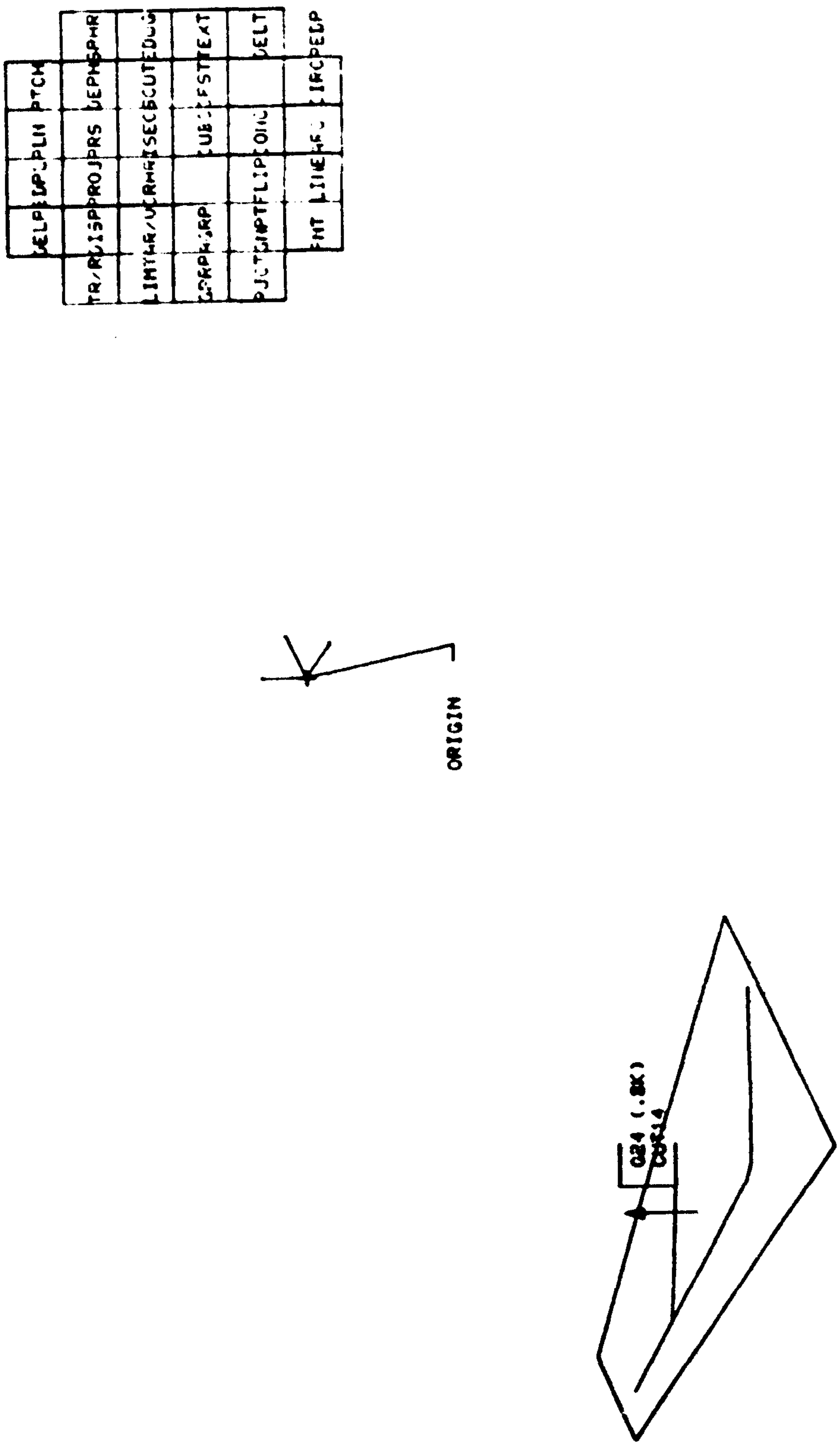

Figure 30: Cutting the Model: Cutter Path Six.

problems had been encountered when transmitting PUNCH.DATA files from the IBM MVS/TSO system downline to the workstation in Ottawa. Randomly spaced blanks and control characters were inserted in the data expanding the length of the file to about three times its normal length. This was down-loaded to a Dynalogic disk drive at the facilities of the National Research Council. Here a program was written in BASIC to read the file and edit out unwanted characters (see Appendix 2). Thus data was then ready to be downloaded to the memory on the Ex-Cell-O 604 milling machine.

For the same data to be run on the Matsuura machine, the PUNCH.DATA file was slightly edited, transferred to the CYBER system and downloaded to a tape punch at DREO via the 300-baud dial-up line. A FACIT 4070 tape punch provided the on-line tape facility. These tapes were then available for the machine shop work.

As a check on the efficacy of the model and programs, the function {CLPLOT fid} on MVS/TSO produced a map of the cutter path in xy-, yz-, and zx- views allowing the operator a check on gross errors in curve plotting over the model surface. This CLIST takes the PRINT.DATA file produced when the APT program has been run and plots the resulting point-to-point coordinates generating a tool path plot based on the processessed NC data and not solely on the model in the CADD database. The function runs without any post-processor information and is a function only of the model geometry.

The CLPLOT Menu contains the following items:

A. Scale
B. Center
C. Window
D. Resize
E. View XY, YZ, ZX, XYZ
F. Erase (TEK only)
G. End
H. Rewind
I. Plot to TOF
J. Skip to record
K. Plot to record
L. Incremental
M. Select alternate line (TEK only)
?. Will cause a menu display.

This menu is invaluable in checking gross cutter path errors, clearance planes, set points, start up points and, if using a three-axis machine, problems of undercuts and surface overlaps.

However, it is still difficult to observe changes in surface curvature that are smaller than the cutter radius. If the cutter is attempting to make a pass over such a geometry, it will back track somewhat cutting out a small trench of approximately the same dimensions as the cutter radius.

An example of the CLPLOT routine is shown in Fig. 31. This is CLPLOT CT4NRC showing part of the mask surface between the lens form and the periphery face seal. xy-, yz- and zx- views are displayed. The arrows

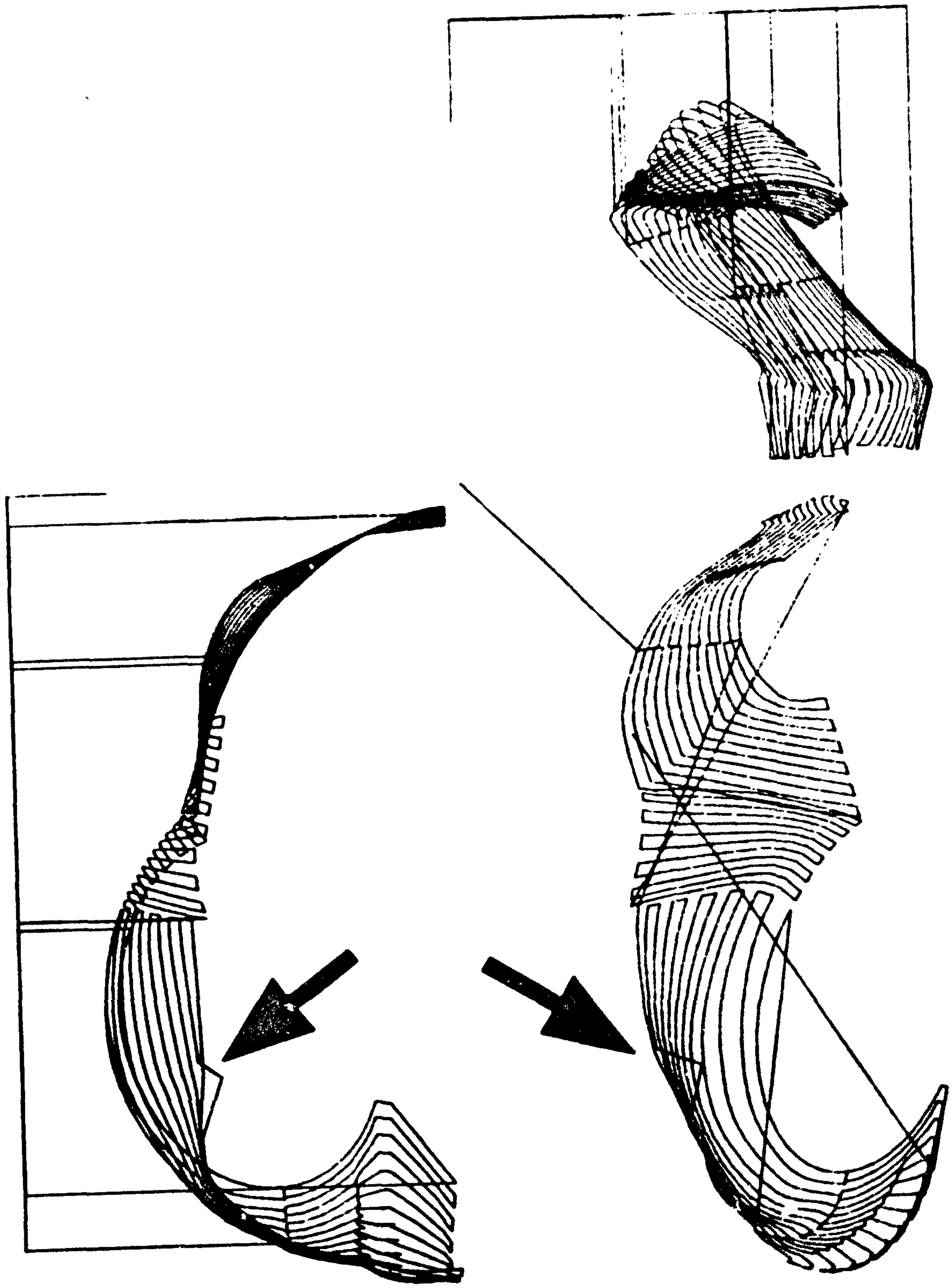

Figure 31: Three Orthogonal Projections of a Cutter Path.

point to a pass of the cutter that makes a plunge into the work. It was not clear where the surface geometry was at fault and the error was edited out in the PUNCH.DATA file.

5.1 Data Set Editing for Numerical Control Programs

When the APT source code has been run the final product is the PUNCH. DATA file. Some editing of this was carried out on the MVS/TSO FORTRAN processor. This involves removing some M commands that were unnecessary (M commands are executable instructions for the machine controller). Two models were constructed on CADD and two NC data sets were created: one post-processed for a Matsuura machine with a Yasnac controller and the other for the Ex-Cello-0604 machine with a Bendix controller.

5.1.1 Data Sets for the Matsuura Machine

For this machine a post-processor was written. This was incorporated into the CLIST, EXMILL3.CLIST, and the CLIST was executed building up APT source code for the second concept model. The PUNCH.DATA files were transferred to the MCAUTO CYBER account and punched on paper tape at DREO over a 1200 baud link-up. The tapes were then passed to the machine shop.

5.1.2 Data Sets for the Ex-Cell-O 604 Machine

For this machine a second post-processor was written and an APT source code built up in the same way as in 3.1.1 for the third concept model.

The PUNCH.DATA file was edited on-line on the FORTRAN processor and transferred to the CYBER account. Then the file was transferred over the 1200-baud line to a Dynalogic disk drive. Following storage on disk, the file was further edited by having excess blanks and control characters removed. This was done by running the file through a program (DND.TAPE.S), written in BASIC for the TSS IBM processor at the National Research Council. See Fig. 32 for a flow chart representation of this system. Figure 33 shows the format of the PUNCH.DATA file before and after editing with the BASIC program. It should be noted that many of the control characters in the top left specimen do not appear as printed characters, so the total nature of the format transformation is not self-evident. The specimen on the bottom right shows the modified format ready for the Bendix controller. The complete program, or set of programs, for a model of one side of the mask-form is 289 blocks of 255 characters, or 73,695 characters.

To run off a right-hand image of the programs, an axis inverter is used on the NC machine controller and the same programs run again.

Figures 34, 35, 36 and 37 show the set-up of the work in (Do-All machineable wax) on the machine table. Various views of the model are shown showing the cutter at work on the material.

When the model is finished, it is ready for surface finishing. The surface finish is determined by the scallop height left after the passage of the machine tool and this, in turn, is determined by the number of passes per inch the cutter makes over the surface of the material.

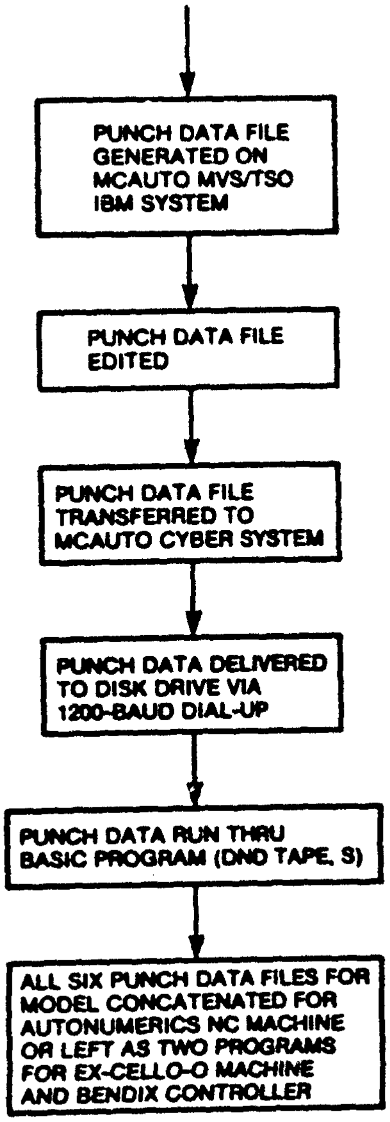

Figure 32: Data Management from IBM Punch Data to Shop-Floor N/C Machine.

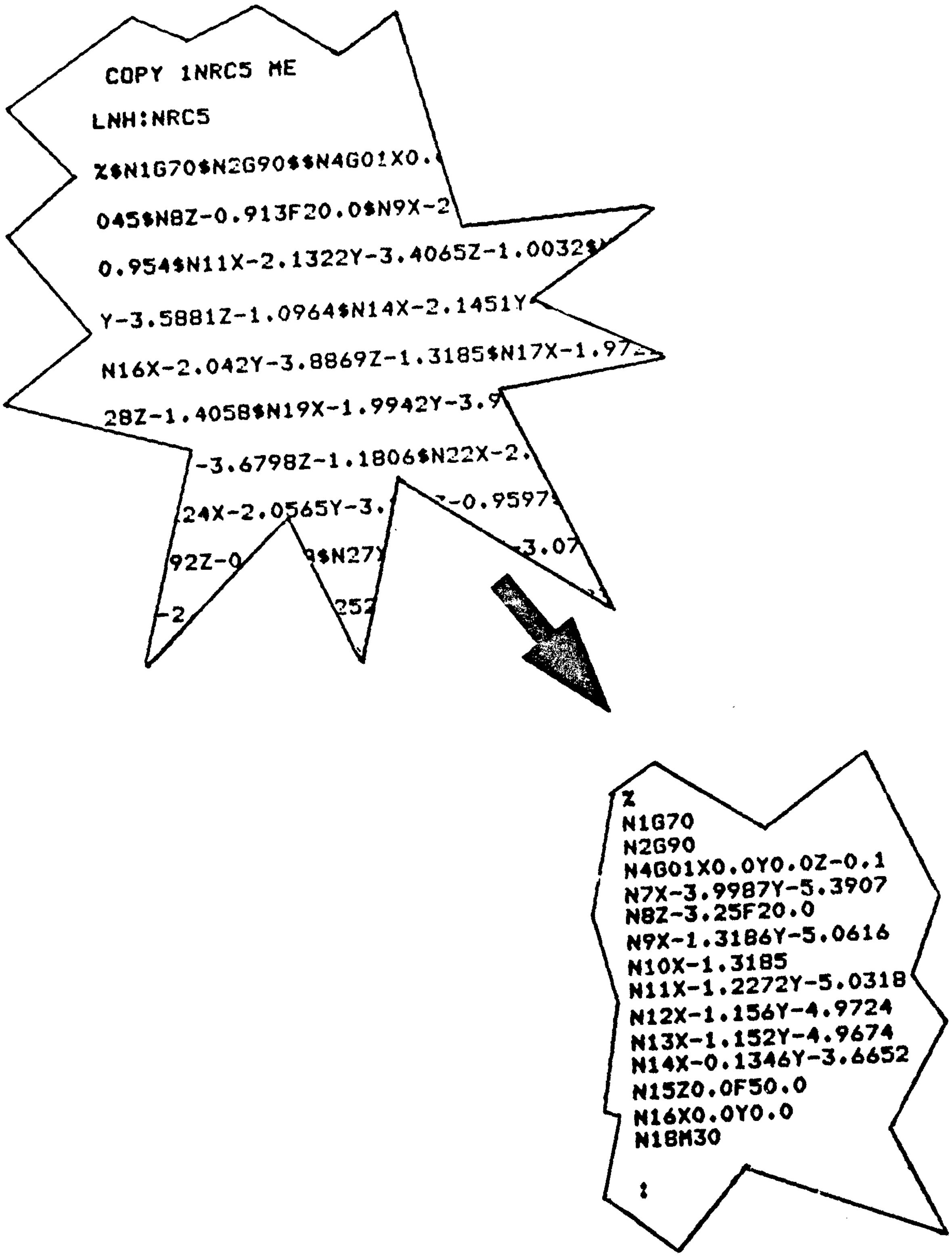

Figure 33: Data Reformatting through Program :DND TAPE,S.

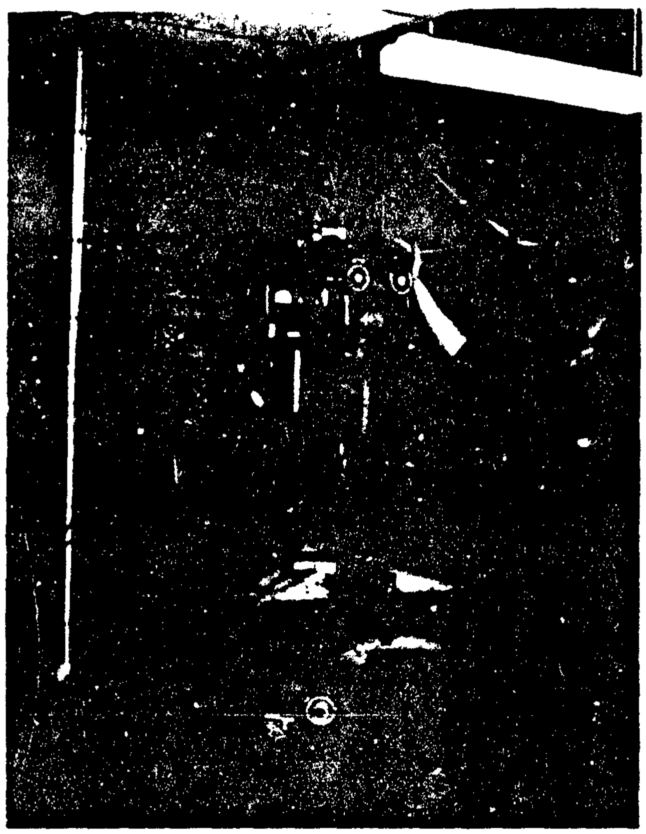

Figure 34: Work Set-up on EX-CELL-O Machine.

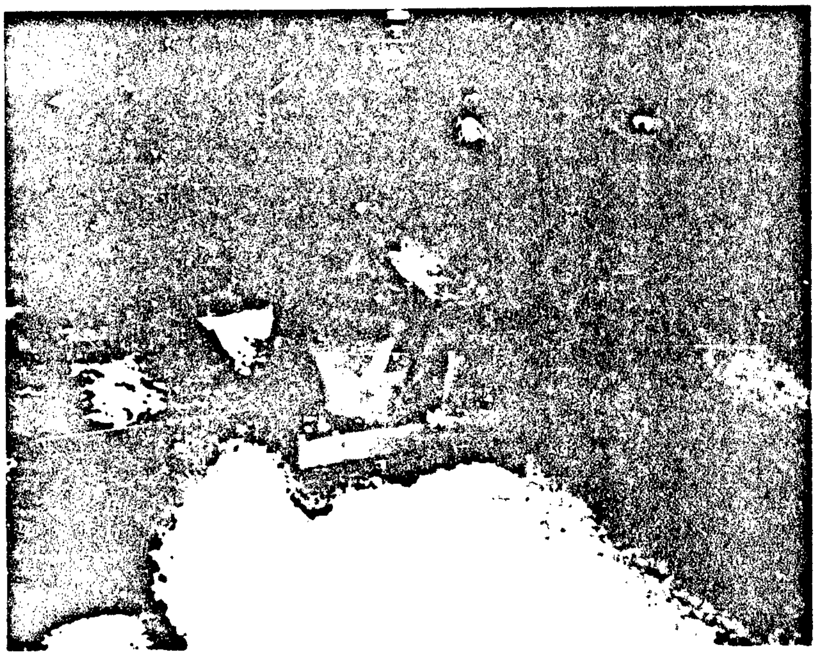

Figure 35: Cutting in Progress.

Figure 36: Cutting in Progress.

Figure 37: Cutting in Progress.

For finer surface finish the wax may be scraped and/or treated with a heat gun to smooth off the scallop material. When the finish is satisfactory, the wax model may be copied onto a harder material, such as wood to produce a model in a material suitable for a base to vacuum-forming.

6.0 SUMMARY

The installation and operation of a computer-aided design and manufacturing system has been described. This system has been used for the design of models for new respirator facepiece shapes and these models have been manufactured on both a Matsuura and an Ex-Cell-O three-axis milling machine.

Numerical control programming for complex sculptured surfaces has been performed for two different NC machine/controller combinations. In one case, a data management system dispensing with the use of paper tape has been set up. Models have been cut in wood 1 and machineable wax.

Design changes have been performed and models modified in the computer. Further, the new models, combinations of design changes and previously used models, have been re-programmed and cut on the NC machine showing the capabilities of engineering design on a computer system.

Some problems were encountered with this method of design. These were mainly due to the nature of the software available at the time and the limitations of CAD and CAM interfaces.

The nature of the CADD database demands that surfaces with arbitrary geometry in three dimensions must be defined as patch surfaces, that is, surfaces that are constructed from two sets of parametric cubic curves. As a results of this, cubic curves must be plotted over each patch making up the generalized surface. The number of patches making up each generalized surface depends on how closely the patch surface must match the original data points: the closer the match required, the larger the number of patches required to make up each surface. Thus a complex, free-form surface is built up from patches.

To cut such surfaces on a three or five-axis numerical control machine requires the plotting of sets of cubic curves over each patch element. Curves have to be plotted over each patch and as the patches vary in size, and if a fixed number of curves are plotted per patch, the scallop height of excess material is then a variable and difficult to control.

Further, although entities such as curves and surfaces may be grouped with the AUTOGROUP function, the software contains no mechanism to enable the operator to check whether or not the cutting tool will interfere with another surface when performing its cuts. This is left to the operator checking the whole process on the graphics terminal. Once a surface has been modelled, and the tool paths for the machine cutter have been plotted, it is possible to generate from the NC data file, using the CLPLOT command, a graphical presentation of the cutter location. This serves as a rudimentary check on the integrity of computer-generated machine path, but, with storage tube graphics, and no means of displaying graphically the tool itself, interference between the tool and other surfaces cannot be displayed or computed.

As a result of this, it has proved very difficult to off-set complex surfaces (composed of large numbers of patch surface elements) and maintain the integrity of the geometry. The importance of this becomes apparent when new cutter paths have to be plotted on the off-set geometry. These cutter paths must all be contiguous and matched to a patch surface so that any off-set operation that results in gaps or overlaps between surfaces means that a new patch must be inserted and further cutter path elements overlaid on these.

Because of these and other considerations only a one-surface model was produced suitable for vacuum-forming a thermoplastic. The difficulties of the geometries immediately become apparent when constructing surfaces separated by a few thousandths of an inch as is the case in a mold where the cavity and the core are separated by these amounts.

Time itself has been a partial solution to some of these problems. In the intervening time, enhancements have been made to numerical control machining software that essentially either overcome or circumvent these problems. The major problems of the NC package: surface recognition, surface interference, curve plotting for the cutter path etc., have almost all been resolved. For example, some software will now accept the model data, request the parameters of the finished product such as residual material scallop height, and produce a program with the requisite number and distribution of surface cutter paths.

A future development for further reducing the turn-around time between design and manufacture would be the installation of a numerical control machine, on-site, with a DNC link with the computer system.

7.0 ACKNOWLEDGEMENTS

I would like to thank Mr. Gordon Moore of the Development Workshop, National Research Council, Montreal Road, Ottawa, for his cooperation and assistance throughout this work. I would also like to thank Dr. Ken Steele of the Computer Graphics Division, National Research Council, for valuable discussions and advice.

8.0 REFERENCES

(1) DREO Tech Note (82-17)

(2) Interactive Buffer for 4014/4015 Terminals, Tektronix Inc., P.O. Box 500, Beaverton, Oregon, 97077, 1977.

(3) Supermux 480 Users Manual Doc. No. SM 48-UM-00, Infotron Systems, Cherry Hill Industrial Center, Cherry Hill, N.J. 08003.

(4) Studies to Establish Quantitative Parameters for the Design of Large and Small Sizes of the New Protective Mask. D.H. Mangelsdorf, M.N. Goldberg, W.R. Sautschi, SYNSIS INC., L.A., CA. 90065, Edgewood Arsenal Contractor Report ED-CR-76100.

(5) Computer-Aided Design for Complex Geometry Molds, D.J. Hidson, Conference Proceedings AUTOFACT 5, Computer and Automated Systems Association of the Society of Manufacturing Engineers, One SME Drive, P.O. Box 930, Dearborn, Michigan. 48121

APPENDIX 1

MATH DEFINITION OF ENTITIES

APPENDIX 1

MATH DEFINITION OF ENTITIES

All the geometric models in CADD have a mathematical foundation in three-dimensional space. These, of course, may be displayed at any time by detecting the particular entity and picking function key GPRP (geometric properties). Unless other specific arrangements are made, all the values are determined by a right-hand orthogonal co-ordinate system. A global coordinate system is normal, but local coordinate systems may be instituted using matrix transformations.

Some examples are shown in the following, including the representation of parametric cubic curves.

POINT

The position of a point is determined by three coordinates

$$X = A,\ Y = B,\ Z = C$$

Detecting a point and then geometric properties will display the x, y and z coordinates and H = and V =. H and V are horizontal and vertical values from the local screen origin.

LINE

A line is a planar entity but the plane is arbitrary. The representation is of the form

$$AX + BY = -D$$

On detection of GPRP, the following data is given for a line:

X = X coordinate from origin
Y = Y coordinate from origin
Z = Z coordinate from origin
cos = Angle cosines. The sum of the three angle cosines is 1
TRUE L = true length
H = local horizontal screen coordinate distance to origin
V = local vertical screen coordinate distance to origin.

$$DH = |H2 - H1|$$

$$DV = |V2 - V1|$$

SLOPE = DV/DH
ANGLE = ARCTAN (DV/DH)
LENGTH = Local screen distance between H and V coordinates.

CONIC

The conic curves are formed by the intersection of a plane with a right circular cone. The curves so generated are the ellipse, parabola and hyperbola. These are represented by

$$AX^2 + BXY + CY^2 + DX + EY = -F$$

These are all planar curves. When a conic is detected followed by GPRP (geometric properties) the following variables are displayed

X,Y,Z = The X,Y,Z coordinates of the end points of the curve and three intermediate points. There are five points required for conic definition.

θ1 - θ5 = Theta is the angle calculated (in the plane of the conic) between the tangent to the curve at each point and a local horizontal axis.

M1 - M5 = M is the slope of the tangent at the point that is measured.

LENGTH = True length of the curve, that is, the integral of ds.

A,B,C,D,E,F = The coefficients of the equation.

H,V = Local screen horizontal and vertical coordinates of the five points defining the conic.

PARAMETRIC CUBIC CURVE

This is a very versatile function that can approximate an arbitrary curve in three-dimensional space. All the coordinates axes are mapped in parametric space as a cubic function in u. Each coordinate is thus represented as a cubic in u. For example,

$$V(u) = Au^3 + Bu^2 + Cu + D$$

$$V'(u) = 3Au^3 + 2Bu + C$$

and

$$0 < u < 1$$

By substituting u = 0 and u = 1, a set of four equations is formed:

$$\begin{aligned} V(0) &= D \\ V(1) &= A + B + C + D \\ V'(0) &= C \\ V'(1) &= 3A + 2B + C \end{aligned}$$

The expression for the curve in three-dimensional space is:

$$X = A_x u^3 + B_x u^2 + C_x u + D_x; \ X = F(u)$$

$$Y = A_y u^3 + B_y u^2 + C_y u + D_y; \; Y = F(u)$$

$$Z = A_z u^3 + B_z u^2 + C_z u + D_z; \; Z = F(u)$$

and $u = 0$ and $u = 1$ are the end-points. For planar curves, the slopes are expressed as the first derivatives:

$$\frac{dy}{dx}, \quad \frac{dz}{dx}, \quad \frac{dy}{dz}$$

In parametric space the slopes are the components of the actual tangent vector:

$$\frac{dx}{du}, \quad \frac{dy}{du}, \quad \frac{dz}{du}$$

These two are related by

$$\frac{dy}{dx} = \frac{dy}{du} \; \frac{du}{dx}$$

A special feature of the parametric curve is that the shape of the curve may be varied by changing the length of the parametric tangents without changing the real slope:

$$\frac{dy}{dx} = \frac{dy}{du} \; \frac{du}{dx} = \frac{K(dy/du)}{K(dx/du)}$$

K does not affect dy, but it does affect the parametric tangents.

The function key, CUBC, will change any picked line, arc, circle or conic to a cubic. The conversions of lines are parabolas are exact. The others are close approximations.

PARAMETRIC CUBIC PATCHES

These are the extension of the concept of parametric cubic curves to three-dimensional space to define complete surfaces. These patches (strictly parametric bi-cubic patches) are defined along one side by the parameter u used in the cubic curve definition and along the other orthogonal dimension, another parameter, w, is used. The patch is defined from $u = w = 0$ to $u = w = 1$.

A single patch defined in x, y and z requires three 16-term equations:

$$V(u,w) = (u^3 \; u^2 \; u \; 1)(M)(B)(M)^T(w^3 \; w^2 \; w^1 \; 1)^T$$

where M is a matrix of integers derived from the general equations. $(M)^T$ is the transpose of (M). V(u,w) shows a general patch; all specific data is contained in the (B) matrix.

This (B) matrix is a 4 by 4 matrix that determines the geometry of the patch.

$$B = \begin{vmatrix} V_{00} & V_{01} & V_{00w} & V_{01w} \\ V_{10} & V_{11} & V_{10w} & V_{11w} \\ V_{00u} & V_{01u} & V_{00uw} & V_{01uw} \\ V_{10u} & V_{11u} & V_{10uw} & V_{11uw} \end{vmatrix}$$

Here V_{01} is the position value (x,y or z) of the patch where u = 0, w = 1. To find V_{01u}, the derivative of the patch equation with respect to u must be taken, then solved for u = 0, w = 1. The cross product terms define the internal geometry of the patch.

The patch surface is very important as it forms the basis of surface defintions for the regional milling portion of CADD which enables sculptured surfaces to be cut out.

APPENDIX 2

PROGRAM TO ELIMINATE EXTRANEOUS CHARACTERS FROM PUNCH.DATA FILE (IBM SYSTEM)

APPENDIX 2

PROGRAM TO ELIMINATE EXTRANEOUS CHARACTERS FROM PUNCH DATA FILE (IBM SYSTEM)

```
10   REM  PROGRAM TO DELETE NULS AND BLANKS
20   REM
30   DIM  A$250, B$1, C$250, F1$30, F$30, E$32, D$1, G$1, H$250
40   REM
50   PRINT  "INPUT CURRENT FILE NAME"
60   REM
70   INPUT F1$
80   REM
90   OPEN #P1%, F1$, 255, 0, S%, E%, E$
100  IF E%    66 THEN 170
110  PRINT "FILE NOT FOUND"
120  PRINT "INPUT 'N' TO REENTER FILE NAME"
130  PRINT "INPUT 'Q' TO QUIT"
140  INPUT D$
150  IF D$ = "Q" THEN 460
160  GOTO 50
170  PRINT "INPUT NEW FILE NAME"
180  INPUT F$
190  CALL "CREATE": F$, 256, 0, E%, E$
200  IF E%    74 THEN 300
210  PRINT "FILE ALREADY EXISTS"
220  PRINT "INPUT 'Y' TO OVERWRITE"
230  PRINT "INPUT 'N' TO REENTER FILE NAME"
240  PRINT "INPUT 'Q' TO QUIT"
250  INPUT G$
260  IF G$ = "N" THEN 170
270  IF G$ = "Q" THEN 460
280  CALL "DELETE" : F$, E%, E$
290  GOTO 190
300  OPEN #P%, F$, 255, 0, S%, E$, E$
310  FOR I = 1 TO 9999
320  C$ = CHR$(20)
330  INPUTLINE #P1%, -1, 0, E%, E$ : A$
340  FOR J = 1 TO 250
350  B$ = SEG$(A$, J, 1)
360  IF B$ = CHR$(0) THEN 400
370  IF B$ = CHR$(32) THEN 400
380  C$ = C$ & B$
390  IF B$ = CHR$(13) THEN 410
400  NEXT J
410  H$ = SEG$(C$, 3)
420  PRINT #P% : H$
430  IF SEG$(H$, LEN(H$) -2, 3) = "M30" THEN 450
440  NEXT I
450  PRINT #P% : CHR$(28)
460  CLOSE #P%
470  CLOSE #P1%
480  PRINT "YOU ARE DONE"
490  END
```

AD-A164408

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall document is classified)

1. ORIGINATING ACTIVITY
Defence Research Establishment Ottawa
Department of National Defence
Ottawa, Ontario, Canada K1A 0Z4

2a. DOCUMENT SECURITY CLASSIFICATION
UNCLASSIFIED

2b. GROUP

3. DOCUMENT TITLE

COMPUTER-AIDED DESIGN OF A RESPIRATOR FACEPIECE MODEL

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)
REPORT

5. AUTHOR(S) (Last name, first name, middle initial)

HIDSON, David J.

6. DOCUMENT DATE
DECEMBER 1984

7a. TOTAL NO OF PAGES
60

7b. NO OF REFS
5

8a. PROJECT OR GRANT NO

9a. ORIGINATOR'S DOCUMENT NUMBER(S)

DREO REPORT NO. 902

8b. CONTRACT NO

9b. OTHER DOCUMENT NO.(S) (Any other numbers that may be assigned this document)

10. DISTRIBUTION STATEMENT

UNLIMITED DISTRIBUTION

11. SUPPLEMENTARY NOTES

12. SPONSORING ACTIVITY

13. ABSTRACT

This paper describes the evaluation and acquisition of CAD/CAM technology required for the design and development of complex sculptured surfaces for molding rubber and elastomeric materials. Benchmark tests incorporating the complex 3-D geometry that such a design project must handle were performed with various systems vendors and a time-sharing system was chosen. Geometry was constructed using bi-parametric cubic patches and cutter paths were plotted over these surfaces. A post-processor has been prepared for a three-axis numerical control milling machine and a cavity cut to vacuum-form a thermoplastic rubber for a prototype.

DSIS
77-066

Security Classification

KEY WORDS

computer-aided design

sculptured surfaces

molds

respirators

anthropometric data

human engineering

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the organization issuing the document.

2a. DOCUMENT SECURITY CLASSIFICATION: Enter the overall security classification of the document including special warning terms whenever applicable.

2b. GROUP: Enter security reclassification group number. The three groups are defined in Appendix 'M' of the DRB Security Regulations.

3. DOCUMENT TITLE: Enter the complete document title in all capital letters. Titles in all cases should be unclassified. If a sufficiently descriptive title cannot be selected without classification, show title classification with the usual one-capital-letter abbreviation in parentheses immediately following the title.

4. DESCRIPTIVE NOTES: Enter the category of document, e.g. technical report, technical note or technical letter. If appropriate, enter the type of document, e.g. interim, progress, summary, annual or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the document. Enter last name, first name, middle initial. If military, show rank. The name of the principal author is an absolute minimum requirement.

6. DOCUMENT DATE: Enter the date (month, year) of Establishment approval for publication of the document.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the document.

8a. PROJECT OR GRANT NUMBER: If appropriate, enter the applicable research and development project or grant number under which the document was written.

8b. CONTRACT NUMBER: If appropriate, enter the applicable number under which the document was written.

9a. ORIGINATOR'S DOCUMENT NUMBER(S): Enter the official document number by which the document will be identified and controlled by the originating activity. This number must be unique to this document.

9b. OTHER DOCUMENT NUMBER(S): If the document has been assigned any other document numbers (either by the originator or by the sponsor), also enter this number(s).

10. DISTRIBUTION STATEMENT: Enter any limitations on further dissemination of the document, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this document from their defence documentation center."

(2) "Announcement and dissemination of this document is not authorized without prior approval from originating activity."

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document, even though it may also appear elsewhere in the body of the document itself. It is highly desirable that the abstract of classified documents be unclassified. Each paragraph of the abstract shall end with an indication of the security classification of the information in the paragraph (unless the document itself is unclassified) represented as (TS), (S), (C), (R), or (U).

The length of the abstract should be limited to 20 single-spaced standard typewritten lines; 7½ inches long.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a document and could be helpful in cataloging the document. Key words should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context.