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ABSTRACT

We describe herein the development of a model for an injection-molded protective glove prototype. The technique uses computer-aided design and manufacturing (CAD/CAM) exclusively. The geometric model was constructed in the computer memory corresponding to the best known dimensions for a "regular-large" sized- hand. Special complex surfaces were used to make the model ambidextrous. The machining was carried out on a CNC mill (a Matsuura 1000V with a Fanuc controller) programmed directly from the computer model. Trials were completed first with wax models before the final part was cut from aluminum. Two halves were made and fitted together about a mid-plane to complete the model.

RÉSUMÉ

On décrit ici le développement d'un modèle pour un prototype de gant protecteur moulé par injection. La technique utilise la conception assistée par ordinateur et fabrication assistée par ordinateur (CAO/FAO) uniquement. Le modèle géometrique fut construit dans la mémoire de l'ordinateur de façon à correspondre aux dimensions les plus connues d'un type de main "regulière-large". Des surfaces complexes spéciales furent utilisées pour rendre le modèle ambidextre. L'usinage fut fait sur une fraiseuse à contrôle numérique (une Matsuura 1000V avec un contrôlleur Fanuc) programmée directement à partir du modèle de l'ordinateur. Des essais d'usinage furent complétés sur des modèles de cire avant d'être faits d'aluminium. Deux moitiées furent faites et jointes l'une à l'autre par le milieu pour compléter le modèle.

EXECUTIVE SUMMARY

A new concept in design and prototyping of chemical warfare protective gloves using computer-aided design and manufacturing techniques is described. The object of this work is to produce a latex-dipped model of a new CB protective glove. The current in-service glove is wanting in some properties and requires significant improvement in lifetime, dexterity and fit. A research project has been undertaken to develop a new design with CAD/CAM techniques incorporating the latest anthropometric data for hands.

Complex-geometry shapes were modelled in the computer and were cut using a three-axis numerical control mill. The resulting shape of half a hand (divided about the mid-plane) was the basis of the model and the mirror image was produced by simple axis inversion on the CNC milling machine. The two halves of the model were fixed together using dowels and screws to complete the hand model. The surface was finished and used for dipping to produce latex prototypes.

The model was then subjected to testing and results were gathered for the assessment of the design. The data so obtained will be taken as design inputs for future models of the glove. The factors of interest in this model are the tapered fingers and the effect that this has on the dexterity parameter in combination with the much thinner material of the glove.

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1.0 INTRODUCTION

The work of the Protective Sciences Division at DREO involves the design and manufacture of protective clothing and equipment for the Canadian Forces. Items such as respirators, gloves, boots and clothing to protect against chemical warfare are examples. This paper describes work carried out at DREO on the design and manufacture of several prototype models for an injection-molded chemical warfare protective glove. The production of the prototypes was completed exclusively with computer-aided design and manufacturing (CAD/CAM) techniques.

The protective glove currently in service with the Canadian Forces is a heavy mid-arm length glove based on a knitted material that is dipped several times in a chemical-resistant rubber. The thickness of the glove causes dexterity problems and sweat accumulation when worn for extended periods of time. Insufficient durability has been identified as a deficiency and increased protection against field contamination by petroleum and related products is required. The object of the present work is to produce an improved design for a close-fitting glove, possibly with a liner, which will allow enhanced dexterity, tactility and protection for the wearer. The design philosophy includes the need for an ambidextrous glove.

Earlier work has noted the expanding use of CAD/CAM techniques in the field of bio-engineering (1) and the advantages that accrue to the design engineer who uses them. The limitations show themselves in the area of complex geometry rendition, that is, the continually varying three-dimensional geometry of the human form which resists description by analytical forms. Despite this, the overwhelming advantages of CAD/CAM techniques lie in the efficiency of effort in the domain of prototyping. Complex designs can be rendered and changes from one to another, so necessary in prototyping, may be made without complete re-design of molds. Further, the capability for computer-numerical machining (CAM) means that only changes in the design need be re-programmed, thus reducing unnecessary effort.

At DREO, much preparatory work has been completed. Preliminary investigations and a feasibility study have been performed and reported (2). The design and manufacturing parts of the CAD/CAM process have been integrated and computer-numerical control machines tied into the system by means of specific postprocessor design (3). And the data transmission pathways from the computer to the machine shop have been re-engineered by changing the paper tape data transmission pathway of old to diskettes (4).

The models so far constructed do not contain any significant new anthropometric data. The various designs will be tested for manual dexterity and comfort after latex-dipped models of the gloves have been made. The results of these tests and studies will feed information back to the design process to incorporate functions which enhance finger dexterity and to expunge those factors that give rise to poor dexterity.

Later prototypes will include much more complex and detailed anthropometric data and will consequently contain many more design constraints. The type and quality of such will be determined by the testing program for fit, dexterity and comfort.

The following work describes the layout of the computer system, hardware and software, and the design process in a step-wise fashion. The final machining paths are all illustrated in the figures.

2.0 COMPUTER SYSTEMS AND ARCHITECTURE

The computer system was comprised of a MicroVAX II CPU dedicated to running Unigraphics CAD/CAM software. Modern CAD systems require large amounts of memory in disk storage and the three-disk system in use with the CPU, consisting of a total of 401 MB is the bare essential for the operating system, applications software and the storage.

The computer and peripherals consisted of:

- a DH630Q3 MicroVAX II CPU with,
  - 13 MB of memory,
  - 2 (RD53) 71 MB disks,
  - 1 (RD54) 159 MB disk,
  - 1 (TK50) tape drive,
  - 8 (RS232) ports,
  - VMS operating system, version 5.0,
  - Calcomp 960 plotter and 907 controller.

Version 6.0 of Unigraphics II runs on this CPU. A block diagram of the computer system is shown in Figure 1.

The graphics terminal consisted of a Megatek vector refresh display for the graphics and a small monochrome terminal for the menu display and messages. The data input to the system is usually via a keyboard to the message terminal or a keyboard and/or joystick to the graphics terminal. Data may also be input directly from tape.

3.0 CONCEPTS AND DESIGN

The design of any part using CAD/CAM is no longer a haphazard process involving disparate elements and divided responsibility. The end product has to be kept clearly in sight and the steps closely related to each other. This approach is delineated in our design paradigm.

3.1 Design Paradigm

The design paradigm describes the concepts, design and manufacture of the part as a unified and coherent whole. The procedure can be divided into a number of phases: data input, geometry development, dimensioning, CNC machine path generation, and manufacture as shown in Figure 2. These may be further broken down into steps as shown in Figure 3. These steps were followed in the design process described below.

3.2 Geometry and Surface Definition

Step 1 was classified as data input. Here the envelope of the mid-plane was defined by points representing the extremities of the model in all directions. The origin was chosen to be at the corner of the model and the **xy**-plane of the absolute coordinate system defined the base plane of the model. This is shown in Figure 4.

Step 2, geometry construction, followed once the envelope had been defined. The shape definition began with a two-dimensional layout defining the extent of the geometry in the mid-plane (see Figure 5). The model was taken to be symmetric about the mid-plane so that the finished product could be made from two mirror images. The original motivation behind this line of thought was to make the glove able to fit either the left or the right hand thus eliminating the need to manufacture two gloves for each size. Figure 4 shows the coordinates of critical points such as the ends of the fingers and arc centers from which the geometry was constructed and Figure 5 shows the major points and dimensions. This was the completion of step 2A as shown in Figure 3.

The geometry for the fingers was constructed by rotating the relevant lines and arcs about the centerlines of the fingers and generating surfaces of revolution. Figure 6 shows the surfaces created in this way. The advantage of this type of surface, as far as computation is concerned, is that it is constructed from simple curves and requires the minimum of memory. The more of these surfaces that are included in the model, the more efficient will be the management of memory in the computer.

The surfaces were all labelled for ease of future editing. The nomenclature was "S1" through "S50" and is shown in Figures 7 and 8. Some of the numbers are missing, e.g. S44, because free-form sculptured surfaces were created from bounded planes and surfaces of revolution and the originals then removed. Step 3 was completed in this way.

3.3 Surface Matching

In order to avoid the irregular joining of surfaces and the problems of an incompatible number of boundaries, surfaces of revolution, tabulated cylinders etc., free-form sculptured surfaces allow the designer to create one surface where there were three or four. The techniques for doing this employ point generation over the surface set. The **POINTS ON SURFACE** function will distribute any number of points over all or a fraction of the surface. These points may be the basis of a new, larger sculptured surface. In this way, the surface geometry may be simplified, although machining of sculptured surfaces may present more difficulties.

Chaining tolerances, which define the accuracy of surface matching, were set to 0.01 inch (0.254 mm). If this parameter is set too tightly (e.g. to <0.001 inch (<0.0254 mm)) then none of the complex surfaces will ever satisfy the condition and none will be able to be matched and/or joined together in surface sets. The surface sets are essential for **PARAMETER LINE** milling operations which allow surfaces with common edges to be treated as one surface in the machining process.

The complete surface geometry is shown in Figure 9 in the form of a meshed surface display and Figure 10 depicts the matching of planar and free-form sculptured surfaces in critical areas: the thumb bulge and the planar top surface of the glove model.

A modification of this shape was made to generate another prototype, **GLOVE3.PRT**, which was made up from all the same surfaces save for the thumb area. This was redesigned to incorporate a bent thumb as may be seen in Figures 11 and 12, the latter showing a fully annotated surface model. Referring to Figure 8, we may see that only four surfaces of the original fifty had to be modified to accommodate these changes (S31 to S34). In fact, to generate the new surfaces, the old ones (S31 to S34) were rotated and two new blending surfaces added, S51 and S52.

The changes may be seen in a quantitative form in the dimensioned drawings in Figure 13 and 14. Both drawings show a selection of radial and linear dimensions (in imperial units) necessary to fix the position and sizes of the critical points and relations.

4.0 CNC MACHINE FUNCTIONS

With the geometric design established, the work was prepared for computer-numerical machining. The size of the blank workpiece (from which the part is cut) must be fixed at the start to prepare all the planar rough cuts which bring the surface as close as possible to the actual surface of the part. (In design terms it helps to imagine the part immersed in the solid block waiting to be "discovered" by the machine tool, rather in the manner of Plato's idealism).

4.1 Blank Size Determination

The blank workpiece measured two by six by twelve inches (51 by 152 by 305 mm) thus completing step 4 (see Figure 4). The **PARAMETER SETS** for the machining were then constructed. These involved specifying the size of the workpiece, the origin for the tool and the machine coordinate system, the points at which the tool will start and finish a machining path (the **START** and **RETURN** points) and the machine zero and **GOHOME** point (all of which must be well beyond the workpiece.)

4.2 Parameter Sets

The **PARAMETER SETS** define a set-up procedure including milling tool information (diameter, radius, taper etc.), feed rates, clearance plane definitions, stocking (the amount of material left on the part after a machining pass) and cut parameters (including stepping, scallop height and material side vector). These numbers may be stored in a variable set and the set may be recalled and applied to any particular cutting path that is being constructed. An example may be seen in Figure 15. Some information (such as feedrates) is best left to the postprocessor unless substantial variations are required in the various paths cutting the part. The **PARAMETER SETS** may be edited and restored at any time.

A set of tools was then defined. For each machine path, the **PARAMETER SET** required for it will demand a tool descriptor. These were endmills (flat-end cutters with zero corner radius) and ballnose mills (cutters with a spherical tip). One-inch and one-half inch diameter endmills and a set of ballnose mills varying between 0.500 inch (13 mm) down to 0.125 inch (3 mm) were defined and stored in a tool library. When demanded for any particular machining path, the tool specifications were called up from the library.

The preparation of the machining paths was further streamlined by defining the start points (**ST**) and retract points (**RT**) for the tool in relation to the workpiece. These define the 'zero' for each particular path such that no matter where on the surface the path starts and finishes the tool still approaches and leaves the part from the same point. If particular geometry needs to be avoided, then these points may be edited at any time. Figure 16 shows the start and return points. The "from" and "go-home" points (**FR** and **GH**) are further removed from the machining process: when the cutting has finished, the tool retreats to this position and it is from this position that tool changes are initiated. All these data were stored in the **PARAMETER SETS** completing step 5. A summary of all the parameter sets, along with their associated operations, defined for this particular part may be seen in Figure 17.

5.0 CNC TOOL PATH PREPARATION

The tool path preparation does not require that the exact properties of the CNC machine and postprocessor be known. However, some knowledge is essential. The facts that must be known include a decision on three-, four-, or five-axis machining, and what tool dimensions will be used for performing this particular cutter path. In other words, only those factors that interact directly with the geometry of the part need be specified. If the actual CNC machine and controller need to be changed between design and manufacture, a different postprocessor can modify the CNC instructions. (The postprocessor converts the **+.CLS**, the cutter location source files generated by Unigraphics, to the **+.PTP** files that the CNC machine can read.)

5.1 Flat Rough Cuts

Preparation began with the blank. The first rough cuts were performed with a flat endmill to cut the depth down from two inches to 1.2 inch (51 mm to 30 mm). These correspond to the path **GLOVE1FLRUF1.CLS** shown in Figure 18. The file nomenclature adopted here shows the part first (**GLOVE1...**) followed by the type of surface cut (**...FLRUF1...**) denoting here a flat cut using endmills. All file names containing **...FLRUFn...** indicate the **n**-th flat cut.*

The next flat cut (**GLOVE1FLRUF2.CLS**) removed most of the material down to the plane z= 0.435 inch (11 mm) which corresponds to the finger diameter and the top of the hand. An island was left to accommodate the hump of the thumb area (see Figure 19). Figure 20 shows the final flat cut (**GLOVE1FLRUF3.CLS**) which followed the perimeter of the hand and removed all excess material down to z= 0.000 inch outside the perimeter.

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*See Appendix A for a full description of the file nomenclature.

5.2 Surface Finish Cuts

We turn now to the preparation of the finish cuts for the sculptured surfaces. The reason for beginning with the finish cuts rather than the rough cuts was that the finish cut is used as the basis of a **ROUGH-TO-DEPTH** pass to remove excess material; that is, the input path name for a roughing cut must be that of a finish cut. Note however, that this refers only to the preparation of the machining paths: in the final analysis, the rough cuts are performed by the CNC machine before the finish cuts. The finish cut is the ideal form that is approached in small steps of rough cuts. The surfaces were labelled and could be cut individually or in groups. Grouping of surfaces wherever possible is advisable as it reduces the number of separate machining paths. The **PARAMETER LINE** mode is used for the surface groups.

When laying out paths across the surfaces, the machine tool must cut downwards into the part. Wherever possible, the z-values of the origin of any particular path should be highest at the beginning of the path.

Various limits must be defined that describe the envelope of the part. The blank clearance plane must be defined as the z-value below which the tool will not pass during rapid moves across the part and is set at z= 2.500 inch (64 mm) (Figure 21). Below the blank clearance plane lies the blank plane at z= 2.000 inch (51 mm): this is the beginning of the part surface where metal will be cut. The base plane at z= 0.000 is the plane describing the lower limit of geometry, that is, there are no surfaces below this point. Lastly, there is the minimum clearance plane at z= -0.500 inch (13 mm) which fixes the minimum allowable z-value that the center of the cutter is allowed: the tool will not project below this whatever the contents of the instruction set.

Figures 21 through 34 show the finish cuts as they were prepared for the final surface. The parallelepiped described by phantom lines represents the blank of material from which the part was cut. The flat rough cuts begin with shape. All the relevant planes are defined[b] and stored as global parameters, that is, they are defined for all machining paths for the part. Groups of surfaces were machined under the **PARAMETER LINE** method and these are shown in the filenames e.g. **GLOVE1FS1_2.CLS**.

The dotted lines extending out of the blank confirm the start and finish motions of the tool as it engages the part and retracts from it. The floor stock on all the finish cuts was, of course, zero, and the scallop height was set for 0.001 inch

[b]The blank plane, blank clearance plane, base plane and minimum clearance plane.

(0.025 mm) giving the smoothest machined surface possible before polishing. The file names transferred to diskette are also shown along with data on the file sizes. These are shown at the end as Figure 52. This completed step 6.

5.3 Rough Surface Cuts

The rough cuts were generated in a similar manner (step 7 in the procedure). Figures 35 through 51 show these. The same process of surface grouping was carried out as for the finish cuts though not always with exactly the same surface combinations. The reasons for this lay in the possible use of different tools for the finish and rough cuts and the different amounts of surface interference that were allowable in each case.

In making a "rough cut", the previously defined finish cut is used as an input. Given that the blank size (the starting block size) is known, then the **ROUGH-TO-DEPTH** function uses the finish cut input as the base of the surface to be "roughed". The cutter will shave off successive planes in the part bounded by the surface declared in the finish cut. Thus the surface presented to the machine for the finish cut consists of the final surface overlaid with steps of material left by the rough cut. A summary of all the machining paths for the part are shown in Figure 52.

Some surfaces were cut singly, while others were grouped together, for instance all the ends of the fingers as shown by **GLOVE1FSENDFING.CLS** which comprised sixteen different surfaces grouped in four groups of four. Floor stock of 0.025 inch (1 mm) was left on all part surfaces. After the finish cuts were complete, the surface of the model had zero floor stock and a scallop height between tool passes of 0.001 inch (0.025 mm). Finer finishing requires polishing.

5.4 Postprocessing the CL files

The cutter location source files (the CLSF or CL files) represent the position of the center of the end of the tool in the coordinate system of the model. Over a flat horizontal surface, this is the same as the point tangent to the part surface.

However, for surfaces curved or inclined at an angle to the vertical, the tip of the cutter will not actually touch the part surface but will be offset from the surface by a certain quantity determined by the cutter shape and edge radii. The cutter will be moving across the part surface tangentially. The purpose of the postprocessor software is to convert the **APT** command structure of the **+.CLS** files to the structure required by the CNC machine and controller. That is the **GO TO** statements are translated to the **NpqrsXxxxxYyyyyZzzzz** point-to-point instructions required by the Fanuc controller. This is done by invoking the **XLATOR** translator which executes the postprocessor software.

This is frequently not enough. The CNC mill often needs specific set-up and shut-down instructions. These are added to each file by running each **.CLS** file through a **GRIP** program **"FILEADDR"** which adds file commands to the header position and commands at the trailing edge of the file. This may be seen in Appendix B. The input file is shown as **"PUNCHFILE.PTP"** and the additions are shown as **"HEADER.TXT"** and **"FOOTER.TXT"** and are shown in Appendix C. When these changes are made the files are ready for transportation to diskette and the Matsuura/Fanuc CNC mill. This completes the steps nine to twelve in the design process.

6.0 THE MODELS

The actual cutting of the models proceeds first with the rendition in CNC wax. This is a polyester material that is suitable for cutting by CNC machines to generate a model but is sufficiently soft that tools will not be damaged if there are errors in the execution of the cut files (**+.PTP**). It serves as a check on the final cut file before the part is committed to metal.

The final model was made from two mirror images of the half-hand model described above. As the y-axis of the part extends from the little finger to the thumb side of the hand, an inversion of this axis produces a mirror image of the part. This was accomplished by performing a "y" to "-y" axis inversion on the Fanuc controller. All the prepared machine files were used to cut the mirror image.

Upon completion of the two halves, holes were drilled in the fingers, palm and wrist of the hand and screws inserted. The final polishing smoothed the screw heads so that they were flush with the part surface. The models were then complete and ready for latex dipping trials.

7.0 CONCLUSION

Forms were designed and manufactured exclusively by CAD/CAM techniques for the model hand. The models served as prototypes for latex dipping to make experimental CW gloves for dexterity trials. The surface of each model was polished to the requisite finish for dipping. The models successfully produced the prototype gloves required.

The variety and complexity of the data required to determine the shape and size of the glove necessitate the formation of a comprehensive testing program by means of which results from the trials of the various prorotypes may be compared and contrasted.

The feasibility of computer-aided manufacturing is thus well-established. The design process using the computer has shown itself to be extremely useful in reducing turn-around time in the manufacture of prototypes. Future work will concentrate on the adaption of more extensive anthropometric data (many more variables will be included in the design dimensions) and the incorporation of information on fit and dexterity from the trials being conducted on the gloves. These data will drive the design changes for the next prototype set.

Future reporting will include the design of a suitable testing protocol, the inferences made from the prototype tests with human subjects, and the design philosophy that will incorporate all the relevant anthropometric data required for an effective, new CB glove for the Canadian Forces.

8.0 ACKNOWLEDGEMENTS

My thanks are due to the CRC Model Shop under the direction of Mr. Ted Wigney whose able management allowed the final forms to be made and to Mr. Mario Carrière for operating the Matsuura CNC three-axis mill.

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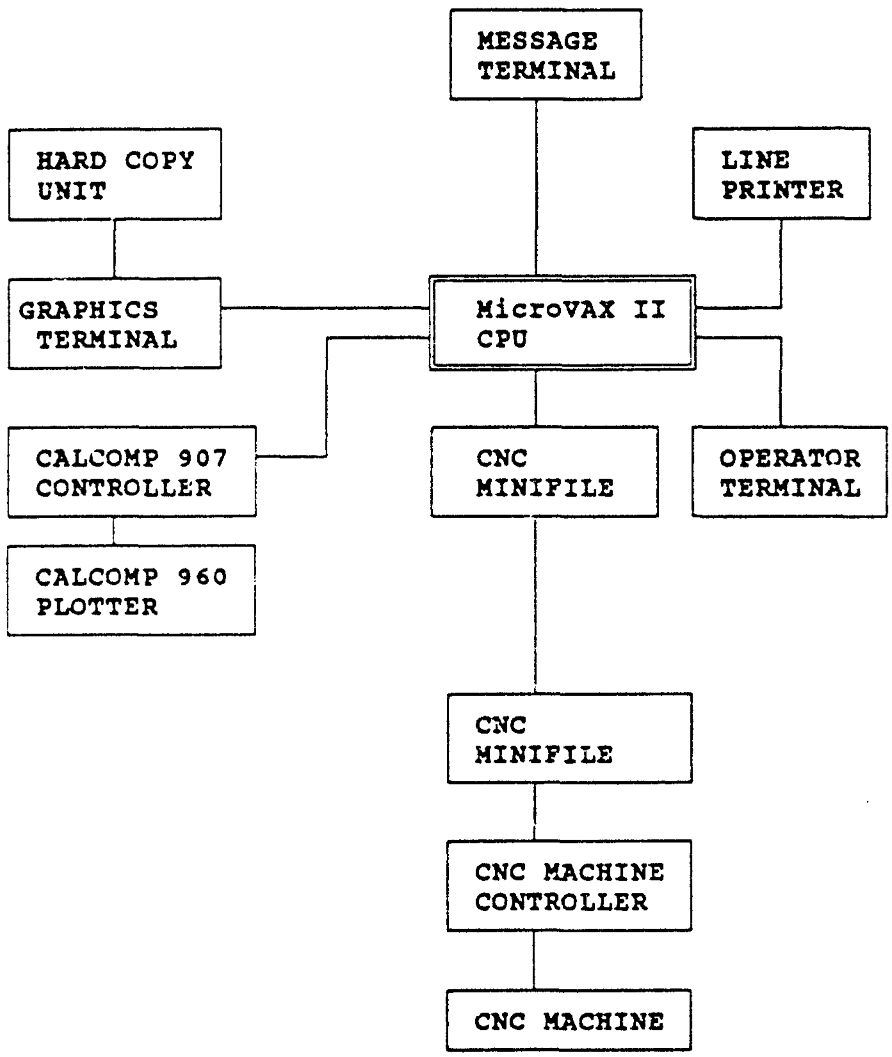

Figure 1: Block Diagram of the Computer system.

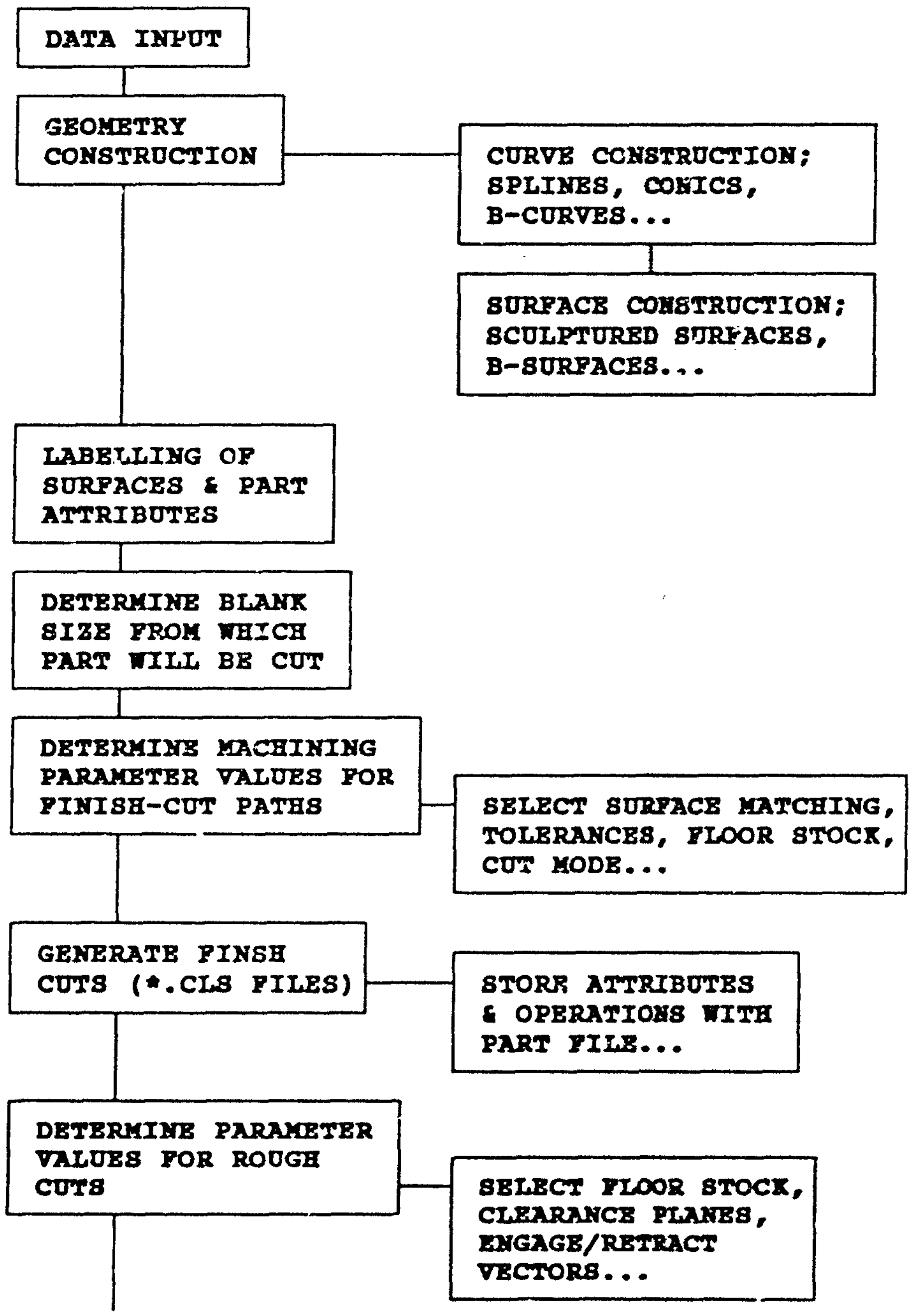

Figure 2: Block Diagram of Design Process

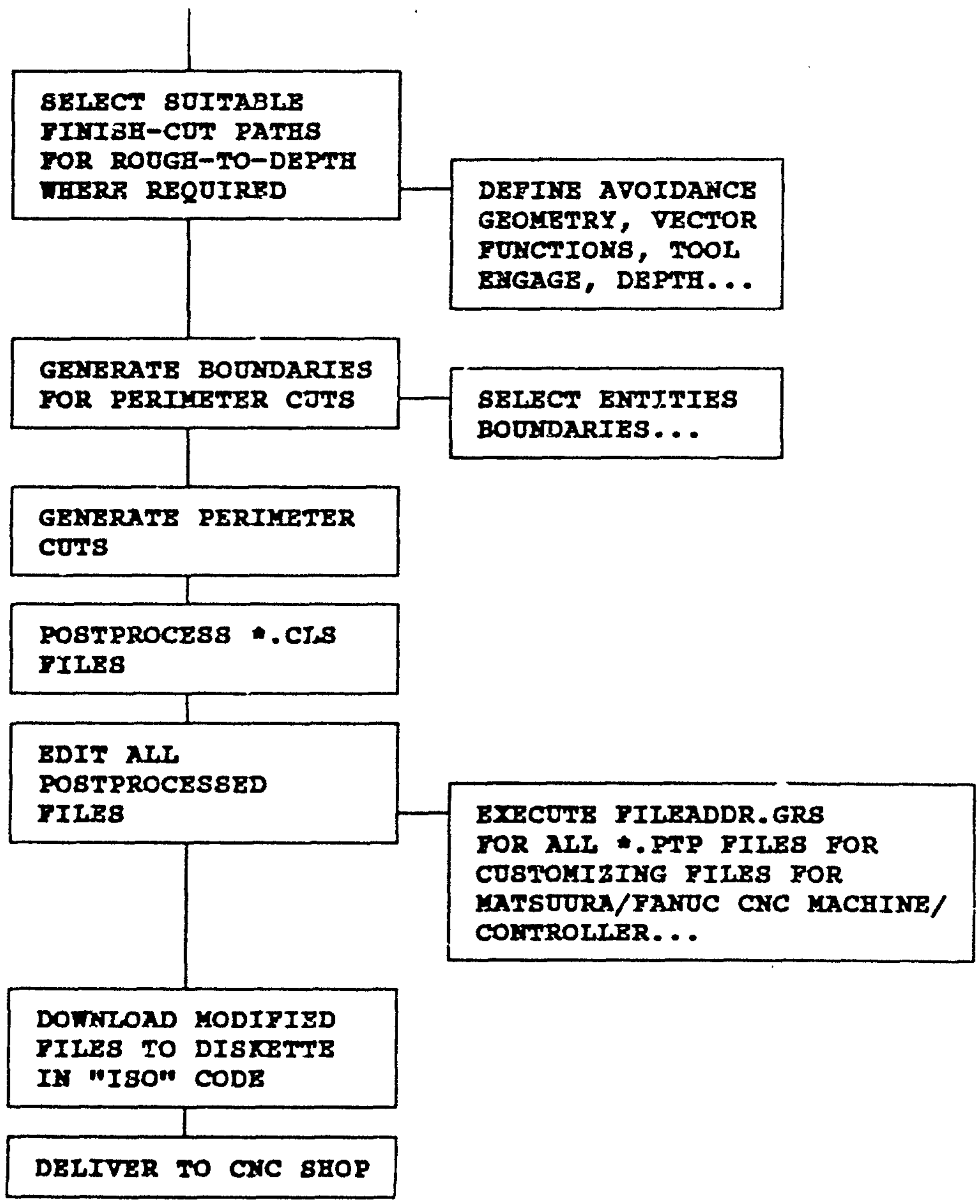

Figure 2: Block Diagram (cont'd)

STEP 1: DATA INPUT	
STEP 2: GEOMETRY CONSTRUCTION	STEP 2A: CURVE CONSTRUCTION, SPLINES, CONICS, B-CURVES...
	STEP 2B: SURFACE CONSTRUCTION, SCULPTURED SURFACES, B-SURFACES...
STEP 3: LABELLING OF SURFACES & PART ATTRIBUTES	
STEP 4: DETERMINATION OF BLANK SIZE FROM WHICH PART WILL BE CUT	
STEP 5: DETERMINATION OF MACHINING PARAMETER VALUES FOR FINISH-CUT PATHS	STEP 5A: SURFACE MATCHING TOLERANCES, FLOOR STOCK, CUT MODE...
STEP 6: GENERATION OF FINISH-CUTS (*.CLS)	STEP 6A: ATTRIBUTES & OPERATIONS STORED WITH PART FILE...
STEP 7: DETERMIMATION OF PARAMETER VALUES FOR ROUGH CUTS	STEP 7A: FLOOR STOCK, CLEARANCE PLANES, ENGAGE/RETRACT VECTORS...
STEP 8: SELECTION OF SUITABLE FINISH-CUT PATHS FOR ROUGH-TO-DEPTH WHERE REQUIRED	STEP 8A: DEFINE AVOIDANCE GEOMETRY, VECTOR FUNCTIONS, TOOL ENGAGE, DEPTH,..

Figure 3: Step Diagram of Design Process

STEP 9: GENERATION OF BOUNDARY FUNCTIONS, PERIMETER CUTS	
STEP 10: POSTPROCESSING OF *.CLS FILES	
STEP 11: EDITING OF ALL POSTPROCESSED FILES	STEP 11A: EXECUTE FILEADDR.GRS FOR ALL *.PTP FILES FOR CUSTOMIZING FILES FOR THE MATSUURA/FANUC CNC MACHINE/CONTROLLER...
STEP 12: DOWNLOADING OF FILES TO DISKETTE IN "ISO" CODE	
STEP 13: DELIVERY TO CNC SHOP	

Figure 3: Step Diagram of the Design Prccess (cont'd)

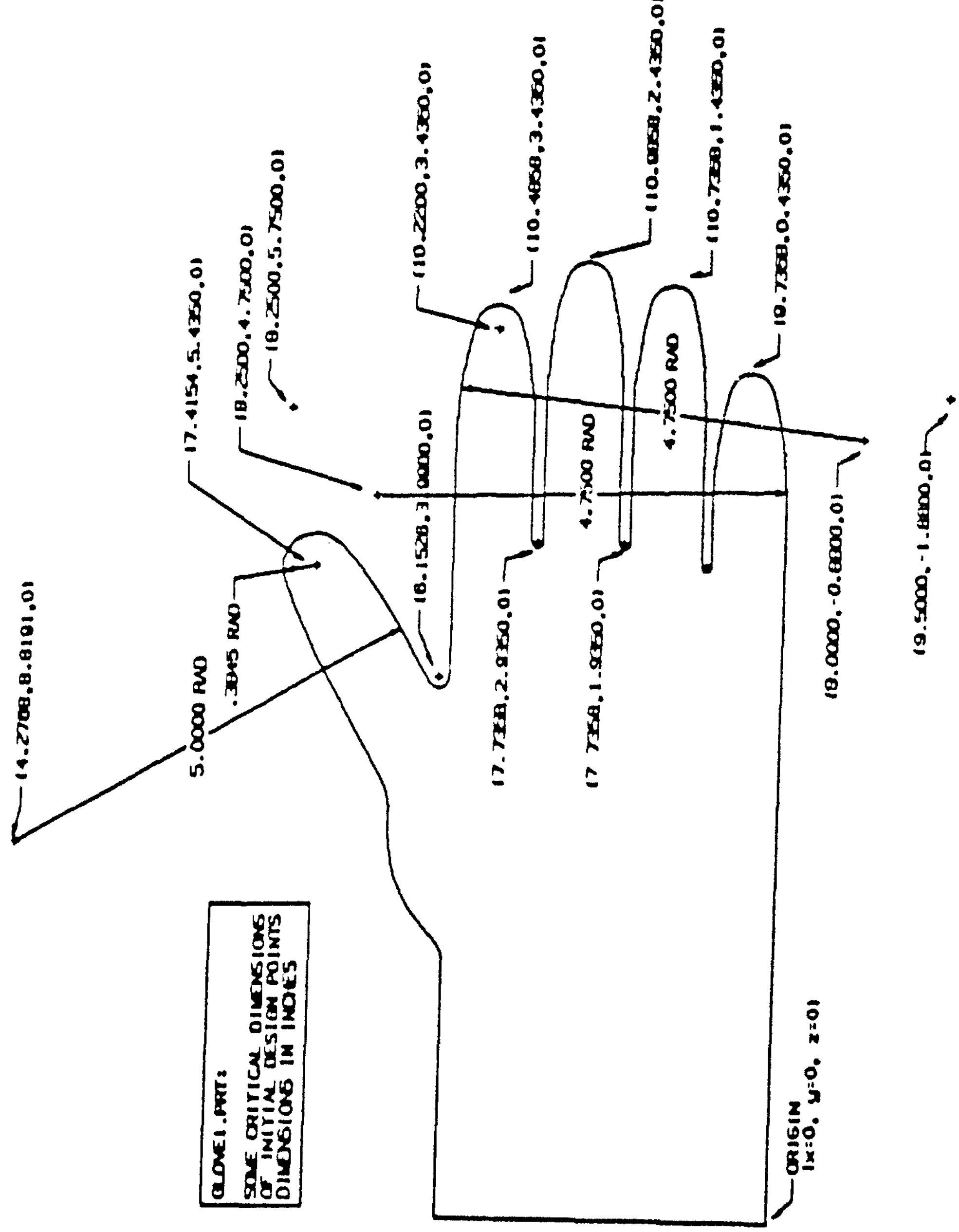

Figure 4: GLCVE1.PRT: Dimensions

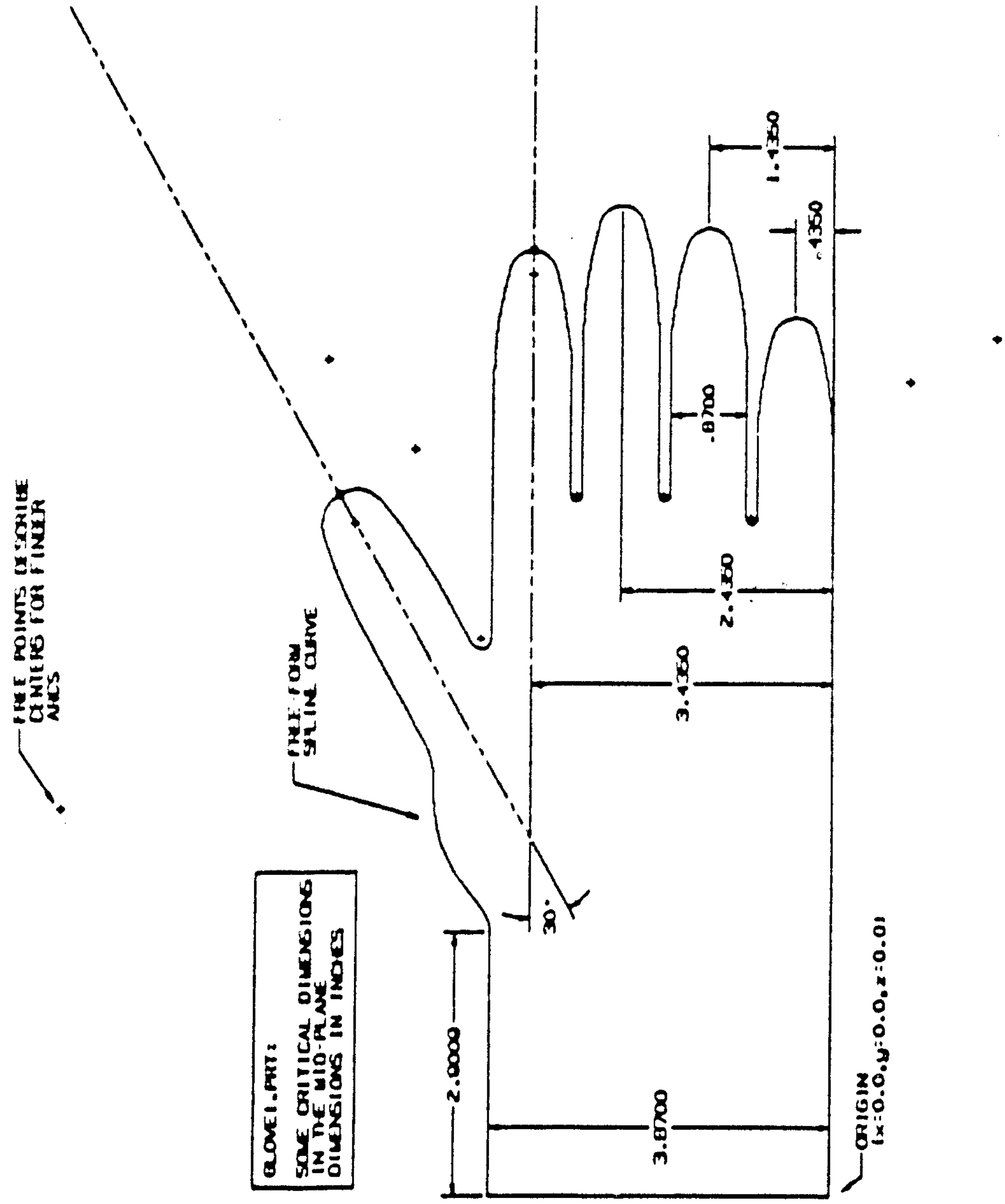

Figure 5: GLOVE1.PRT: Dimensions & Critical Points

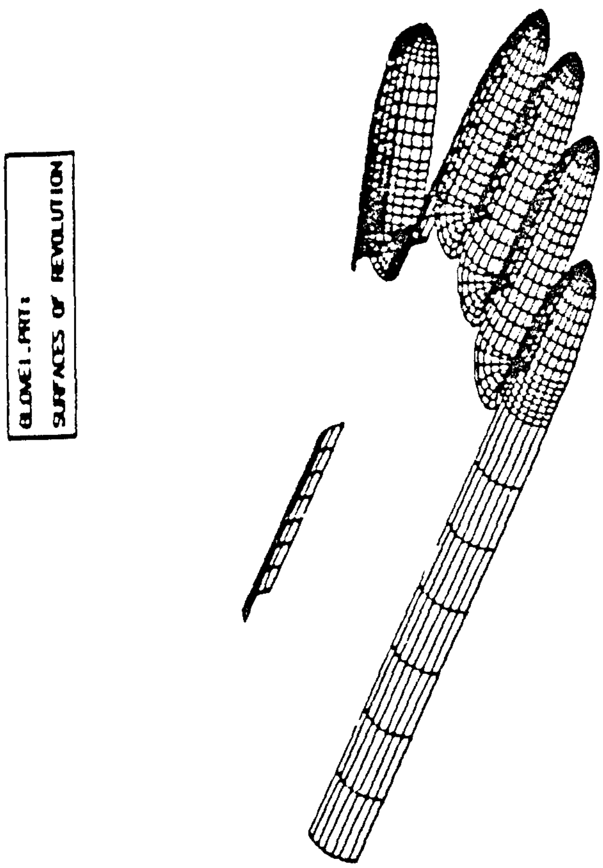

Figure 6: Surfaces of Revolution

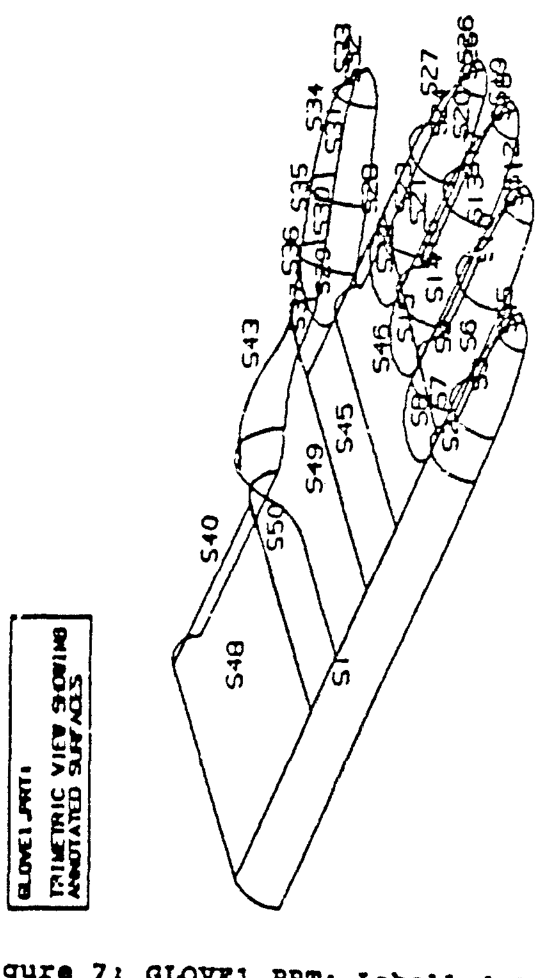

Figure 7: GLOVE1.PRT: Labelled Surfaces

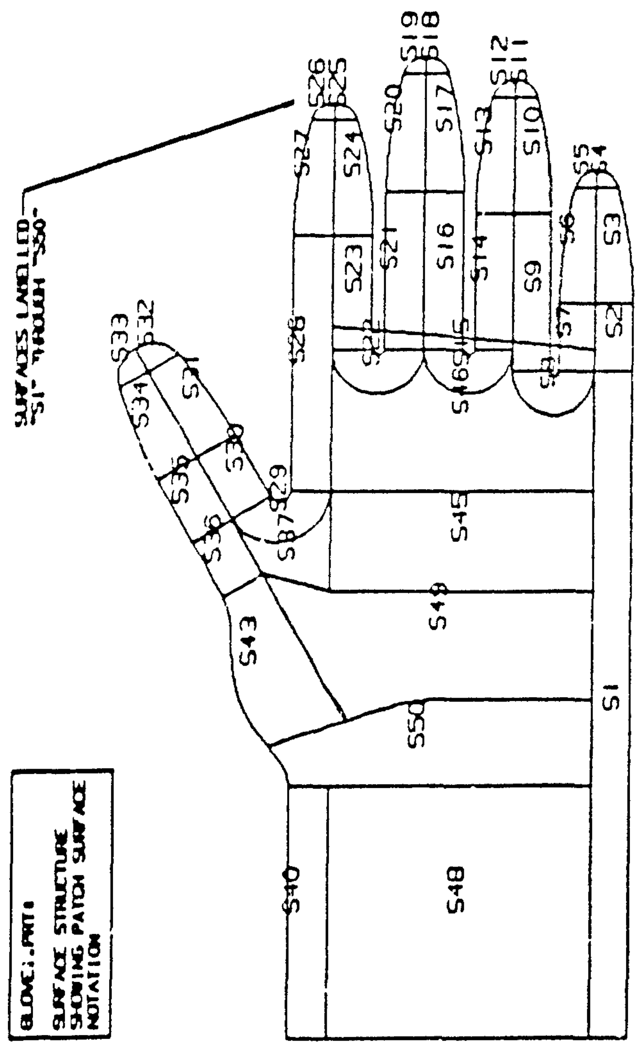

Figure 8: Labelle. Surfaces: Top View

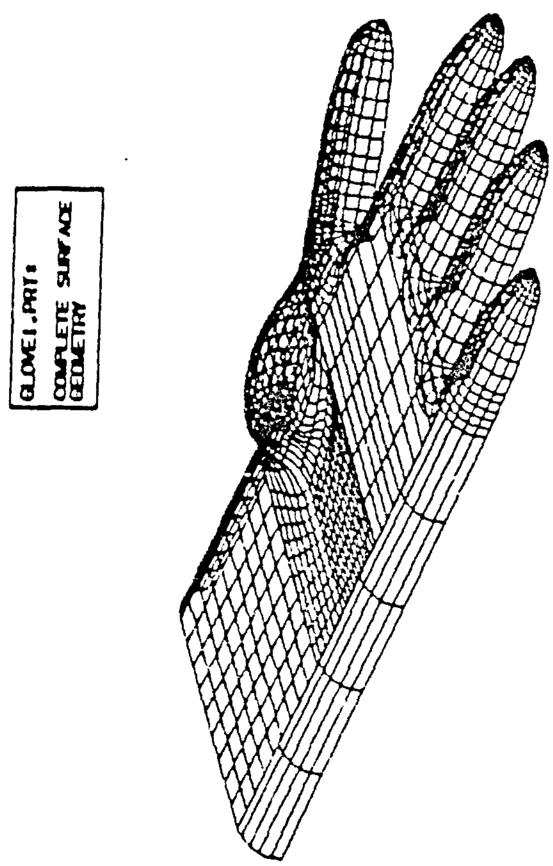

Figure 9: Complete Surface Geometry

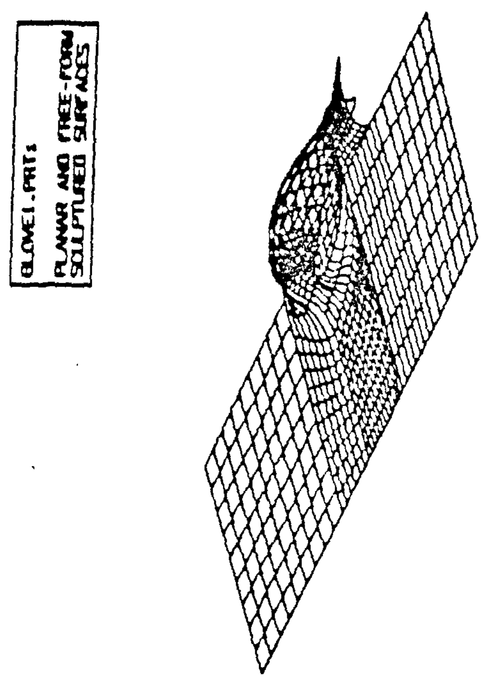

Figure 10: Planar & Free-Form Sculptured Surfaces

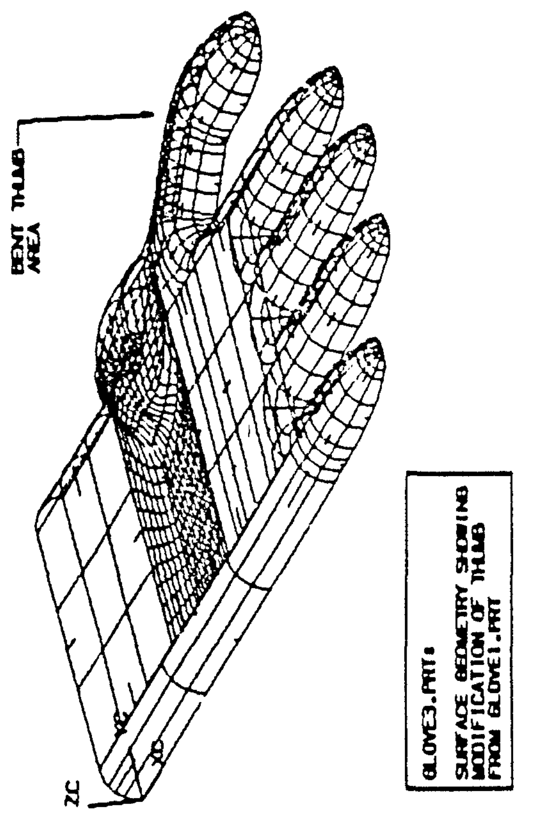

Figure 11: Surface Geometry: GLOVE3.PRT

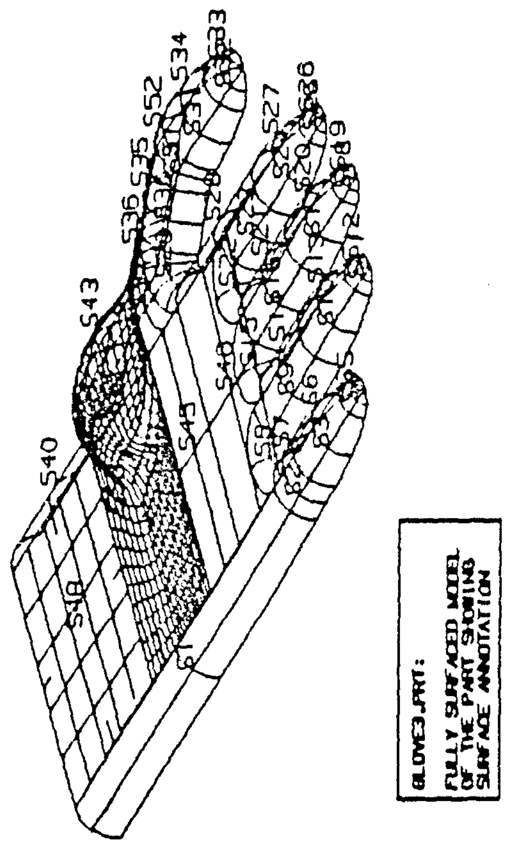

Figure 12: GLOVE3.PRT: Labelled Surfaces

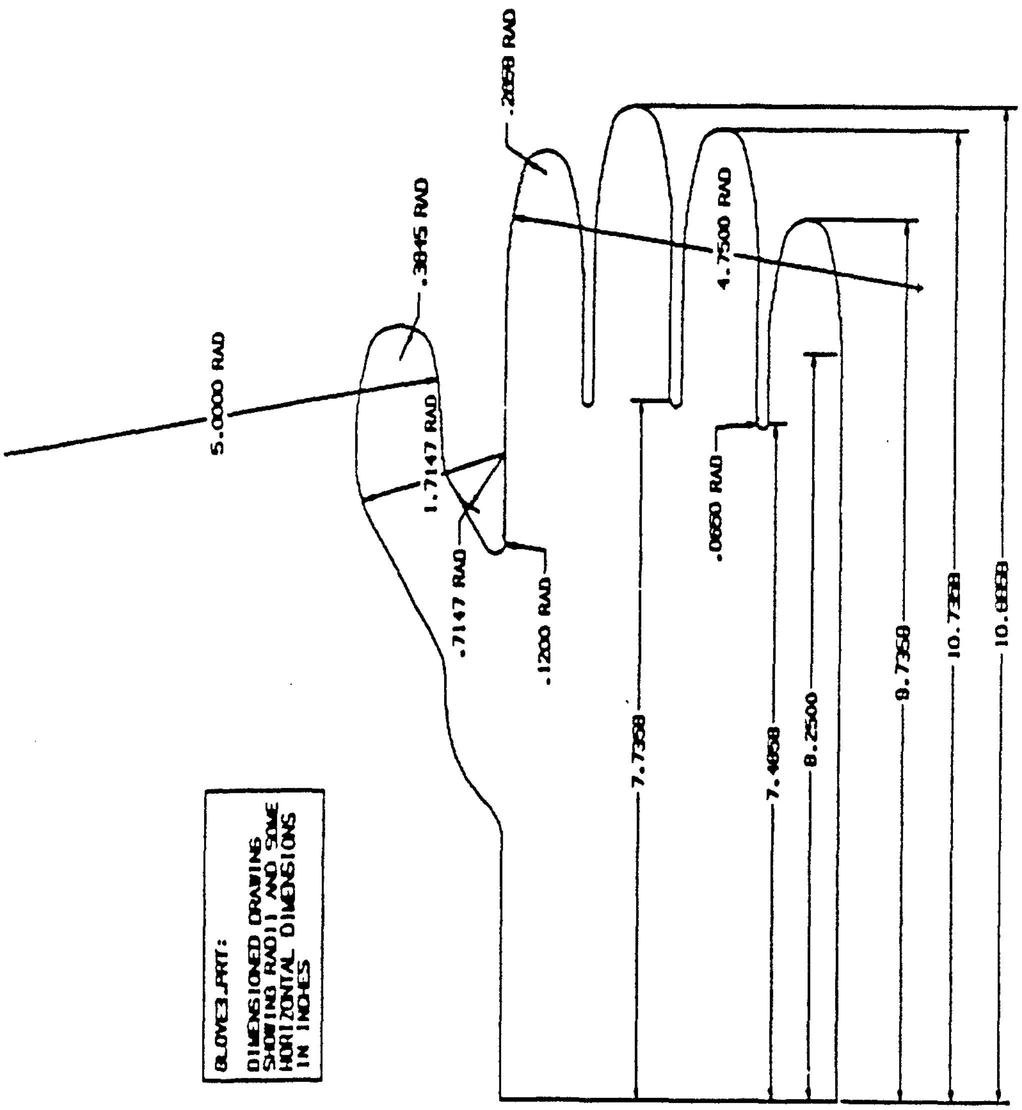

Figure 13: GLOVE3.PRT: Dimensions

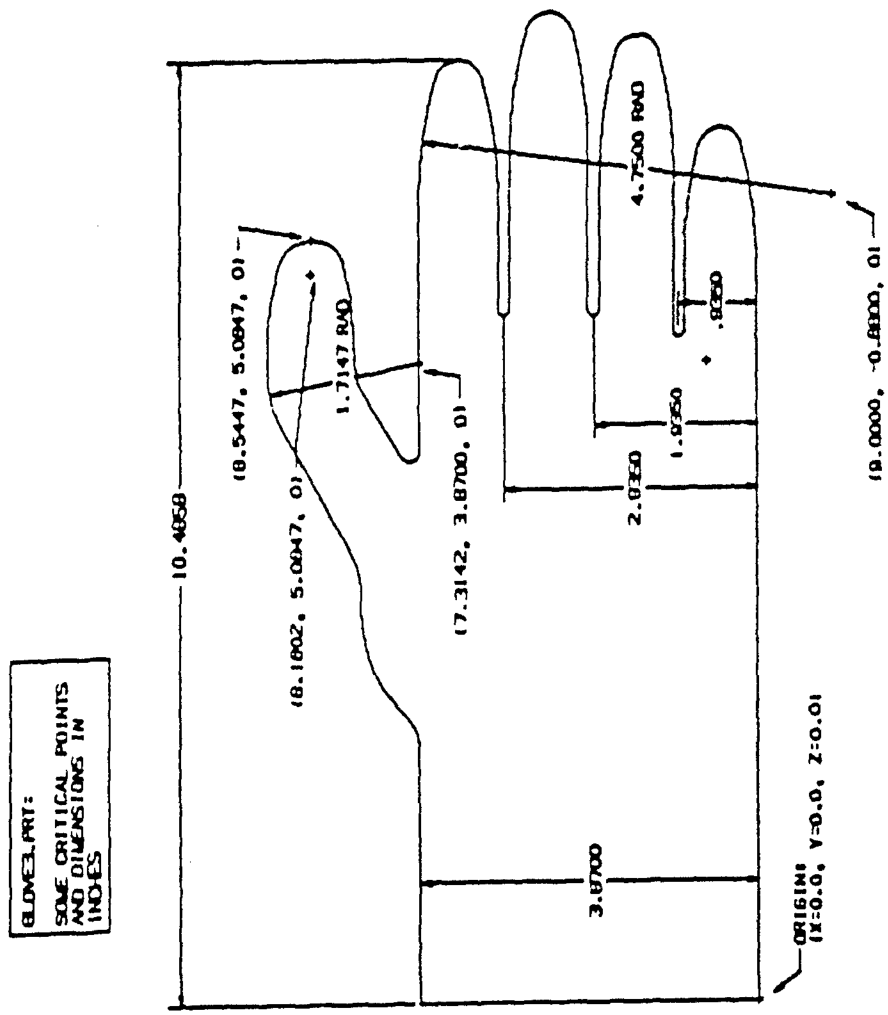

Figure 14: GLOVE3.PRT: Dimensions & Critical Points

```
PART NAME - HAND_MOD3.PRT
PARAMETER SET - P7
PARAMETER LINE MACHINING

TOOL INFORMATION    -T5
MILLING TOOL
   DIAMETER     = 0.3750
   CORNER RAD   = 0.1875
   HEIGHT       = 1.0000
   TAPER ANGLE  = 0.0000
   TIP ANGLE    = 0.0000
   FLUTE LEN    = 1.0000
   Z OFF        = -939.0000
   NUM FLUTES   = 2
   CATALOG NO.  =

POSTPROCESSOR COMMANDS
   NONE ACTIVE

FEEDRATES
   NON CUT UNITS    -IPM
   CUT UNITS        -IPM
   RAPID        = 0.0000
   ENGAGE       = 0.0000
   CUT          =10.0000
   RETRACT      = 0.0000
   FIRST CUT    = 0.0000
   APPROACH     = 0.0000
   STEPOVER     = 0.0000
   RETURN       = 0.0000

REFERENCE COORDINATE SYSTEM
     ORIGIN     = 0.0000, 0.0000, 0.0000
     MATRIX     = 1.0000, 0.0000, 0.0000
                  0.0000, 1.0000, 0.0000
                  0.0000, 0.0000, 1.0000

CLEARANCE PLANE
     NORMAL     = 0.0000, 0.0000, 1.0000
     POINT      = 0.0000, 0.0000, 2.4000

ENGAGE/RETRACT
     ENGAGE TYPE     = NONE
     RETRACT TYPE    = NONE
```

Figure 15: Parameter Sets: Example

```
STOCKING
     FLOOR STOCK          = NONE
     MINIMUM CLEARANCE    = NONE

TOOL AXIS
     TOOL AXIS TYPE       = NONE

CUT PARAMETERS
     CUT TYPE             = ZIGZAG
     STEP TOLERANCES
          STEPPING        = 0.0020
          SCALLOP HEIGHT  = 0.0010
     MATERIAL SIDE        = I,J,K COMPONENTS
          VECTOR          = 0.0000, 0.0000, 1.0000
```

Figure 15: Parameter Sets: Example (continued)

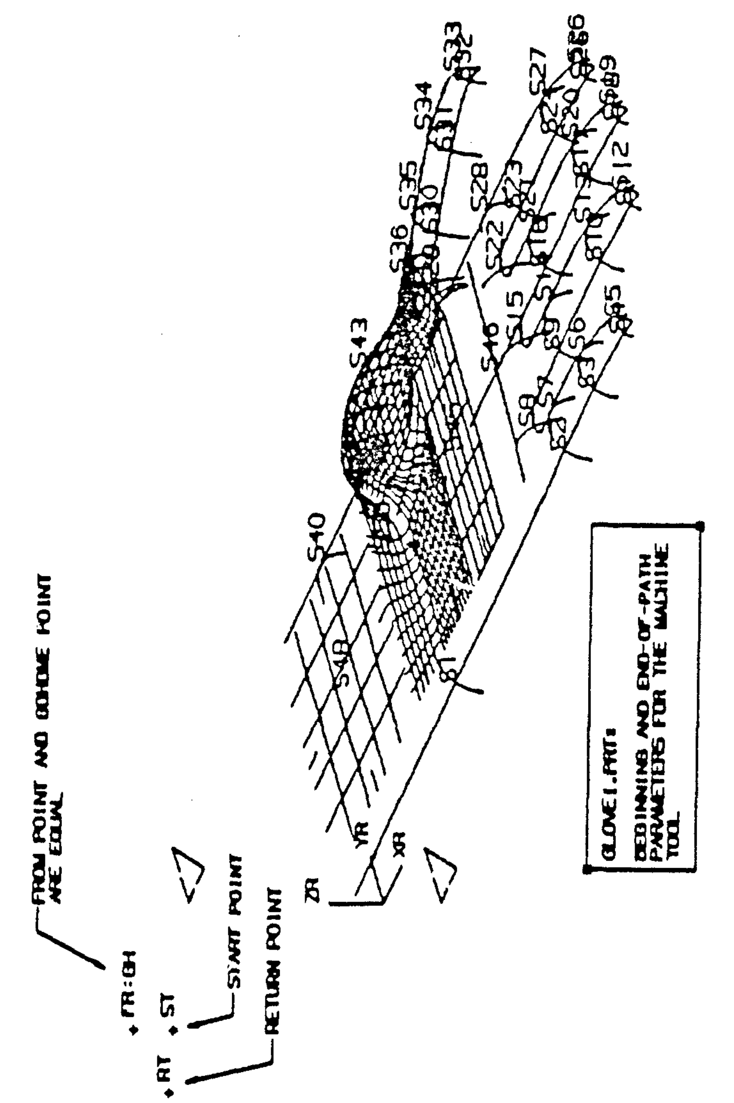

Figure 16: Path Parameters for Machine Tool

PARAMETER SETS AND OPERATIONS
FOR MILLING

GLOVE1.PRT

PARAMETER/POST SET	TYPE	ASSOCIATED OPERATION
ENDFING	PARAMETER LINE	YES
ENDTHUMB	PARAMETER LINE	YES
LUMPSIDE	PARAMETER LINE	YES
MIDFING	PARAMETER LINE	YES
MIDFING1	PARAMETER LINE	YES
MIDFING2	PARAMETER LINE	YES
OP1	PARAMETER LINE	YES
P1	PARAMETER LINE	YES
P10	PARAMETER LINE	YES
P2	FOLLOW POCKET	YES
P3	ROUGH-TO-DEPTH	YES
P4	PARAMETER LINE	YES
P5	PARAMETER LINE	YES
P6	PARAMETER LINE	YES
P7	PARAMETER LINE	YES
P8	PARAMETER LINE	YES
RCS38	PARAMETER LINE	YES
RS38	PARAMETER LINE	YES
RSS38	FIXED AXIS SURFACE CONTOURING	YES
RUFS38	FIXED AXIS SURFACE CONTOURING	YES
THFING	PARAMETER LINE	YES
THSIDE	PARAMETER LINE	YES
THUMB	PARAMETER LINE	YES
TOPHAND	PARAMETER LINE	YES
TOPSURF	PARAMETER LINE	YES
WRIST	PARAMETER LINE	YES

Figure 17: Parameter Sets for GLOVE1.PRT

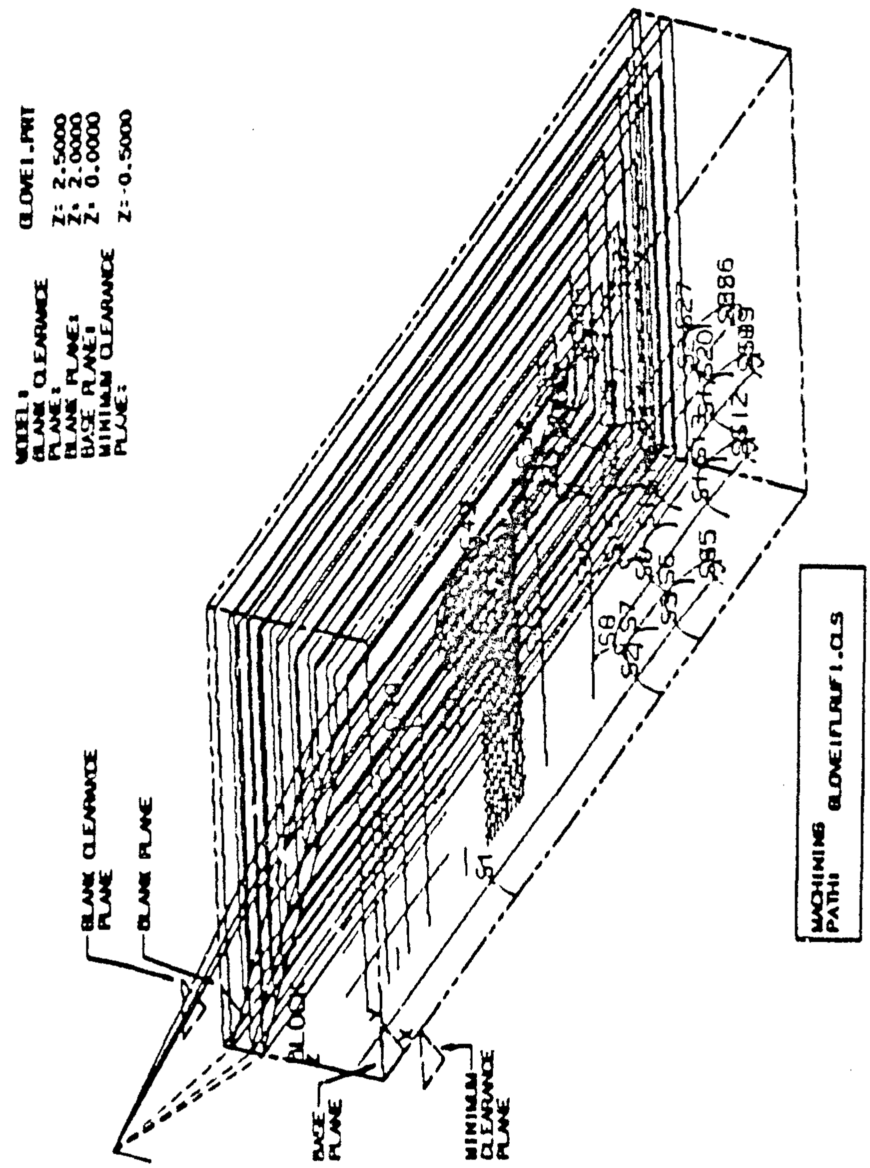

Figure 18: Machining Path: GLOVE1FLRUF1.CLS

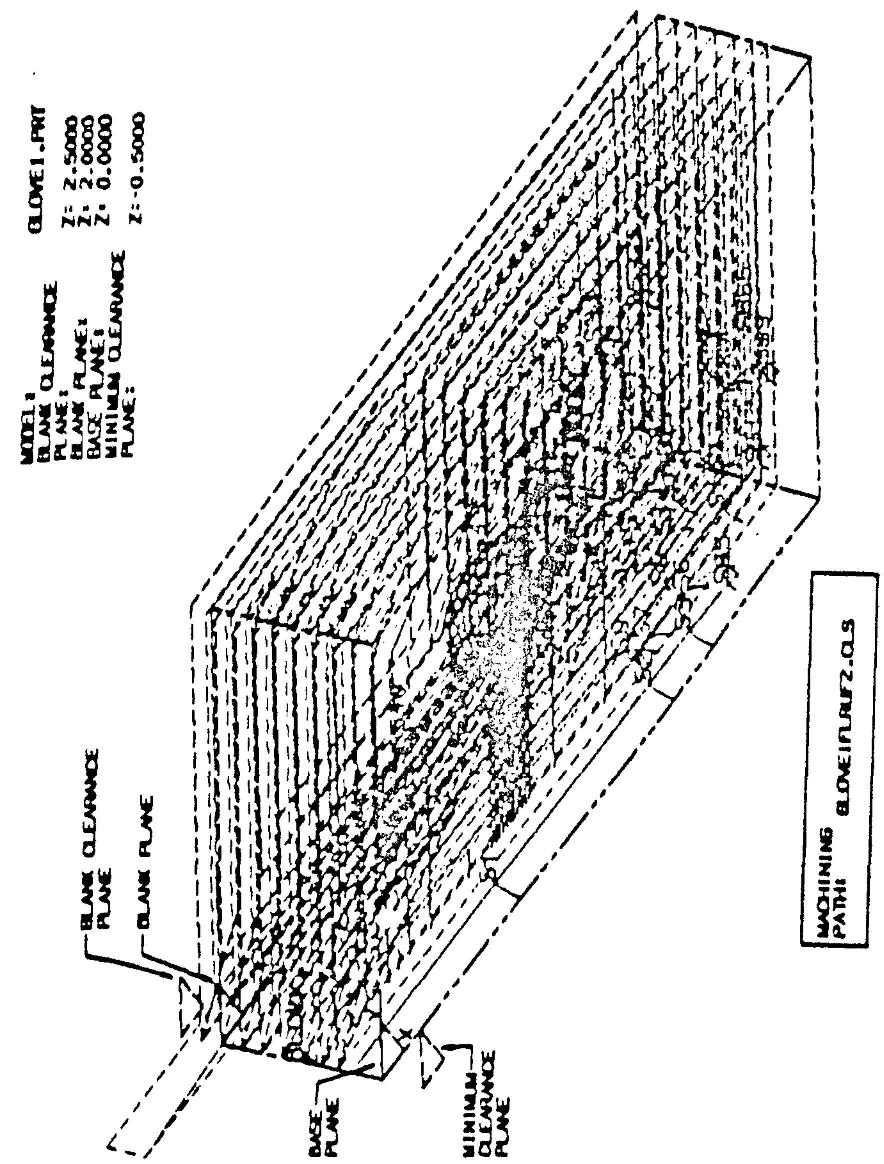

Figure 19: Machining Path: GLOVE1FLRUF2.CLS

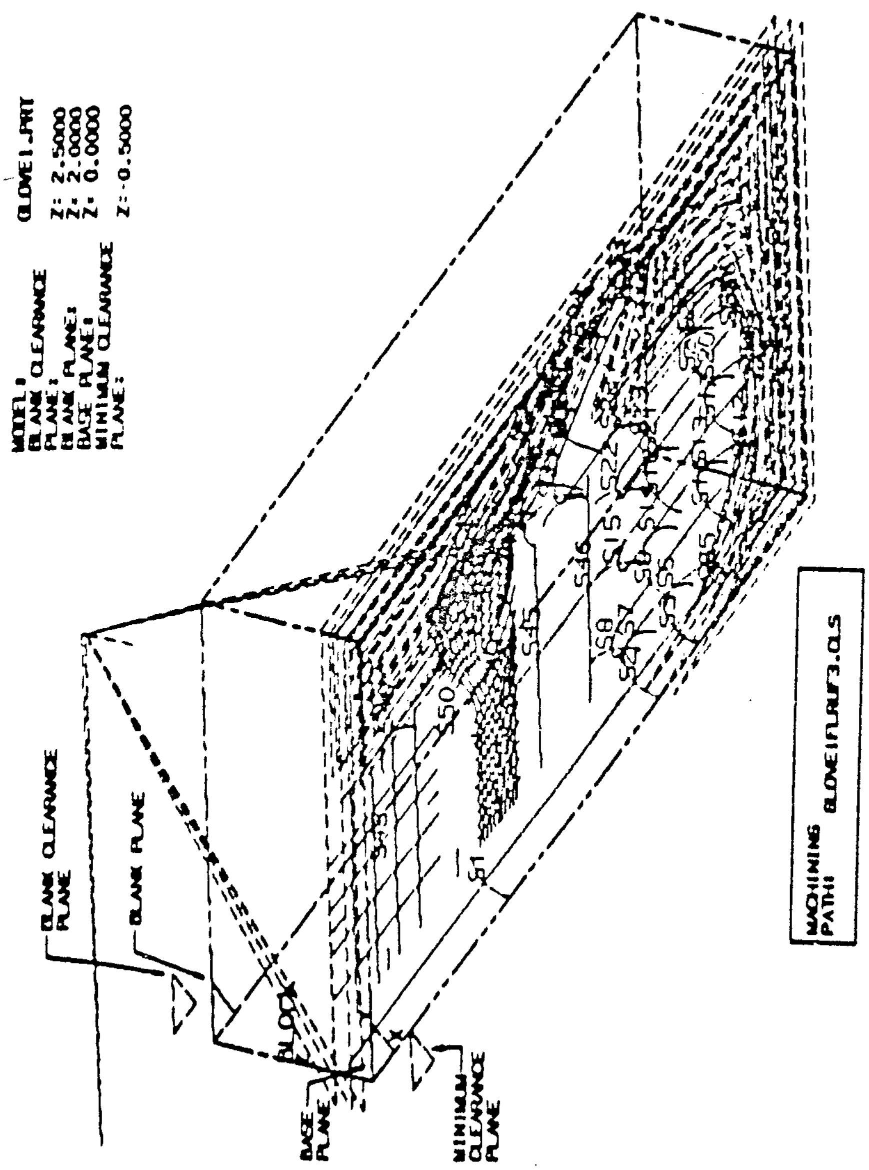

Figure 20: Machining Path: GLOVE1FLRUF3.CLS

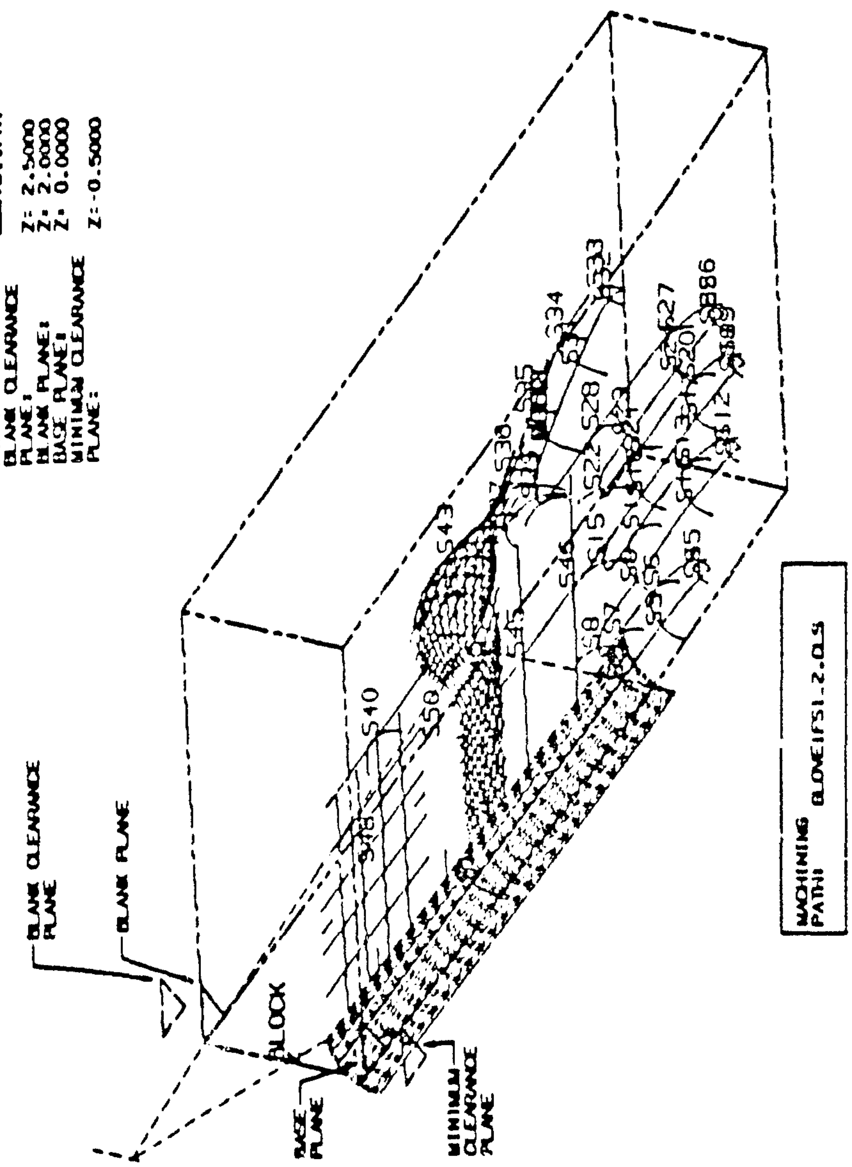

Figure 21: Machining Path: GLOVE1FS1_2.CLS

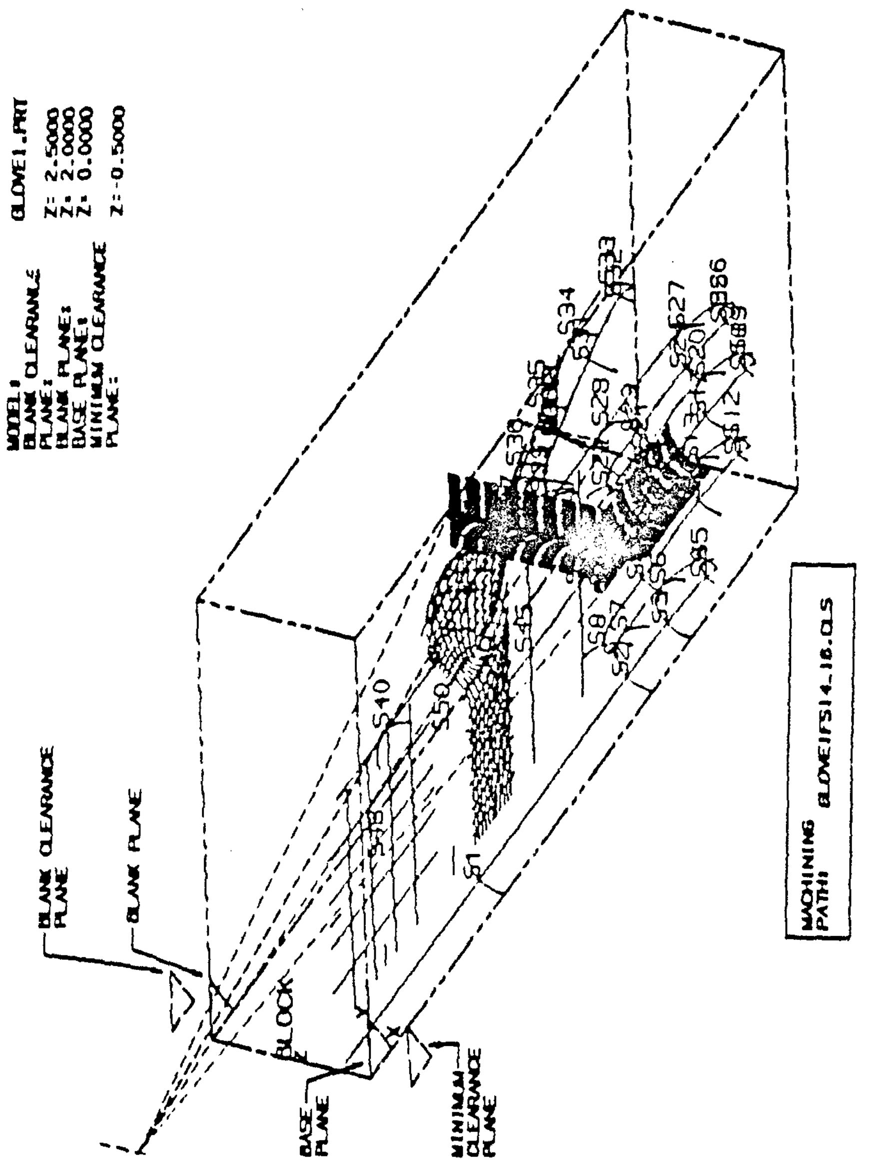

Figure 22: Machining Path: GLOVE1FS14_16.CLS

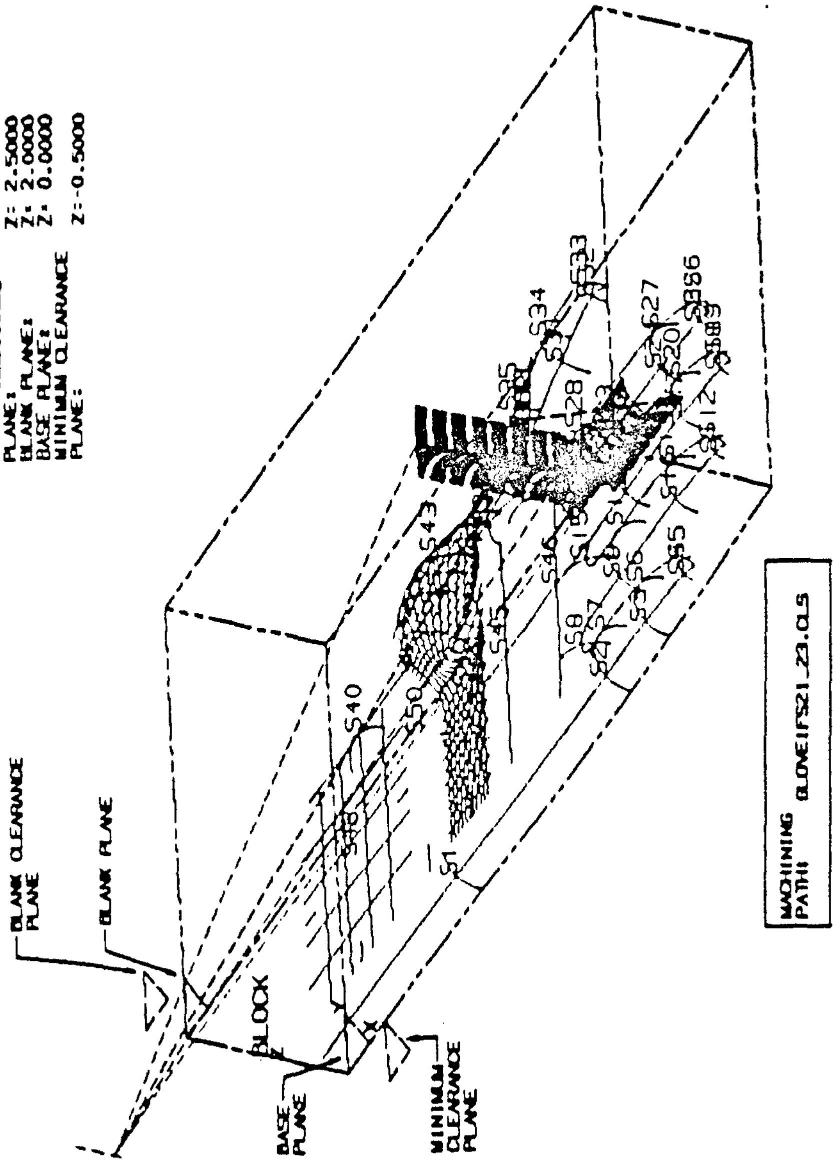

Figure 23: Machining Path: GLOVE1FS21_23.CLS

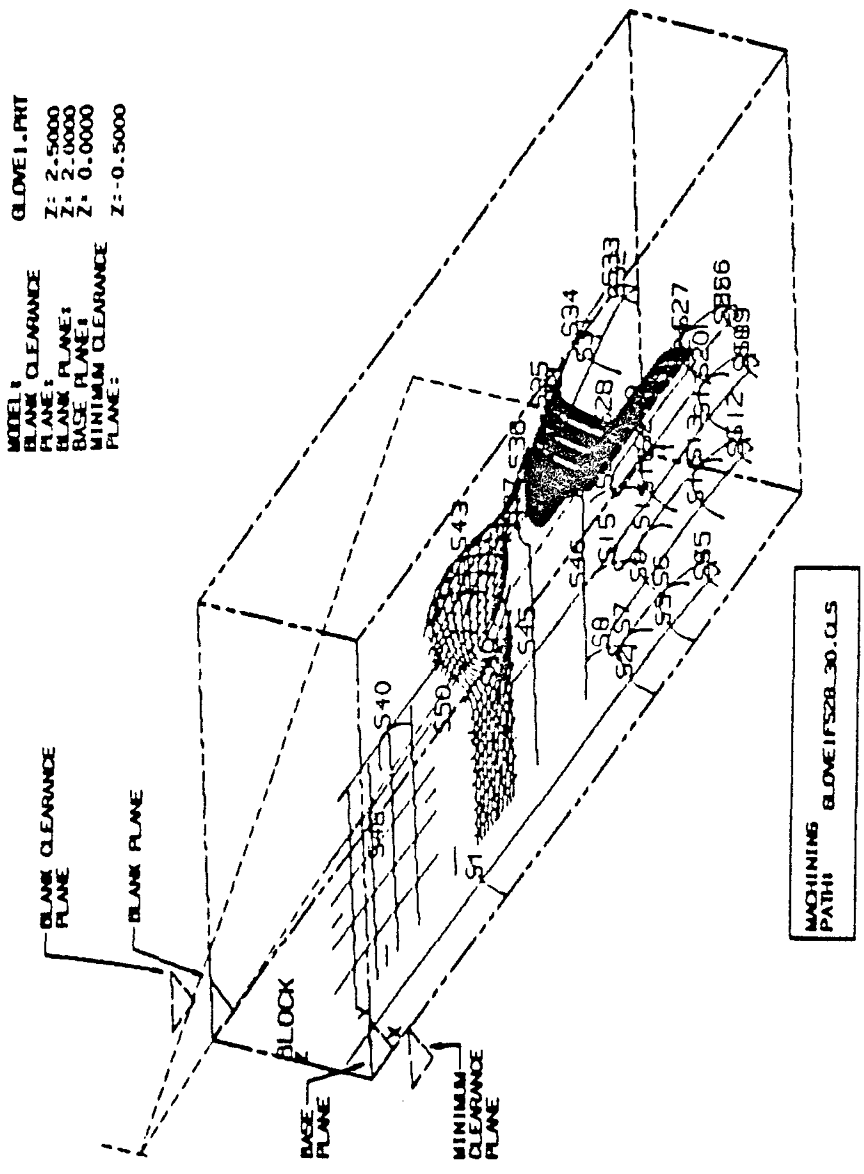

Figure 24: Machining Path: GLOVE1FS28_30.CLS

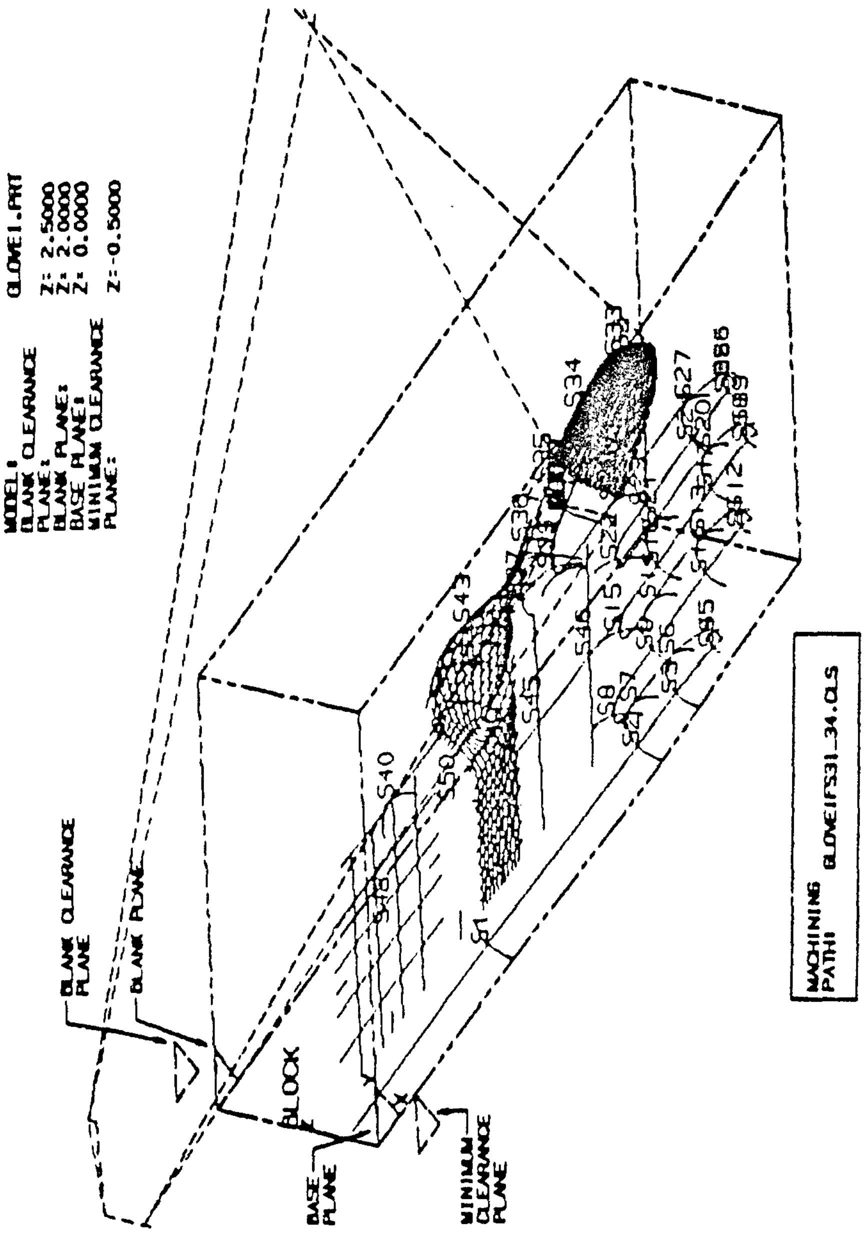

Figure 25: Machining Path: GLOVE1FS31_34.CLS

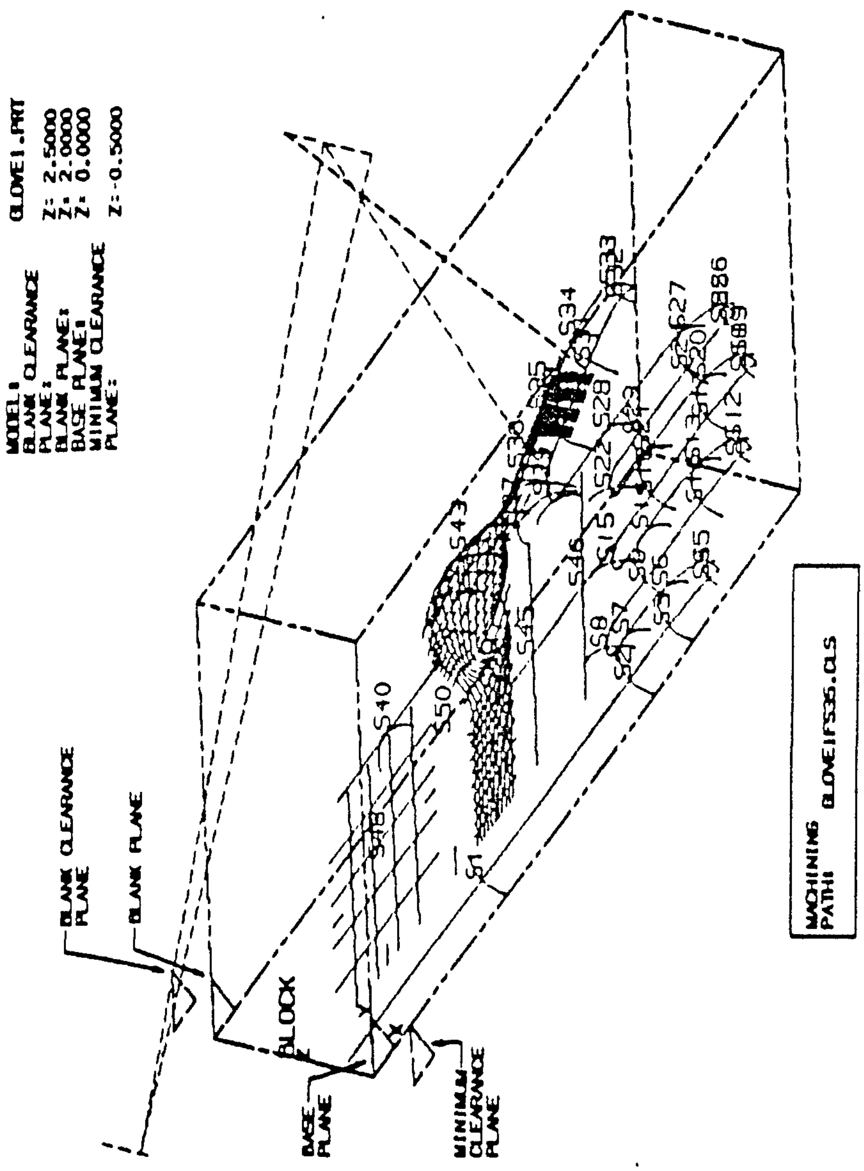

Figure 26: Machining Path: GLOVE1FS35.CLS

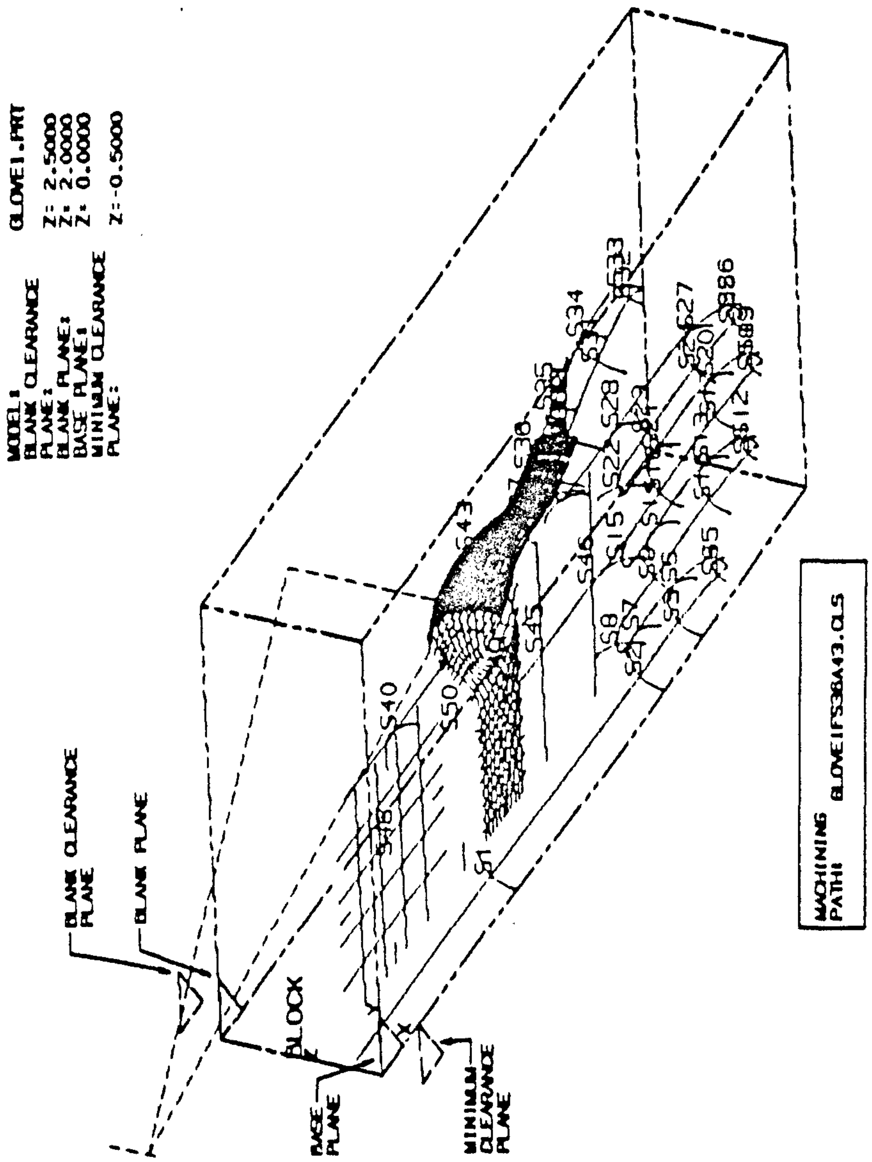

Figure 27: Machining Path: GLOVE1FS36A43.CLS

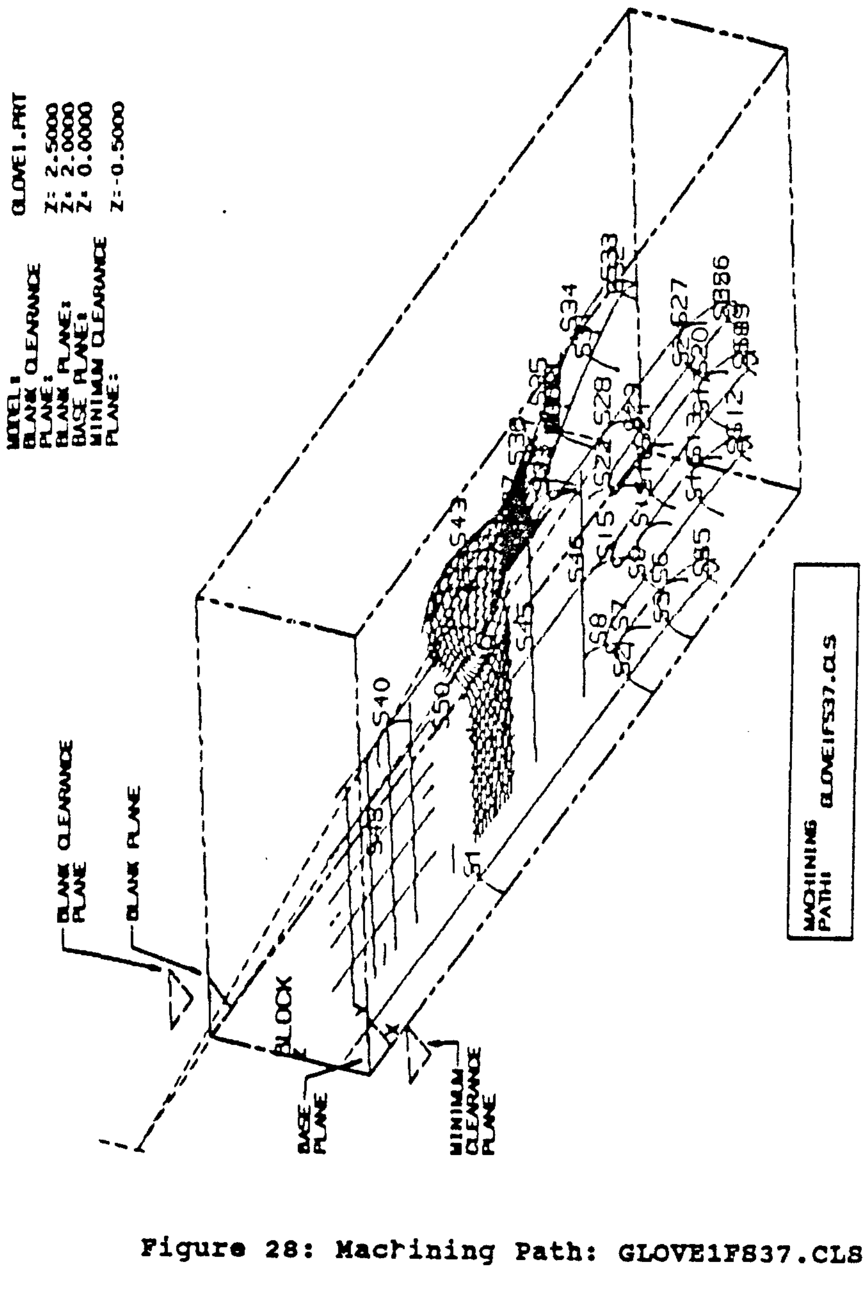

Figure 28: Machining Path: GLOVE1FS37.CLS

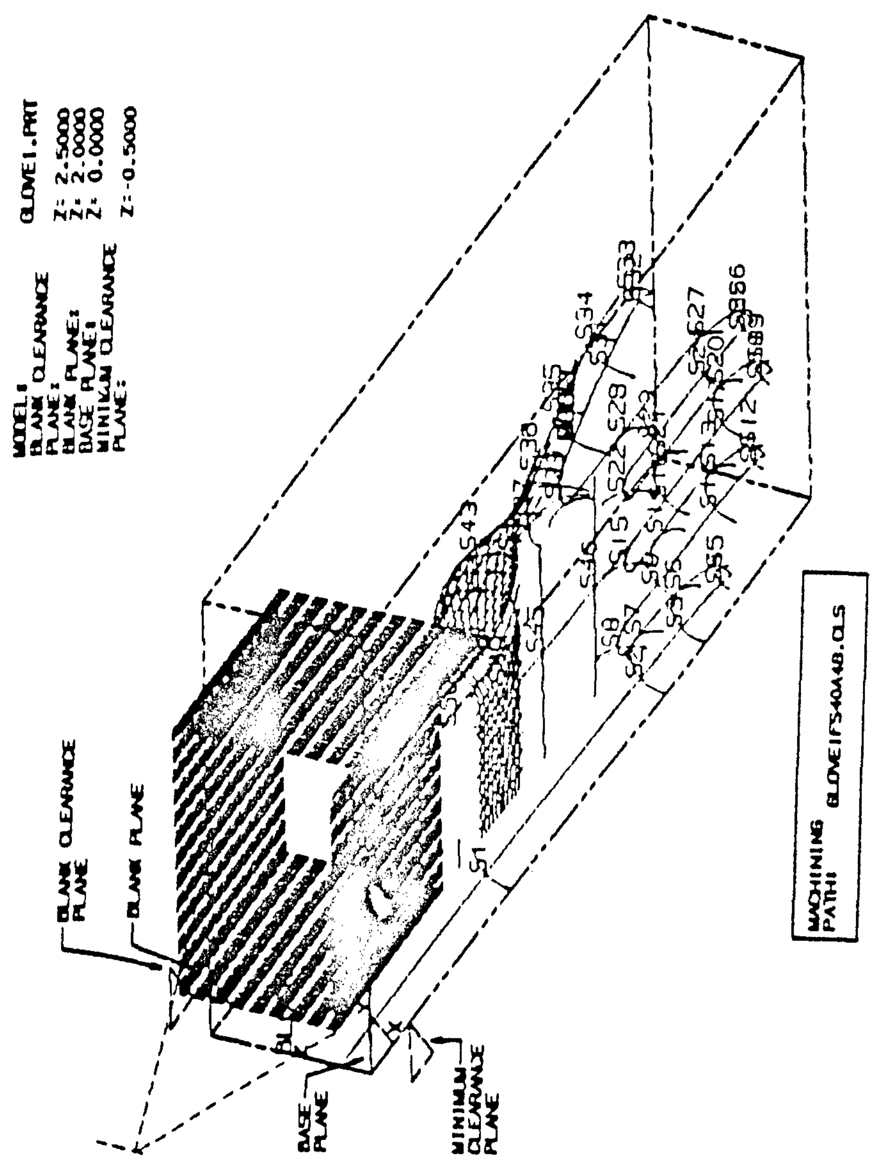

Figure 29: Machining Path: GLOVE1FS40A48.CLS

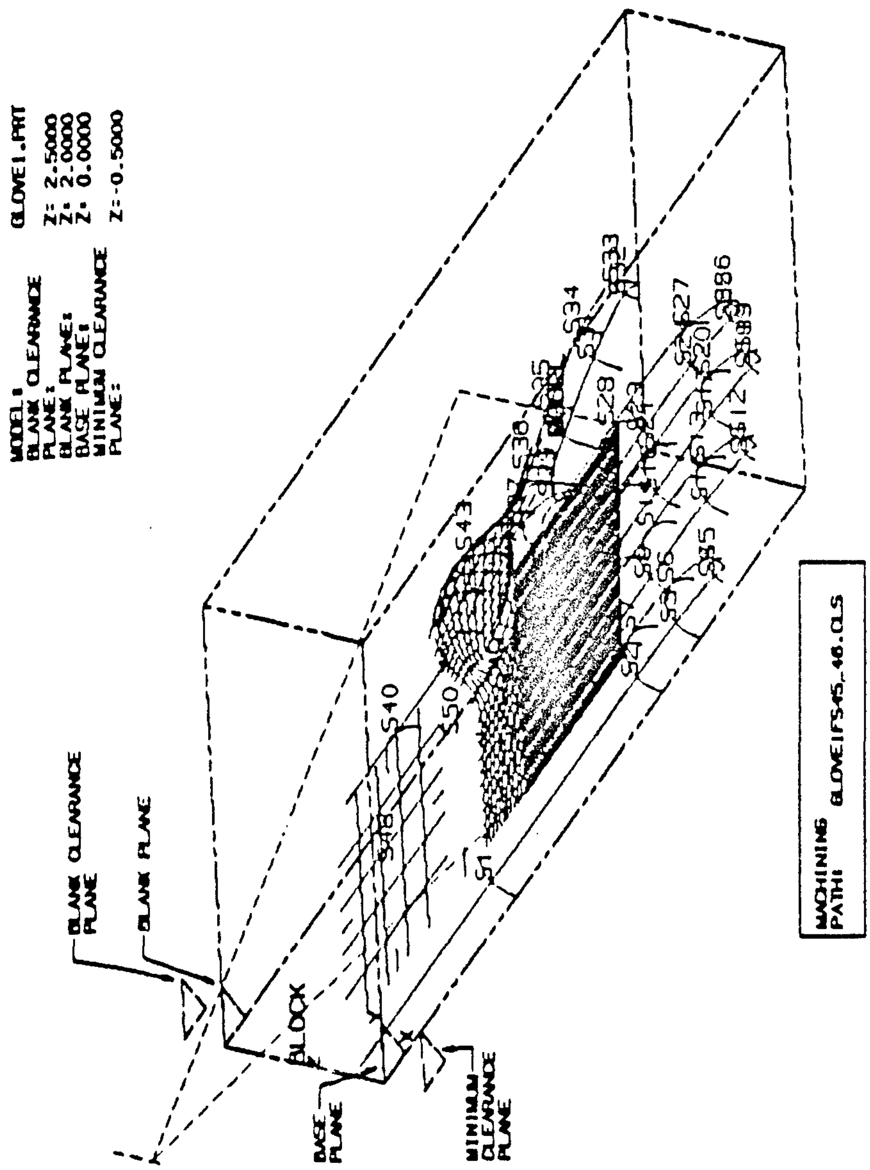

Figure 30: Machining Path: GLOVE1FS45_46.CLS

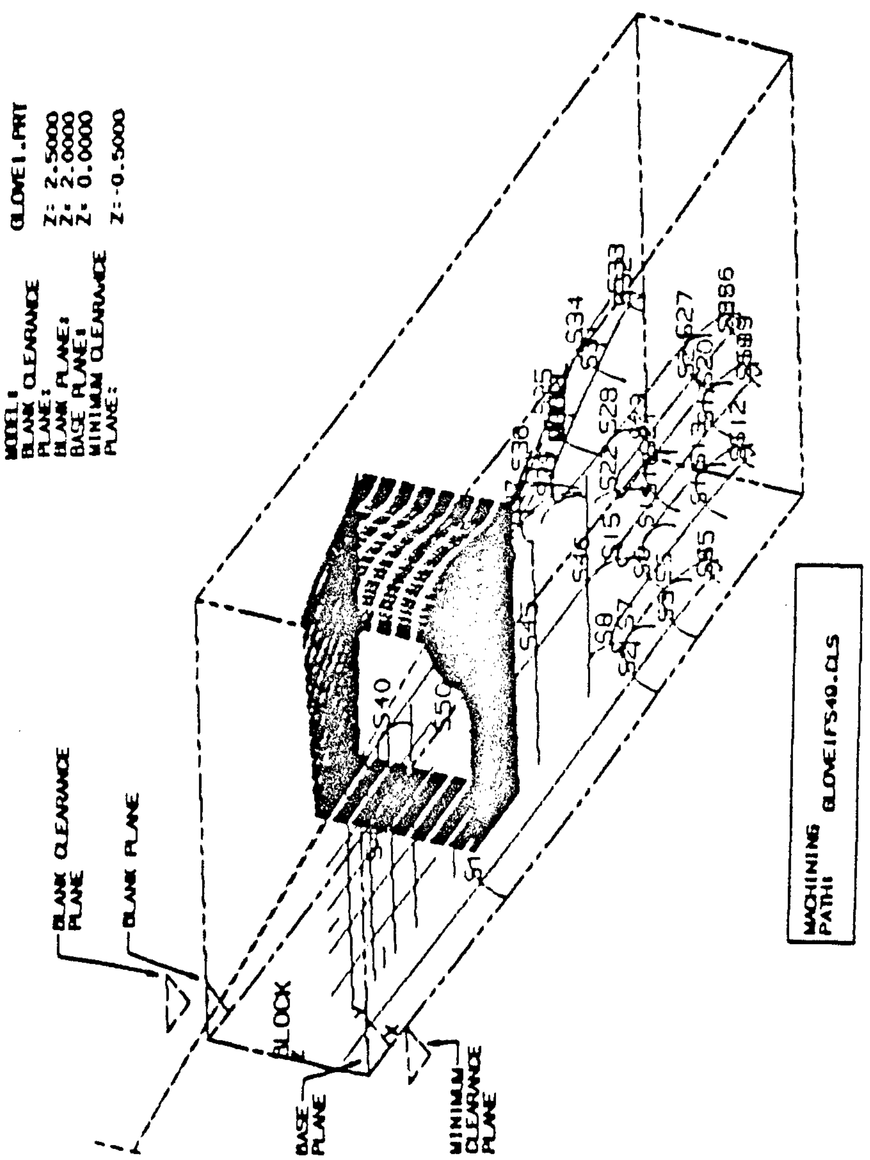

Figure 31: Machining Path: GLOVE1FS49.CLS

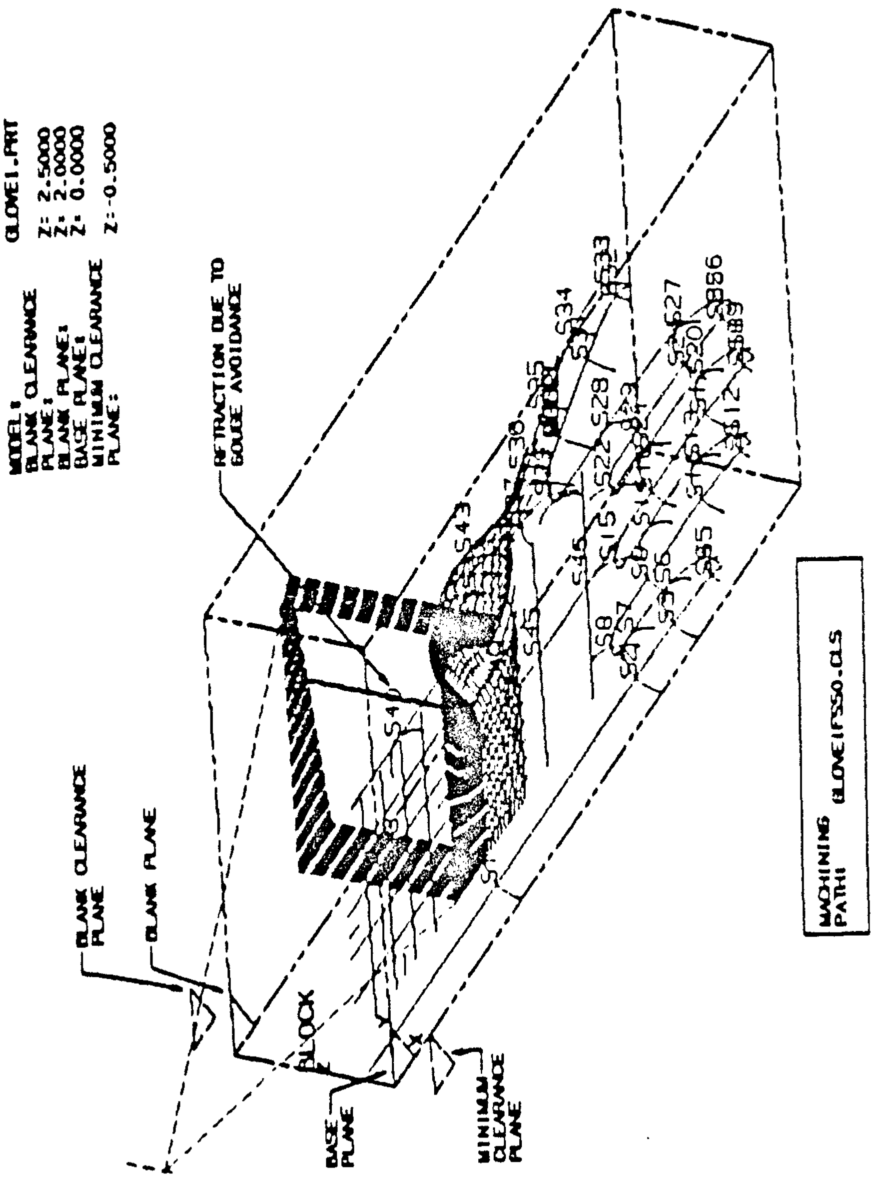

Figure 32: Machining Path: GLOVE1FS50.CLS

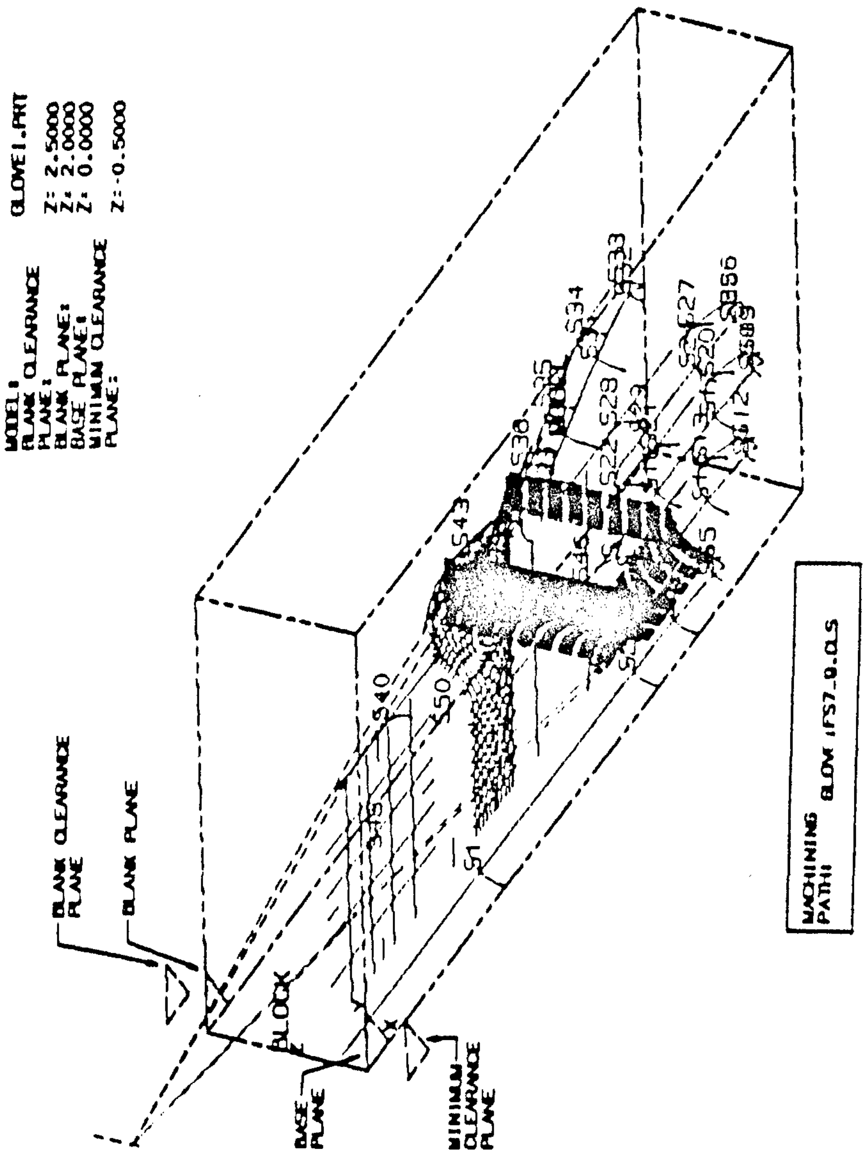

Figure 33: Machining Path: GLOVE1FS7_9.CLS

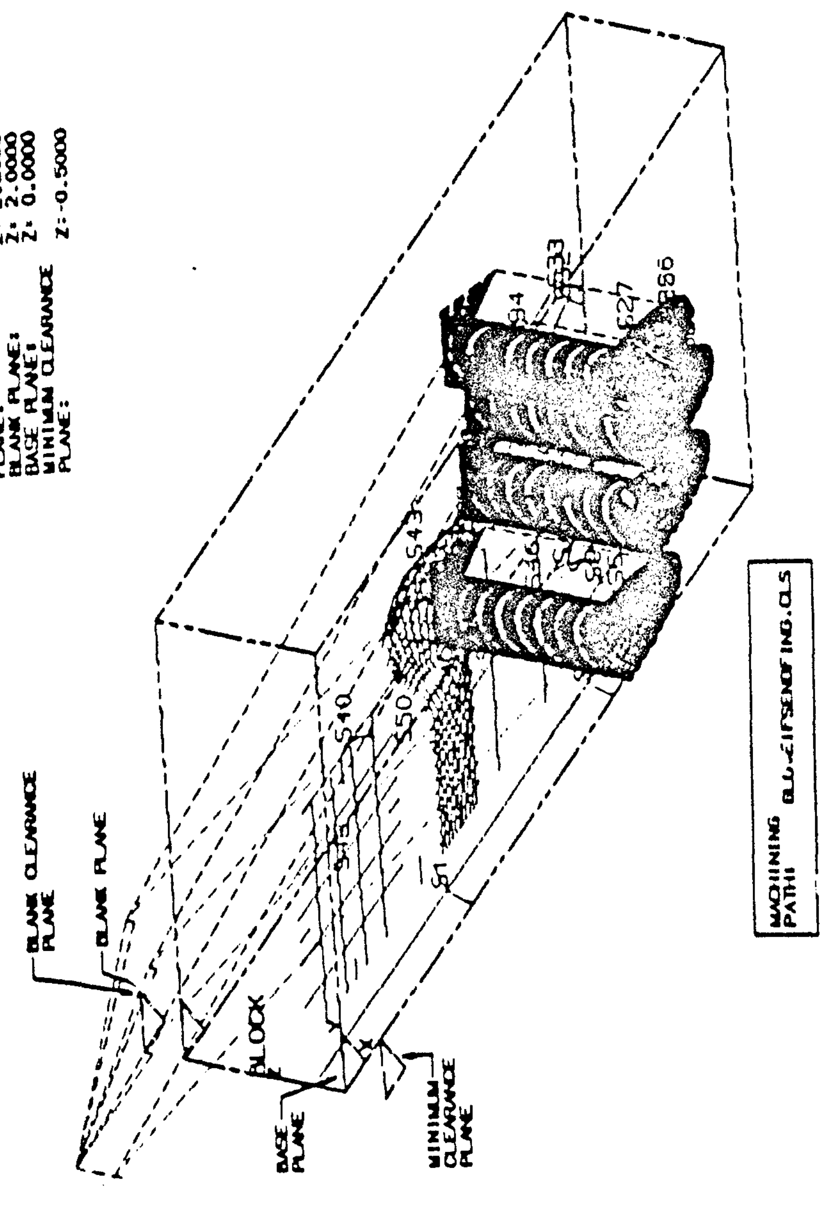

Figure 34: Machining Path: GLOVE1FSENDFING.CLS

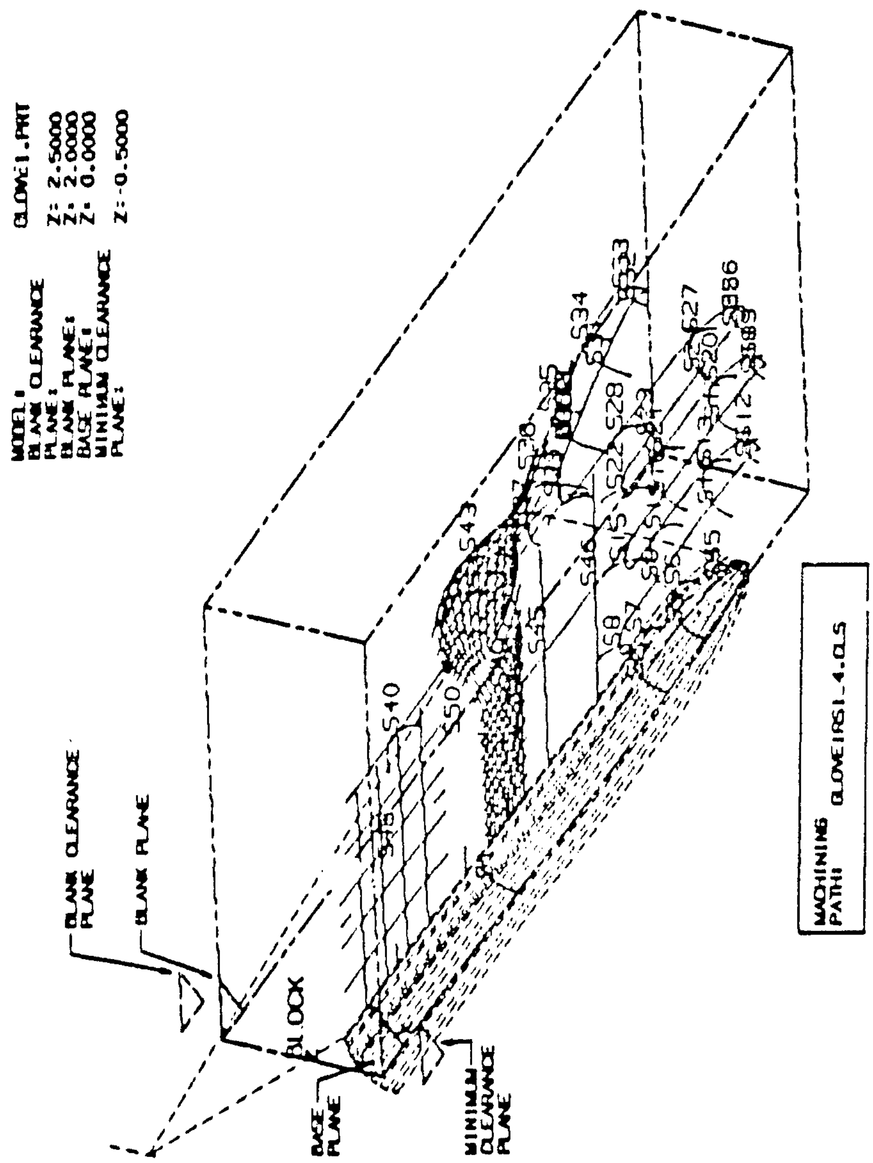

Figure 35: Machining Path: GLOVE1RS1_4.CLS

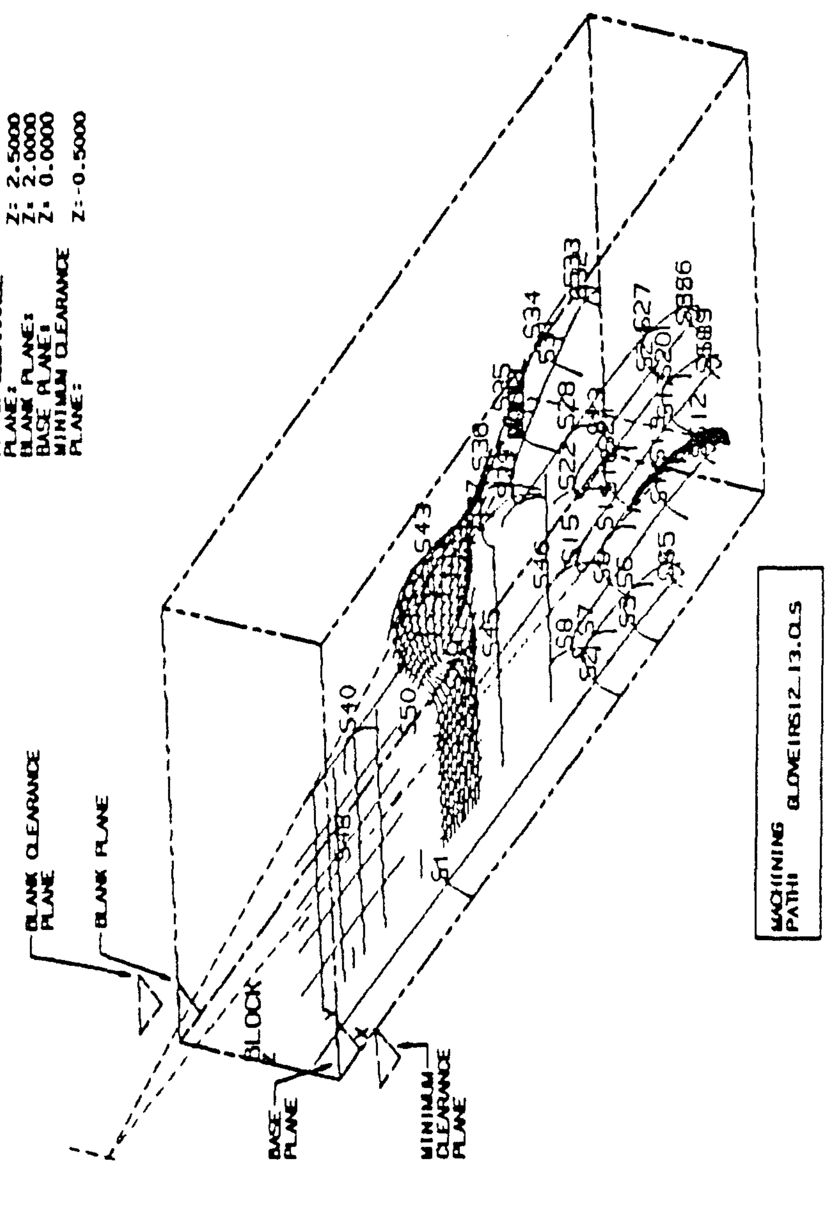

Figure 36: Machining Path: GLOVE1RS12_13.CLS

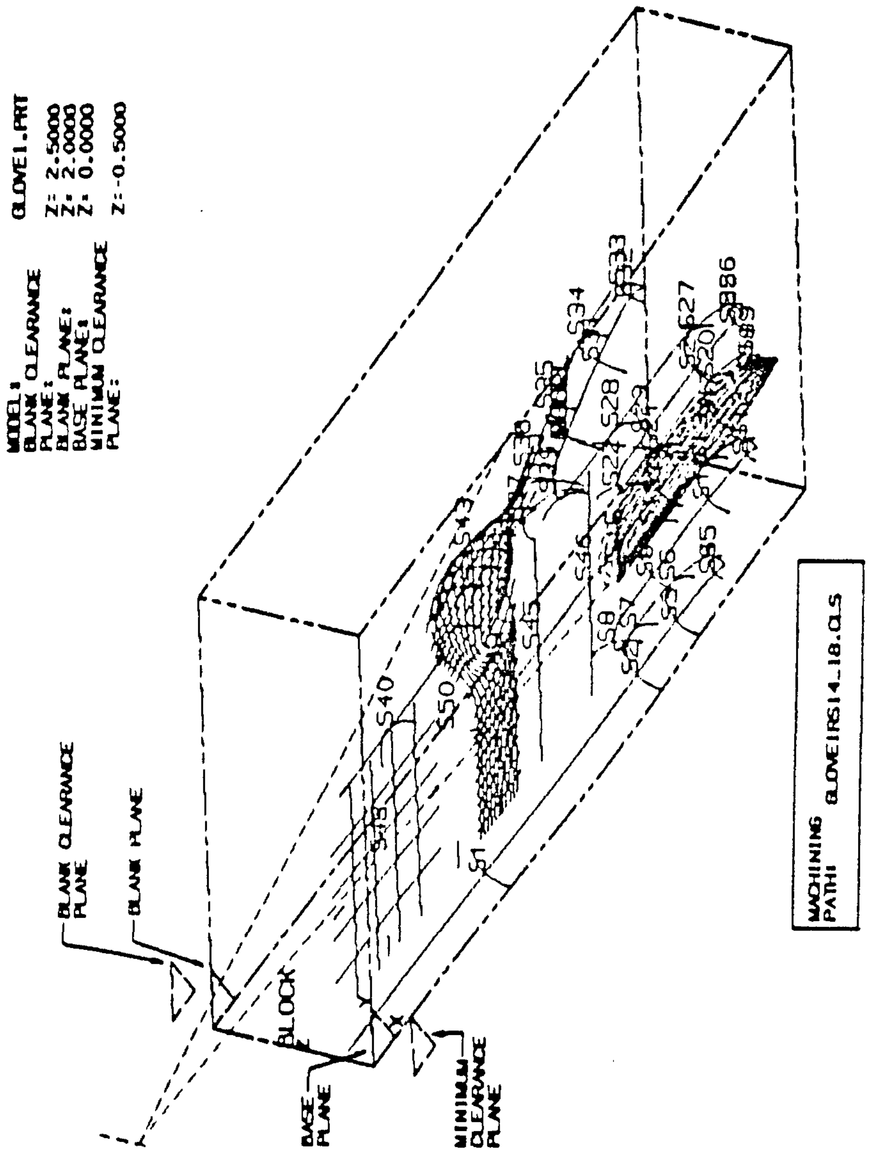

Figure 37: Machining Path: GLOVE1RS14_18.CLS

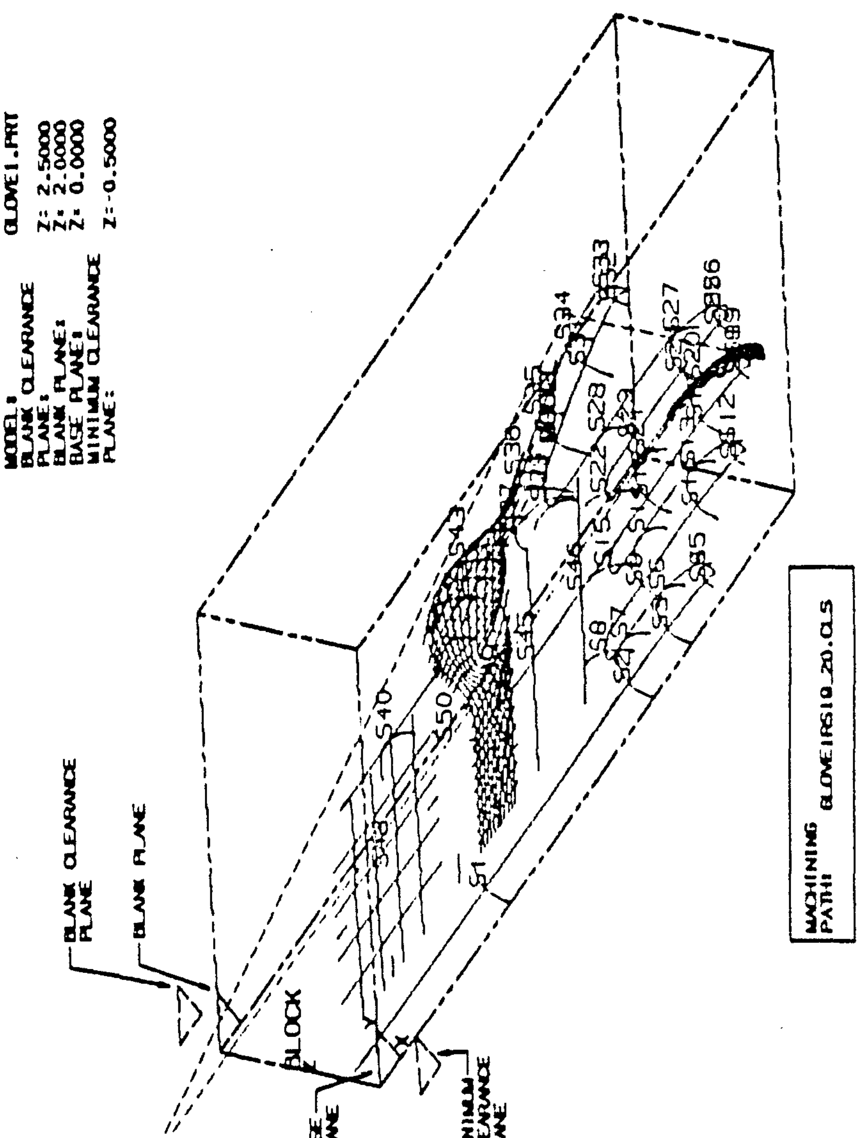

Figure 38: Machining Path: GLOVE1RS19_20.CLS

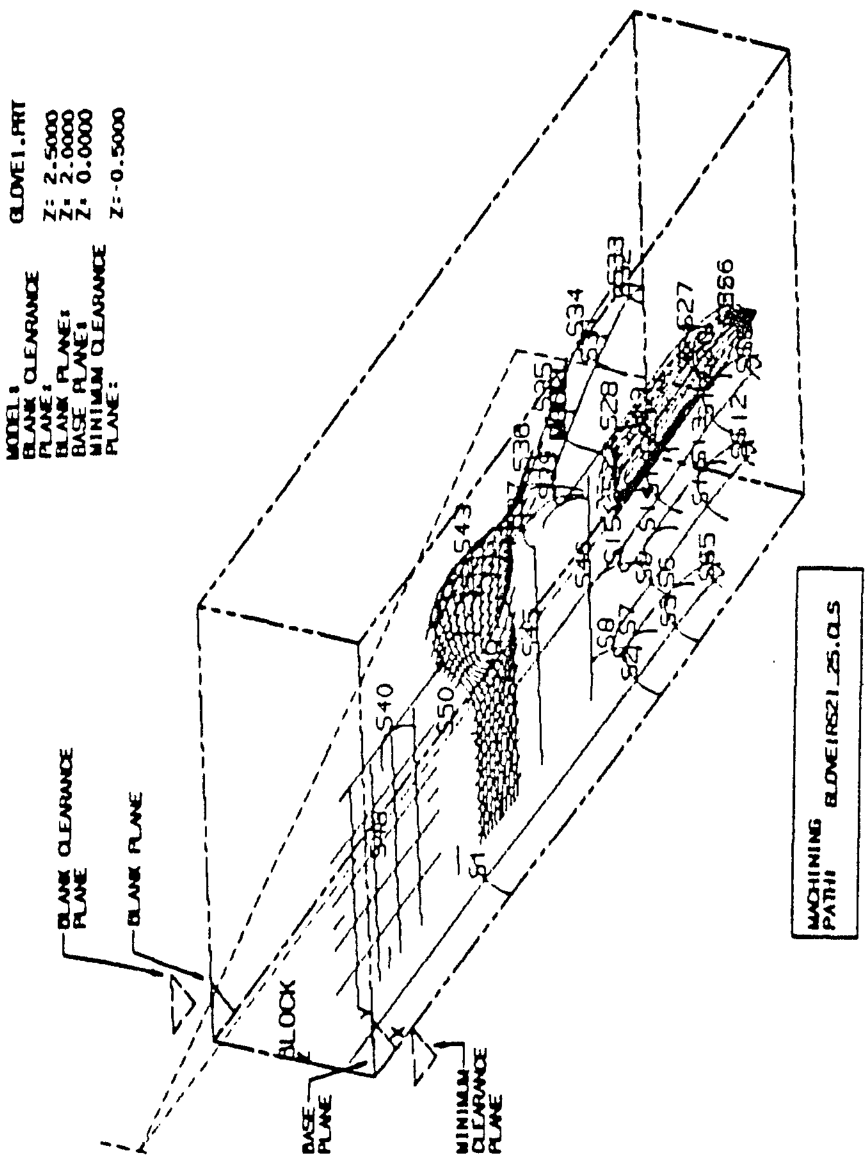

Figure 39: Machining Path: GLOVE1RS21_25.CLS

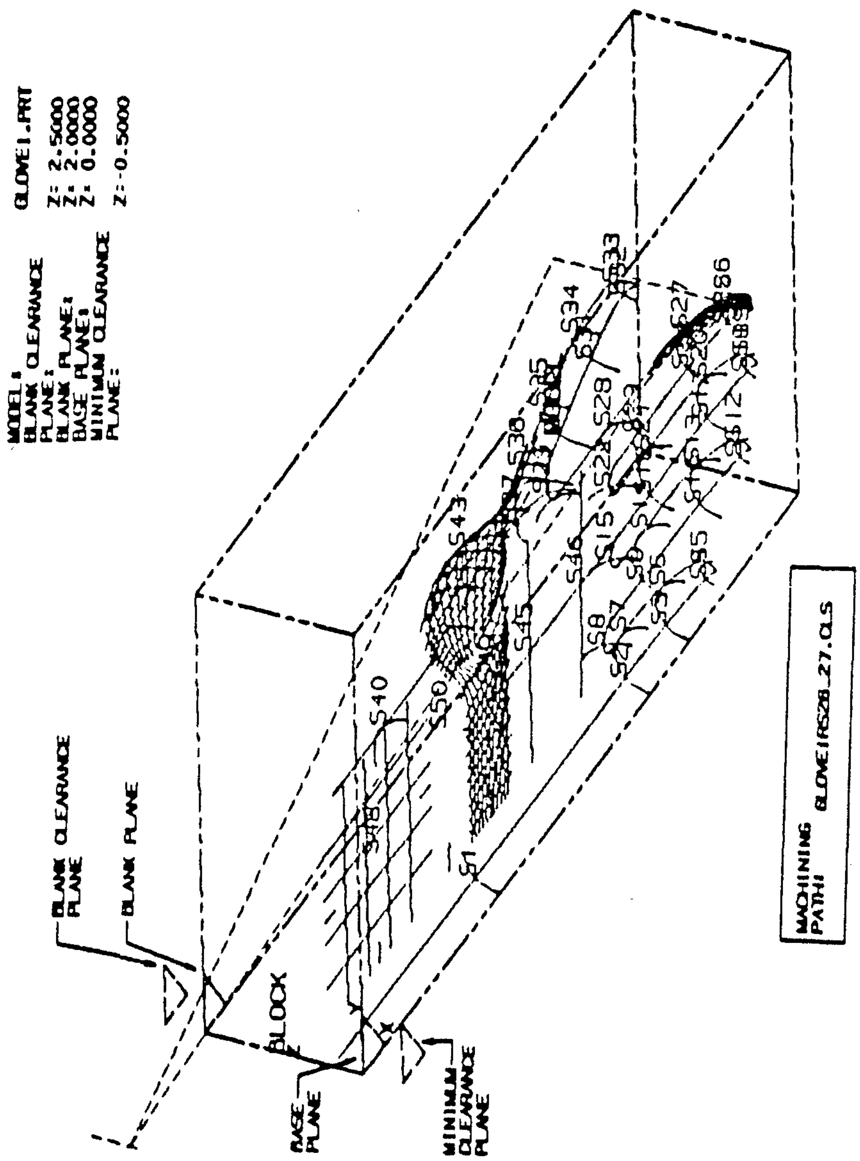

Figure 40: Machining Path: GLOVE1RS26_27.CLS

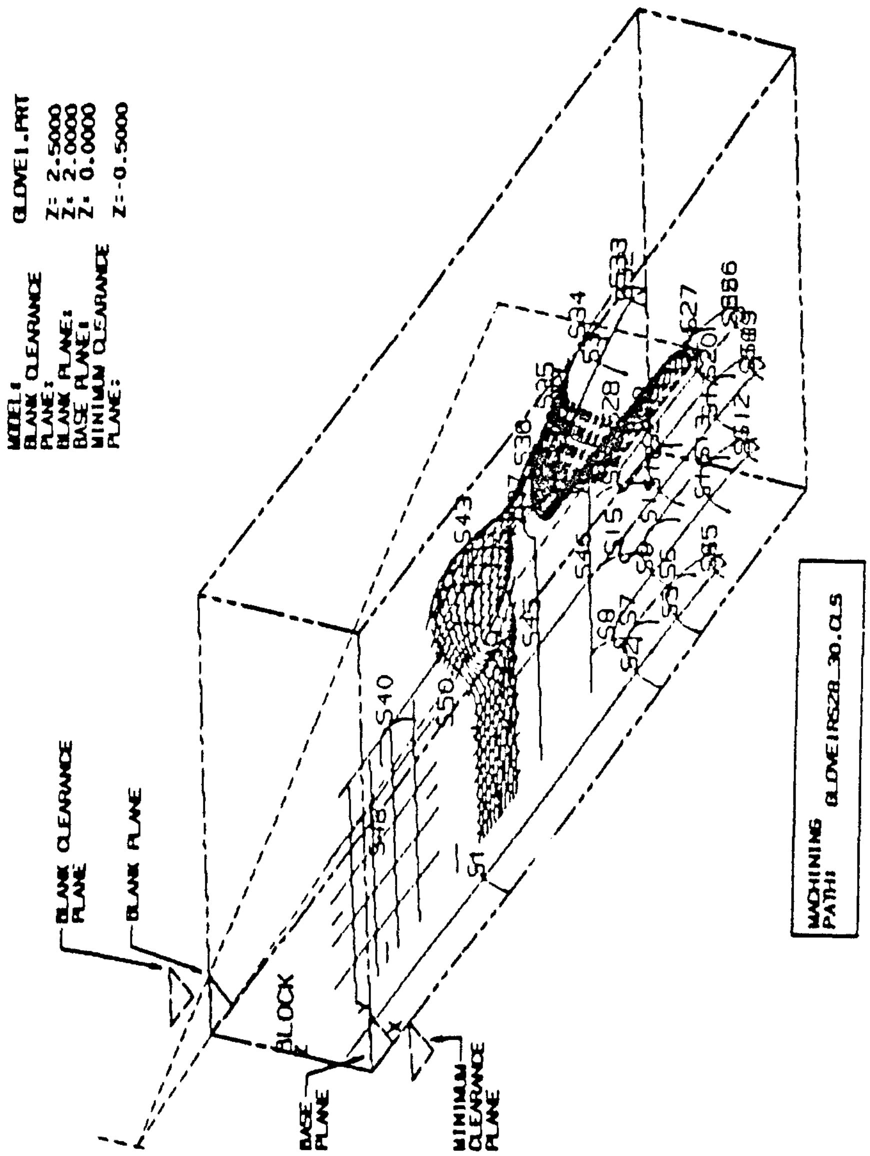

Figure 41: Machining Path: GLOVE1RS28_30.CLS

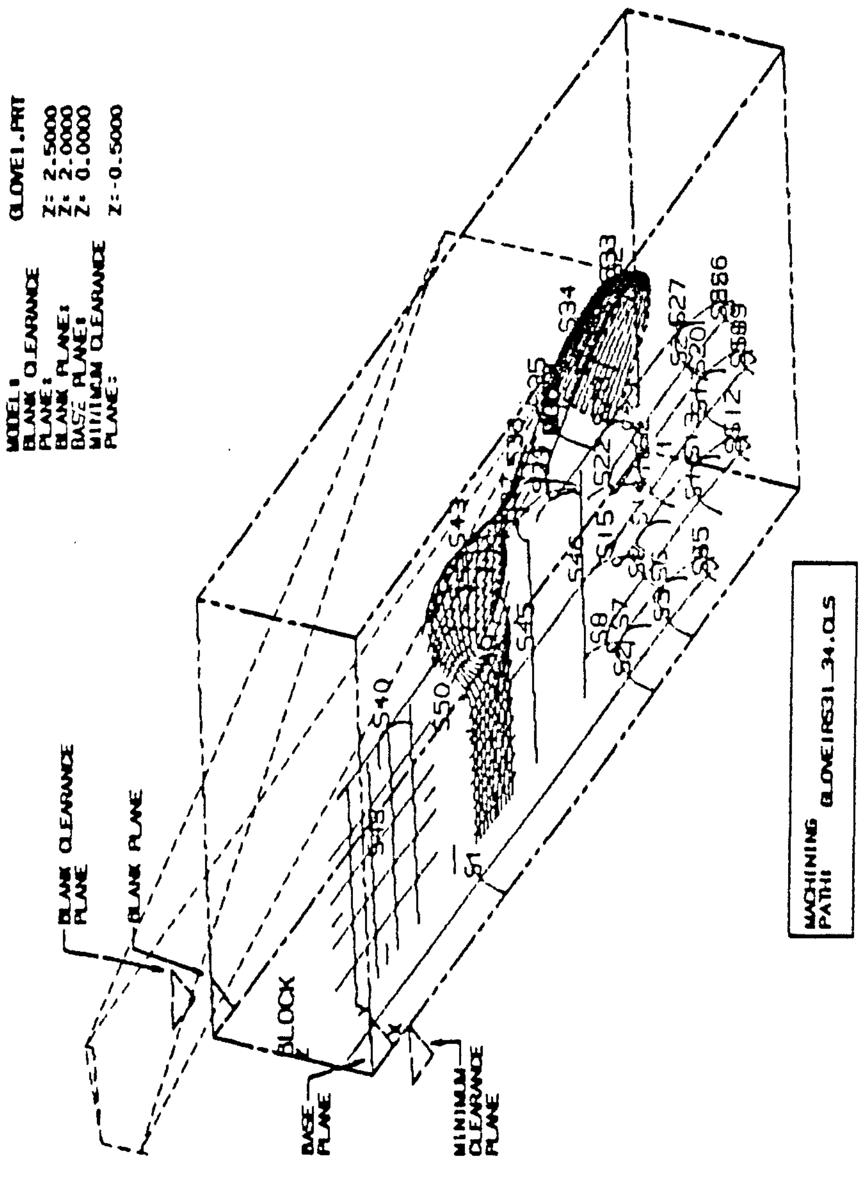

Figure 42: Machining Path: GLOVE1RS31_34.CLS

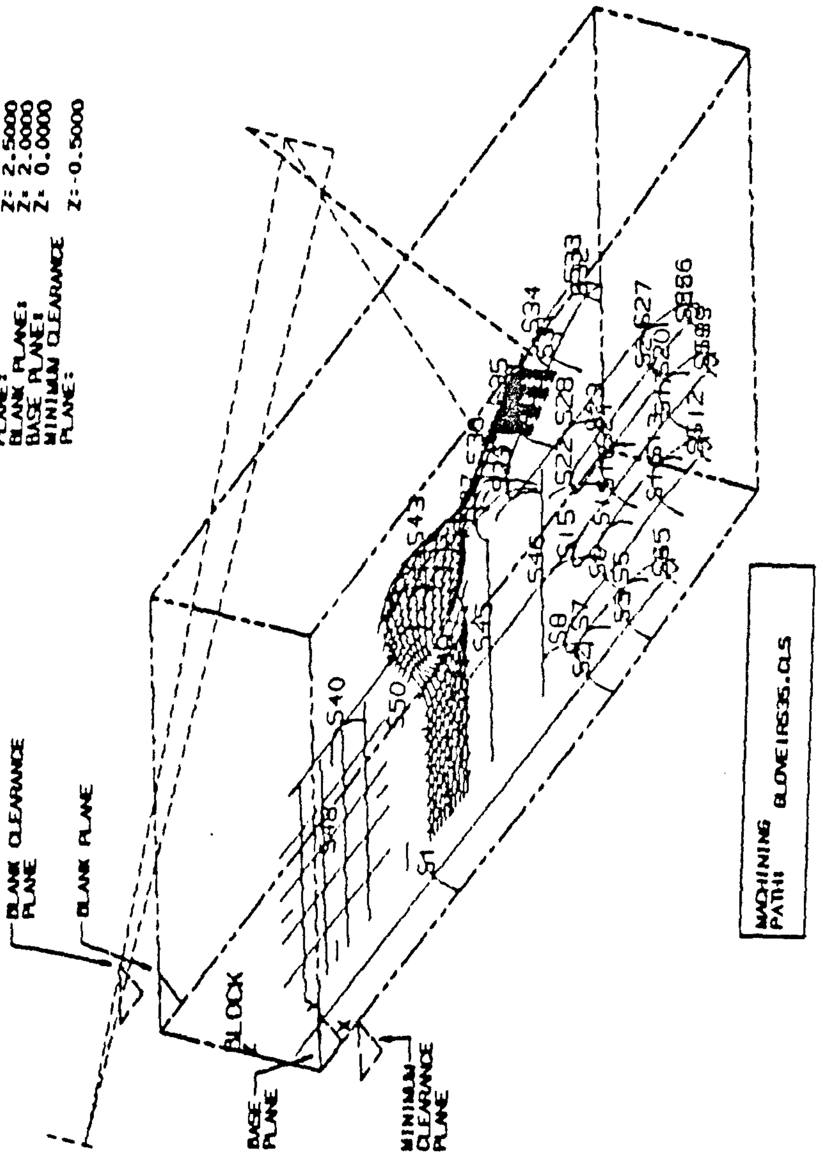

Figure 43: Machining Path: GLOVE1RS35.CLS

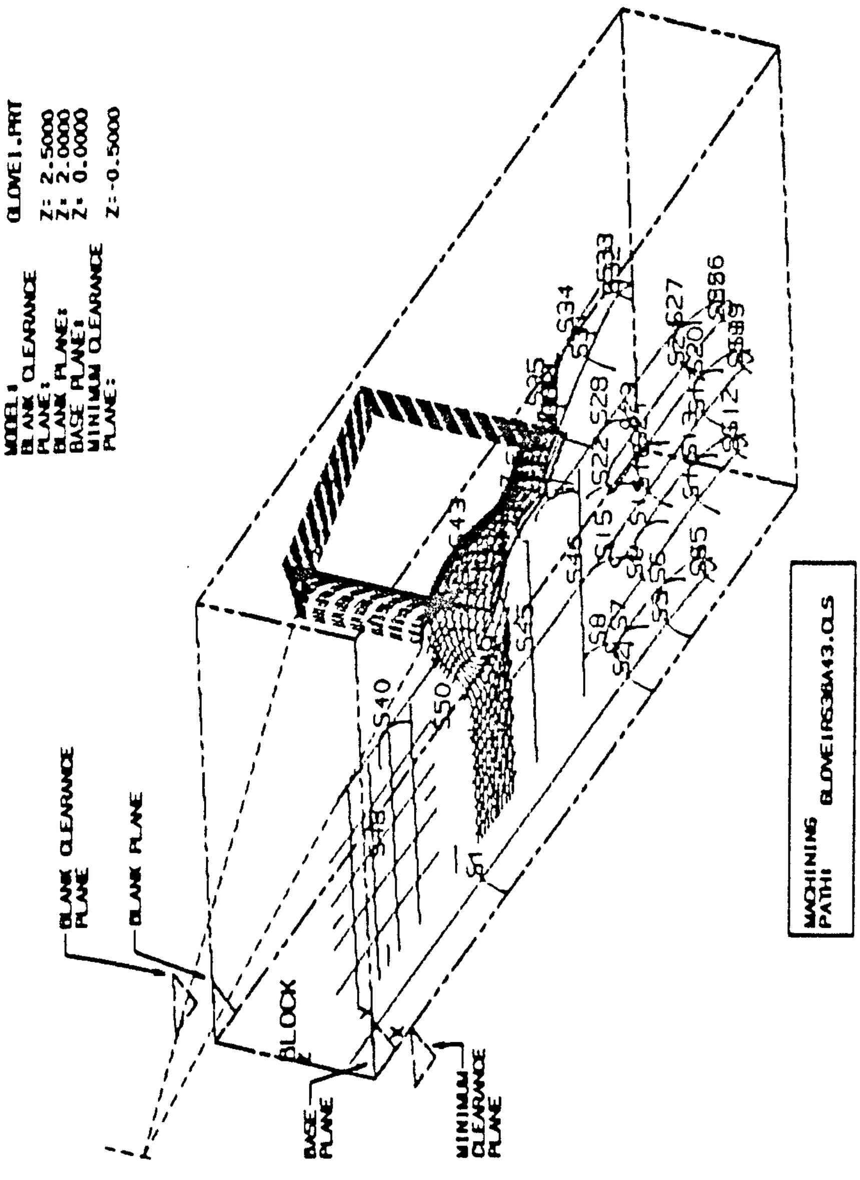

Figure 44: Machining Path: GLOVE1RS36A43.CLS

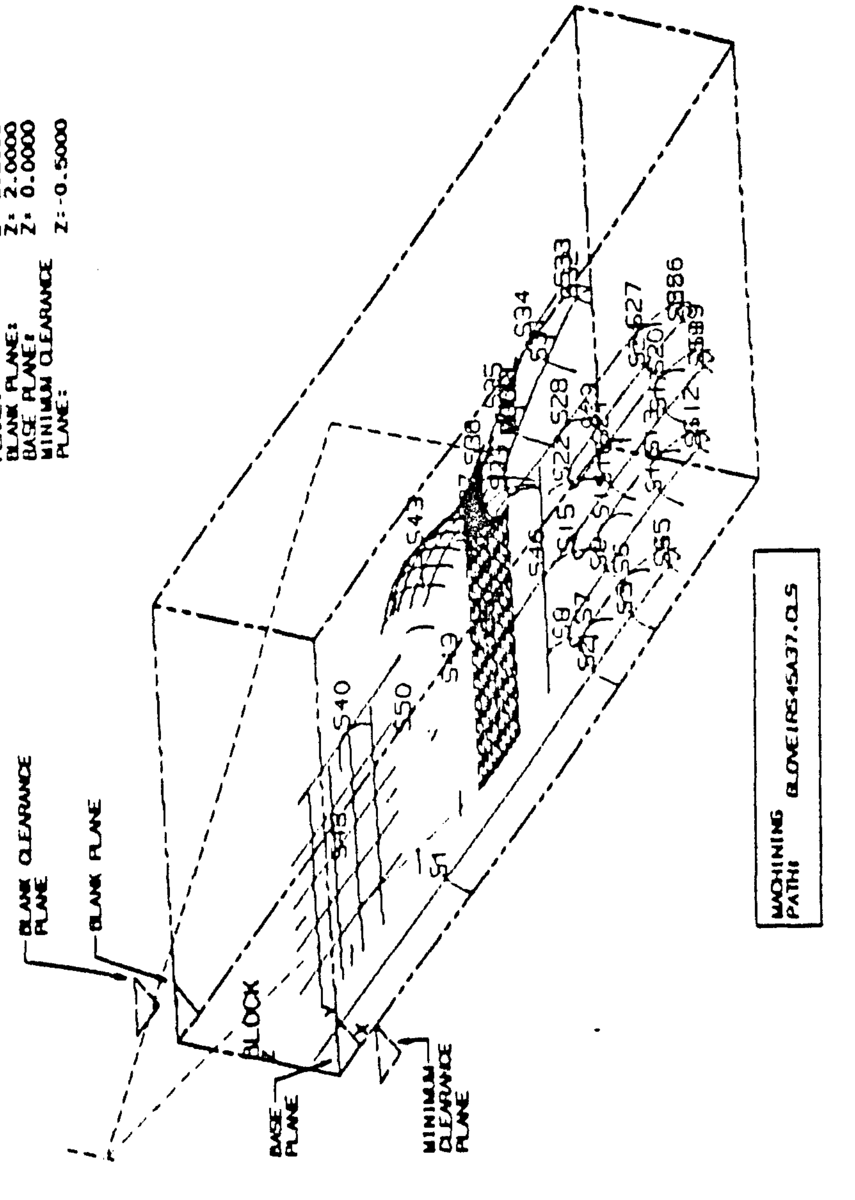

Figure 45: Machining Path: GLOVE1RS45A37.CLS

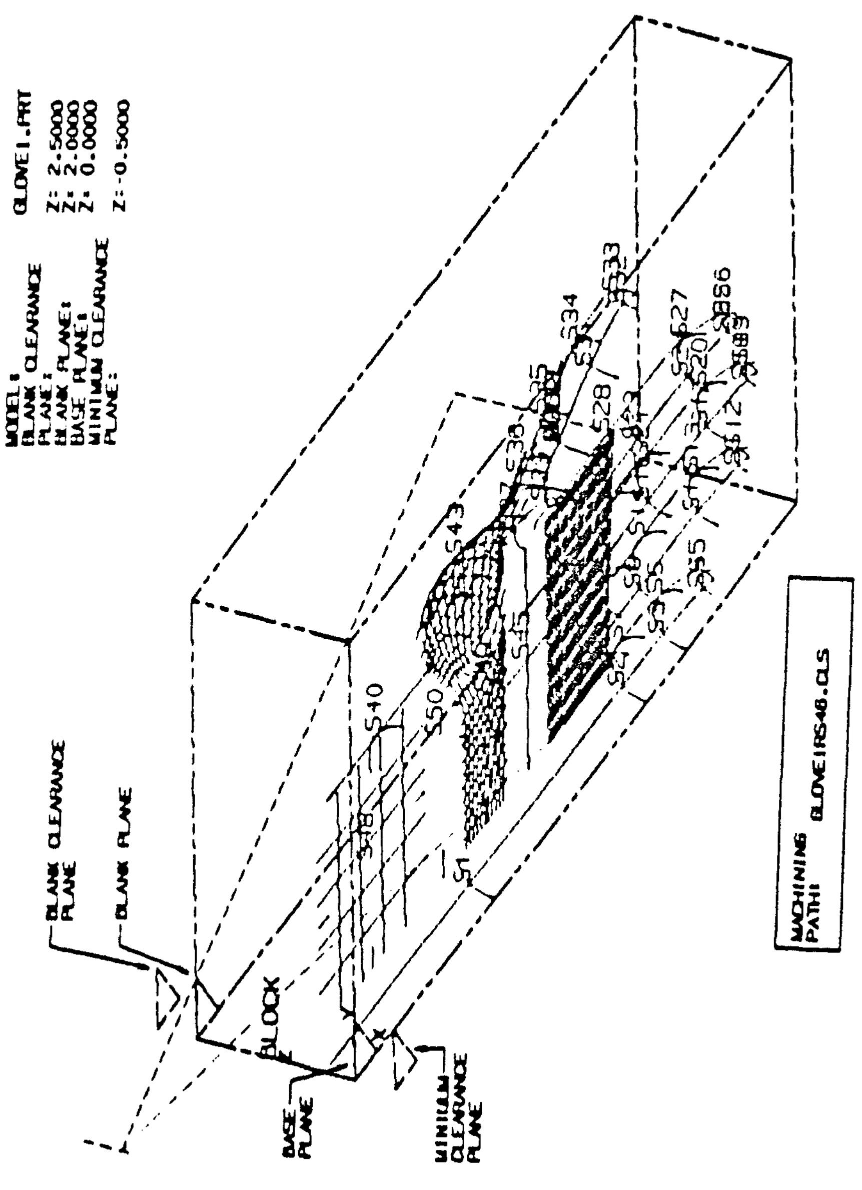

Figure 46: Machining Path: GLOVE1RS46.CLS

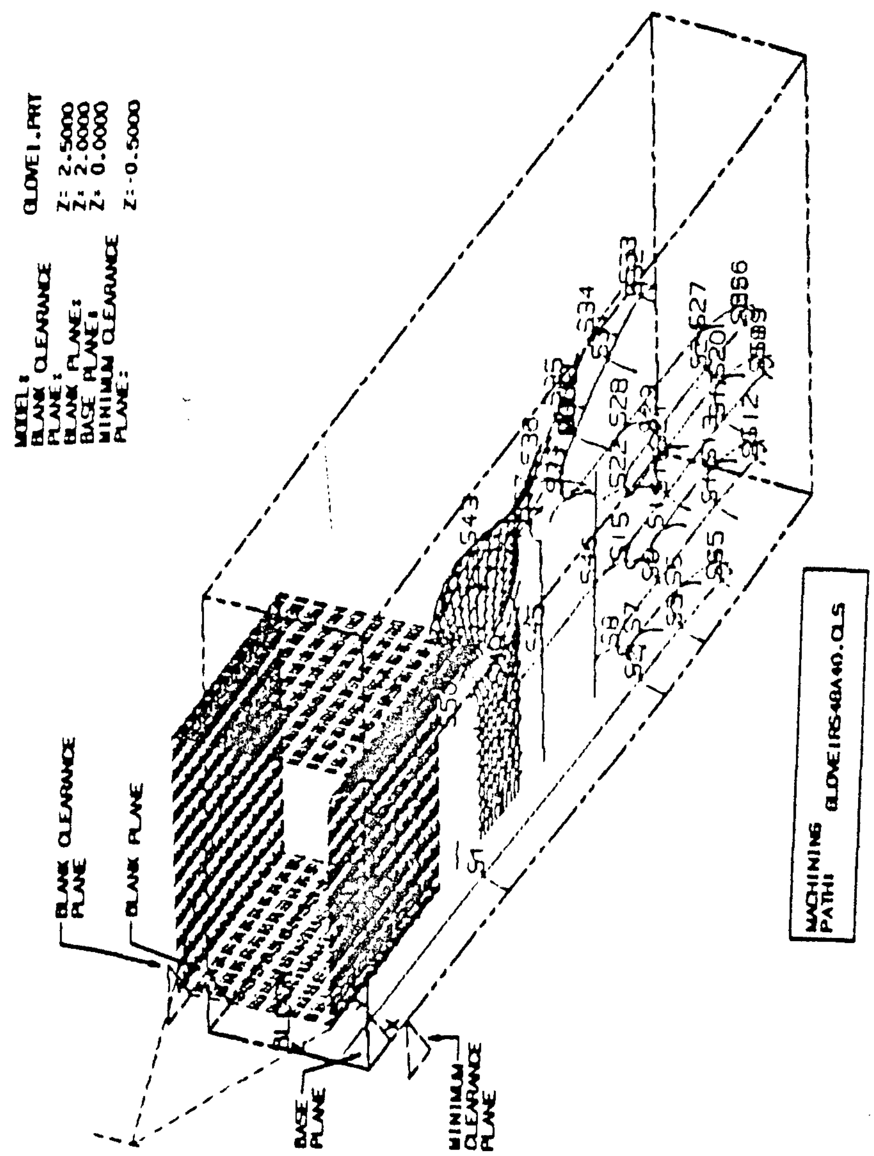

Figure 47: Machining Path: GLOVE1RS48A40.CLS

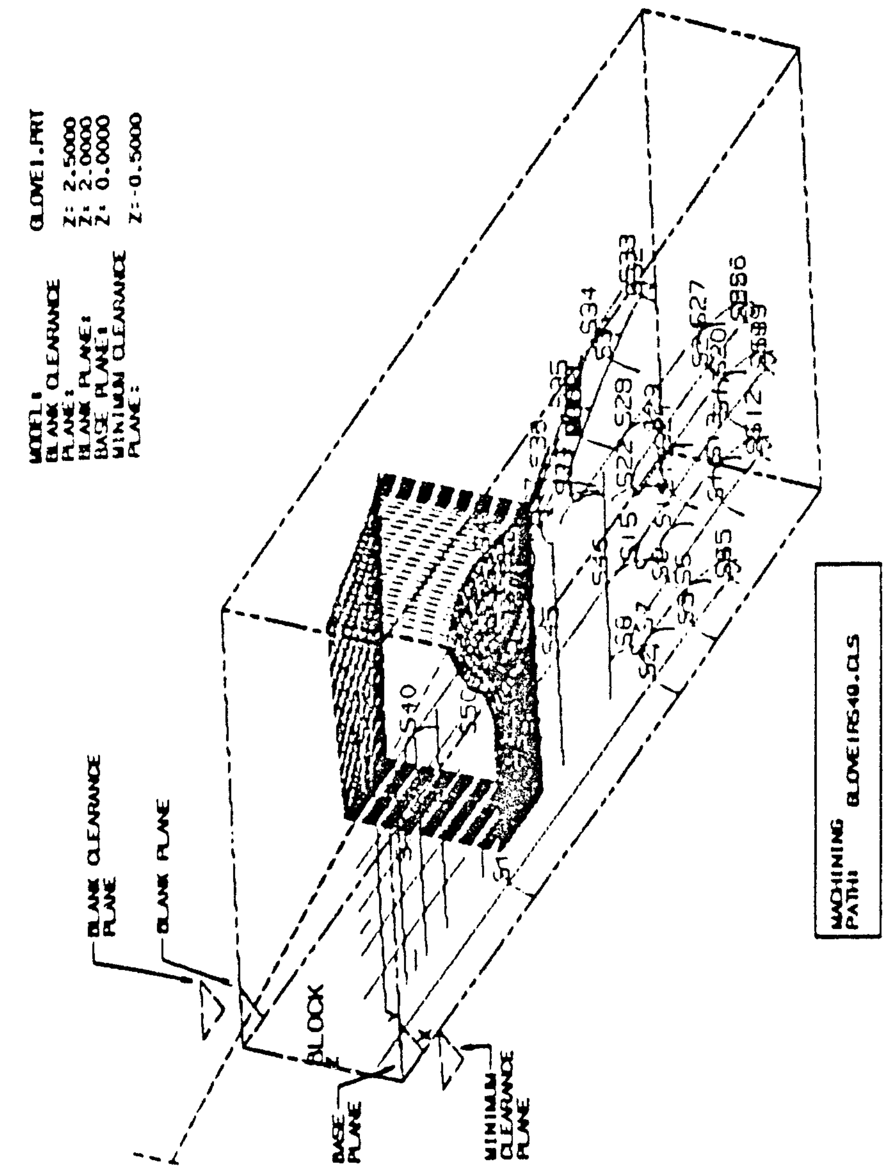

Figure 48: Machining Path: GLOVE1RS49.CLS

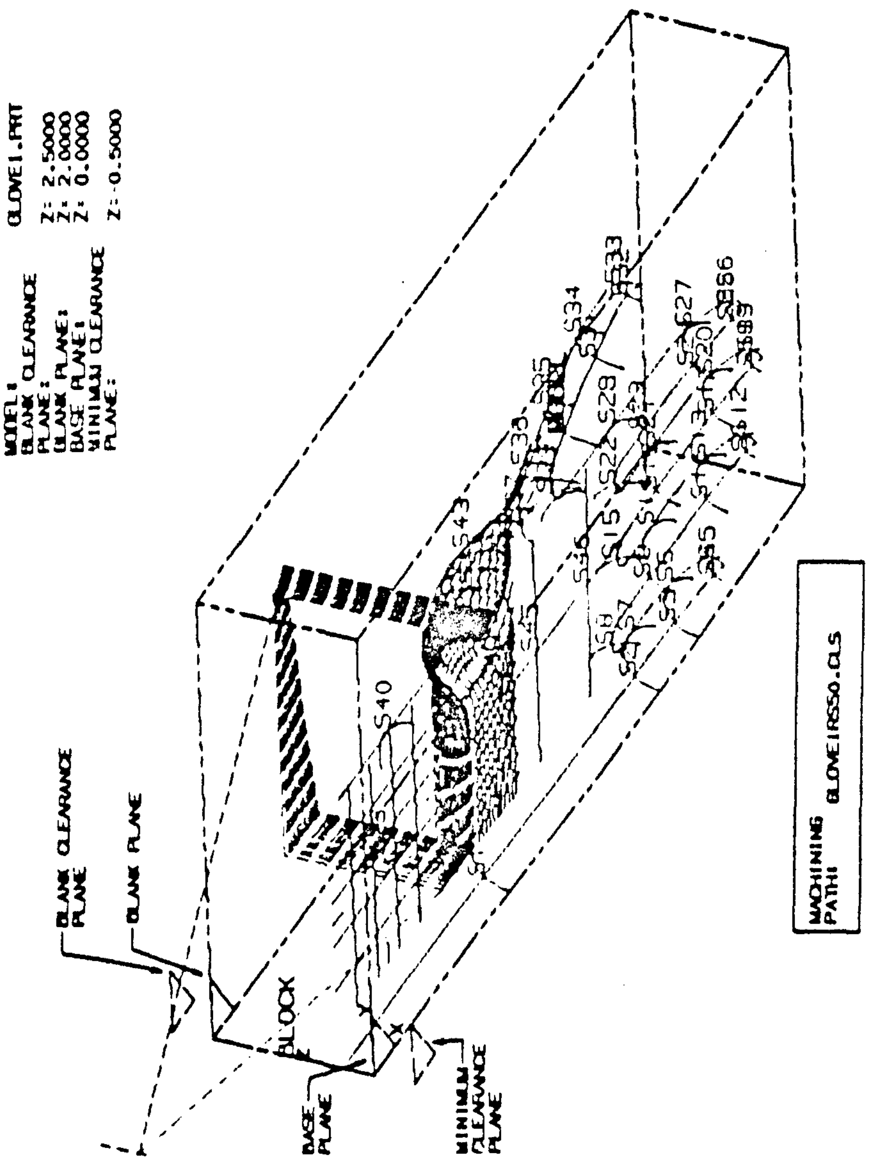

Figure 49: Machining Path: GLOVE1RS50.CLS

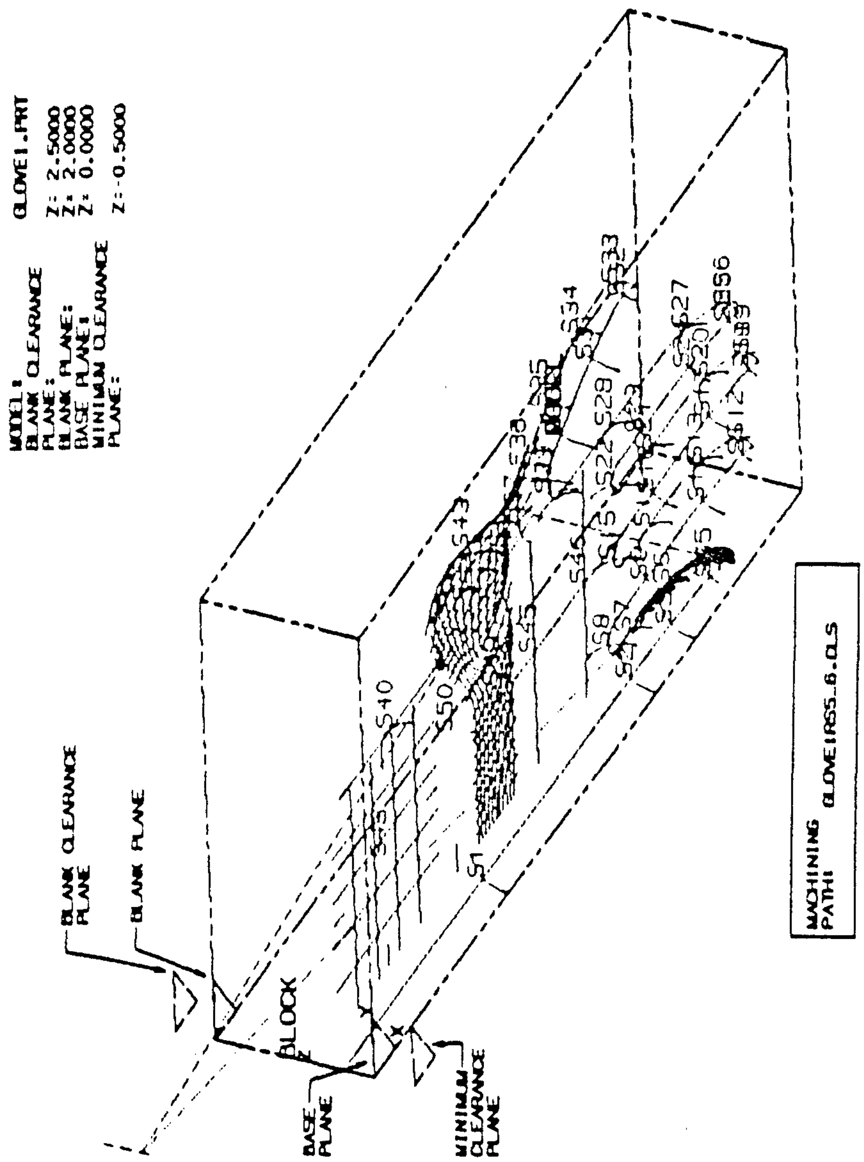

Figure 50: Machining Path: GLOVE1RS5_6.CLS

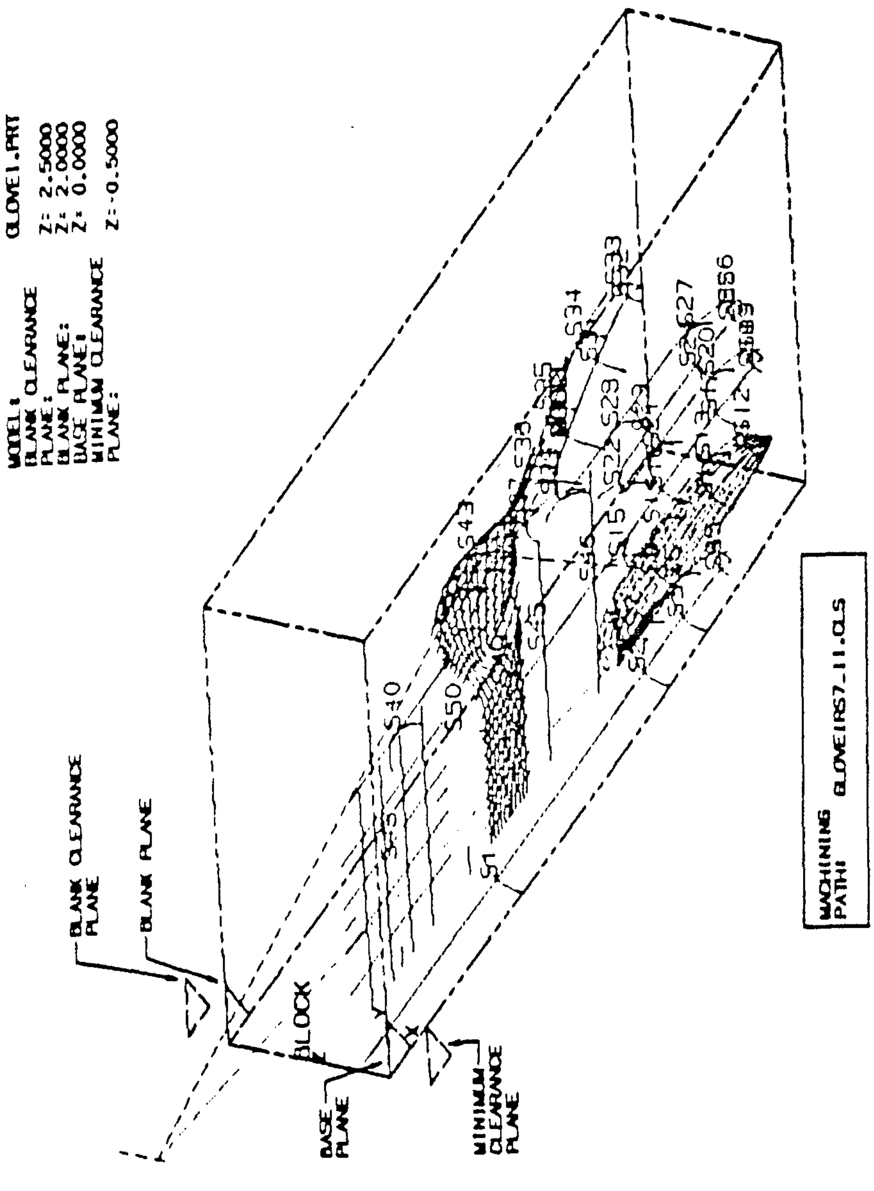

Figure 51: Machining Path: GLOVE1RS7_11.CLS

MACHINING FILES FOR THE PART: GLOVE1.PRT

FILENAME (UNIGRAPHICS)	LENGTH (BYTES)	DISKETTE FILENAME	VOLUME ID
GLOVE1FLRUF1.PTP	3982	001.TXT	111
GLOVE1FLRUF2.PTP	13654	002.TXT	111
GLOVE1FLRUF3.PTP	22594	003.TXT	111
GLOVE1FS14_16.PTP	8162	004.TXT	111
GLOVE1FS1_2.PTP	3482	005.TXT	111
GLOVE1FS21_23.PTP	8162	006.TXT	111
GLOVE1FS28_30.PTP	30676	007.TXT	111
GLOVE1FS31_34.PTP	37558	008.TXT	111
GLOVE1FS35.PTP	5062	009.TXT	111
GLOVE1FS36A43.PTP	28774	010.TXT	111
GLOVE1FS37.PTP	9070	011.TXT	111
GLOVE1FS40A48.PTP	17778	012.TXT	111
GLOVE1FS45_46.PTP	8980	013.TXT	111
GLOVE1FS49.PTP	57202	014.TXT	111
GLOVE1FS50.PTP	53216	015.TXT	111
GLOVE1FS7_9.PTP	8162	016.TXT	111
GLOVE1FSENDFING.PTP	188716	017.TXT	112
GLOVE1RS12_13.PTP	8990	018.TXT	112
GLOVE1RS14_18.PTP	10580	019.TXT	112
GLOVE1RS19_20.PTP	9422	020.TXT	112
GLOVE1RS1_4.PTP	9184	021.TXT	112
GLOVE1RS21_25.PTP	10490	022.TXT	112
GLOVE1RS26_27.PTP	9208	023.TXT	112
GLOVE1RS28_30.PTP	11810	024.TXT	112
GLOVE1RS31_34.PTP	21222	025.TXT	112
GLOVE1RS35.PTP	3982	026.TXT	112
GLOVE1RS36A43.PTP	12908	027.TXT	112
GLOVE1RS45A37.PTP	9878	028.TXT	112
GLOVE1RS46.PTP	4934	029.TXT	112
GLOVE1RS48A40.PTP	9358	030.TXT	112
GLOVE1RS49.PTP	24680	031.TXT	112
GLOVE1RS50.PTP	16462	032.TXT	112
GLOVE1RS5_6.PTP	8682	033.TXT	112
GLOVE1PS7_11.PTP	10610	034.TXT	112
	697630	= TOTAL BYTES	

Figure 52: Machining Files: GLOVE1.PRT

MACHINING FILES FOR THE PART: GLOVE3.PRT

FILENAME (UGII)	LENGTH (BYTES)	DISKETTE FILENAME	VOLUME ID
GLOVE1FLRUF1.PTP	3982	001.TXT	113
GLOVE1FLRUF2.PTP	13654	002.TXT	113
GLOVE3FRPERIM3.PTP	28184	003.TXT	113*
GLOVE1FS14_16.PTP	8162	004.TXT	113
GLOVE1FS1_2.PTP	3482	005.TXT	113
GLOVE1FS21_23.PTP	8162	006.TXT	113
GLOVE3FS51_32.PTP	28406	007.TXT	113*
GLOVE3FS52_33.PTP	28120	008.TXT	113*
GLOVE1FS35.PTP	5062	009.TXT	113
GLOVE1FS36A43.PTP	28774	010.TXT	113
GLOVE1FS37.PTP	9070	011.TXT	113
GLOVE1FS40A48.PTP	17778	012.TXT	113
GLOVE1FS45_46.PTP	8980	013.TXT	113
GLOVE1FS49.PTP	57202	014.TXT	113
GLOVE1FS50.PTP	53216	015.TXT	113
GLOVE1FS7_9.PTP	8162	016.TXT	113
GLOVE1FSENDFING.PTP	188716	017.TXT	114
GLOVE1RS12_13.PTP	8990	018.TXT	114
GLOVE1RS14_18.PTP	10580	019.TXT	114
GLOVE1RS19_20.PTP	9422	020.TXT	114
GLOVE1RS1_4.PTP	9184	021.TXT	114
GLOVE1RS21_25.PTP	10490	022.TXT	114
GLOVE1RS26_27.PTP	9208	023.TXT	114
GLOVE3RS51_32.PTP	11586	024.TXT	114*
GLOVE3RS52_33.PTP	12016	025.TXT	114*
GLOVE1RS35.PTP	3982	026.TXT	114
GLOVE1RS36A43.PTP	12908	027.TXT	114
GLOVE1RS45A37.PTP	9878	028.TXT	114
GLOVE1RS46.PTP	4934	029.TXT	114
GLOVE1RS48A40.PTP	9358	030.TXT	114
GLOVE1RS49.PTP	24680	031.TXT	114
GLOVE1RS50.PTP	16462	032.TXT	114
GLOVE1RS5_6.PTP	8682	033.TXT	114
GLOVE1RS7_11.PTP	10610	034.TXT	114
	682082	TOTAL BYTES	

Figure 53: Machining Files: GLOVE3.PRT

APPENDIX A

NOMENCLATURE FOR FILE STORAGE IN UNIGRAPHICS

In Unigraphics the file structure is built around the format **NAME.SUFFIX** where the **NAME** is the filename and **SUFFIX** is a three-letter addition denoting the file type. In the **DESIGN/DRAFTING** segment of Unigraphics, the parts created have the file type:

GIZMO.PRT

where the **.PRT** indicates a Unigraphics part file.

When reading data into a Unigraphics module, the data (such as a point set) will be in ASCII format and be stored in a text file which may be labelled:

DATA.TXT

The process gets a little more complex when the machining is performed as many files are produced as part of the computation of machining paths. When paths are plotted over the geometry of a part, a cutter location file is produced that contains the generic point-to-point data describing the location of the center point of the cutting tool. These files are labelled:

GIZMO.CLS

When the machining paths are post-processed, other files are produced, namely:

GIZMO.CLF
GIZMO.LPT
GIZMO.PTP

where **.PTP** is the punch-ready file in ASCII that contains the data ready for the CNC machine. The **.LPT** file is a print file and the **.CLF** file is a binary file which need not be of concern here.

For the work described herein, the part file for **GLOVE1** is **GLOVE1.PRT.** The part consists of many surfaces that have to be machined. The flat surfaces that are cut with a flat end mill are represented as:

GLOVE1FLRUFn.PTP

where "**n**" is the **n** th path and **.PTP** denotes the punch file.

As the manufacture of the part involves performing rough cuts and finish cuts the files appear as:

GLOVE1RSp_q.PTP

where "R" represents rough cut and "**Sp_q**" the surfaces "**p**" <u>through</u> "**q**", that is, **p, p+1, p+2,..., q-1, q.** If the descriptor appears as:

GLOVE1RSpAq.PTP

then the surfaces "**p**" <u>and</u> "**q**" are machined.

Then, if we have:

GLOVE1FSp_q.PTP

the "F" represents the finish cut over the surface.

Other file suffices may be **.GRS** or **.GRX**. The **.GRS** denotes a source file in GRIP and the **.GRX** file the executable object code in GRIP.

APPENDIX B

CNC FILE MODIFICATION PROGRAM

The following software was written in GRIP to edit the punch file and add header commands and footer commands as well as editing out null lines.

```
$$ PROGRAM:    FILEADDR.GRS
$$
$$ PROGRAM WILL ADD FILE HEADER AND FOOTER
$$ COMMANDS AND EDIT OUT NULL LINES AT FILE END.
$$
$$ THE HEADER DATA IS CONTAINED IN FILE
$$ "HEADER.TXT" AND THE FOOTER DATA IN
$$ FILE "FOOTER.TXT"
$$
   STRING/FNAM1(40),GNAM1(40),HNAM1(40)
$$
   DATA/FNAM1,'@UGFMDISK:UGMGR:DAVID:HEADER.TXT'
   DATA/GNAM1,'@UGFMDISK:UGMGR:DAVID:PUNCHFILE.PTP'
   DATA/HNAM1,'@UGFMDISK:UGMGR:DAVID:FOOTER.TXT'
$$
   FETCH/TXT,1,FNAM1,IFERR,ERR1:
   APPEND/1
   FETCH/TXT,2,GNAM1,IFERR,ERR2:
   RESET/2
   LDEL/2,START,10,END,10
   APPEND/2
   N=GETL(2)
   LDEL/2,START,N,END,N
   FILE/TXT,2,GNAM1,IFERR,ERR4:
   FAPEND/TXT,1,GNAM1,IFERR,ERR2:
   APPEND/1
   FAPEND/TXT,1,HNAM1,IFERR,ERR3:
   FILE/TXT,1,GNAM1,IFERR,ERR4:
$$
   TERM:
   HALT
$$
   ERR1:MESSG/'ERR1:',' ERROR IN FETCH #1'
     JUMP/TERM:
   ERR2:MESSG/'ERR2:',' ERROR IN FAPEND: MAIN FILE'
     JUMP/TERM:
   ERR3:MESSG/'ERR3:',' ERROR IN FAPEND: TRAILER FILE'
     JUMP/TERM:
   ERR4:MESSG/'ERR4:',' ERROR IN FILING PRODUCT'
     JUMP/TERM:
```

The program uses the two scratch file areas in GRIP to read, sort and edit the punch files so that the sets of commands in the header and footer files may be added on. The strings FNAM1 etc. contain the file names as character strings so that in order to process another punch file, only one file name has to be changed. It is stored under the original name in the amended form.

APPENDIX C

ADDITIONAL CNC FILE COMMANDS

Preliminary commands contained in **HEADER.TXT**

```
10    %
20    OOOOO<CR><LF>
30    G00G17G20G22<CR><LF>
40    G40G49G546G4<CR><LF>
50    G80G91G94G98M77<CR><LF>
60    G28 Z0. M38<CR><LF>
70    G28 X0. Y0. M48<CR><LF>
80    M00<CR><LF>
90    (OPTIONAL ACSII DESCRIPTOR)<CR><LF>
100   M06 T<CR><LF>
110   M03 S<CR><LF>
120   G90G00 G43 Z+2.0 H<CR><LF>
130   X0.0Y0.0Z3.0<CR><LF>
```

Commands contained in trailing file **FOOTER.TXT**

```
10    G90 G00 Z+3.0 M09<CR><LF>
20    G80 G40 G49 M05 G28 Z-2.0<CR><LF>
30    M46<CR><LF>
40    M30<CR><LF>
```

Line 90 in **HEADER.TXT** may be used to insert program names and tool information in man-readable form. Line 20 may also be used for path descriptions e.g. **20 01573<CR><LF>**.

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