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Building oriented surface generation through IGES specification

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ABSTRACT

BUILDING ORIENTED SURFACE GENERATION THROUGH IGES SPECIFICATION

Jujiang Bao

This thesis focuses the use of Initial Graphics Exchange Specification to generate automatically three dimensional surfaces. Currently, different CAD systems utilize their own data formats to generate graphic databases which are not compatible with one another. Besides, most of the existing CAD systems require an interactive data input process which is very much time consuming. In order to solve above problems, an efficient algorithm has been developed in this research to automatically generate portable graphic database following IGES specifications. This portable graphic database can be adopted by different commercial CAD/CAM systems. Using the proposed method, the current design process can be upgraded from the interactive data input method to automatic modelling method that accelerates design process in surface generation significantly. The main objectives of this research are: (1) curtail the surface generation time, (2) reduce the memory space for data storage and communication. A user-friendly program has been written in FORTRAN 77 to apply the proposed algorithm. A case study illustrates the effectiveness of the proposed method.

BUILDING ORIENTED SURFACE GENERATION THROUGH IGES SPECIFICATION

by
Jujiang Bao

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APPROVAL PAGE

BUILDING ORIENTED RULED SURFACE GENERATION THROUGH IGES SPECIFICATION

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This thesis is dedicated to my mother

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TABLE OF CONTENTS

Chapter Page

TABLE OF CONTENTS
(Continued)

LIST OF TABLES

LIST OF FIGURES

Figure **Page**

CHAPTER 1

INTRODUCTION

In modern industry the application of data processing in integrated manufacturing has reached a high level due to the development of CAD/CAM systems. In order to apply the CAD/CAM technology efficiently, the following two important issues should be considered: (1) how to generate a graphic database for CAD/CAM systems effectively; and (2) how to transfer the data series between different systems.

Traditionally, the interactive screen editor method is mainly used to generate data series utilized in CAD/CAM systems(see Figure 1.1). The method requires a large data inputs to create a graphic even though the drawing object can be expressed by mathematical equations. In general the data calculation and the interactive input consume a large amount of time to build a complicated object. Meanwhile, fewer designers use building oriented method to generate database specified by the individual CAD systems to achieve automatic generation of drawing.

The above two method approaches are limited by the specific data structures of the CAD/CAM systems to be used. The data generated by a CAD system cannot be read by other CAD/CAM systems. Different internal data structures impede the data communication between different CAD/CAM systems.

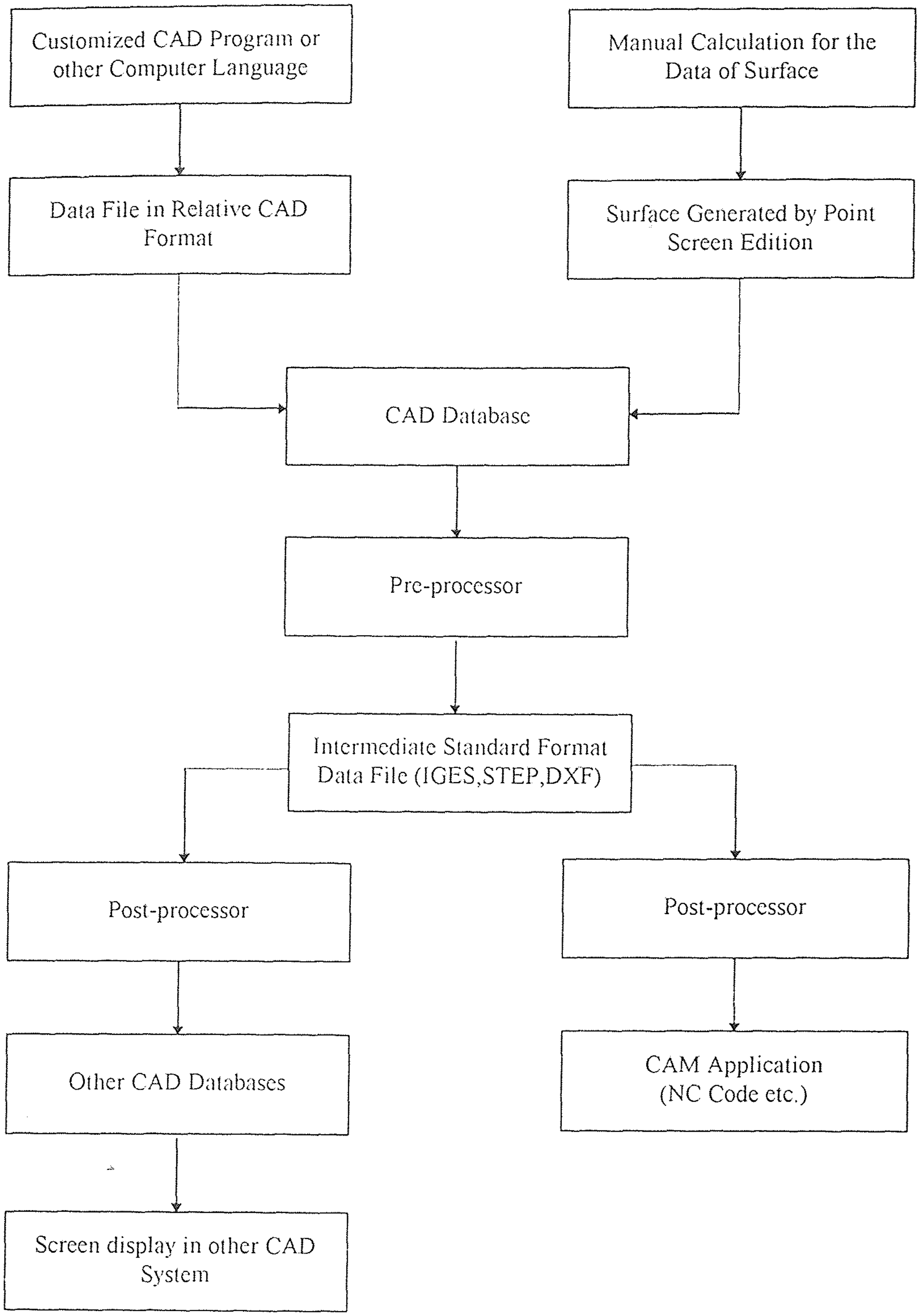

Customized CAD Program or other Computer Language
Manual Calculation for the Data of Surface
Data File in Relative CAD Format
Surface Generated by Point Screen Edition
CAD Database
Pre-processor
Intermediate Standard Format Data File (IGES,STEP,DXF)
Post-processor
Post-processor
Other CAD Databases
CAM Application (NC Code etc.)
Screen display in other CAD System

Figure 1.1 Traditional Use with CAD/CAM

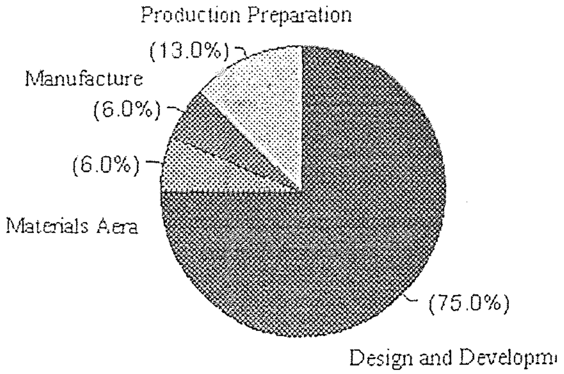


Figure 1.2 Analysis of Product Cost

The improper data transfer hinders the designer's efforts to improve the quality and productivity of his design process. The design and development expenditures make up to almost 75 percent of the total production cost (as shown in Figure 1.2), which significantly affects the competitiveness of the product. In order to achieve an economical process, it is necessary to develop a standard interface between different CAD/CAM systems.

A standard for the data exchange interface (namely Initial Graphics Exchange Specification, IGES) has been developed. It is designed mainly as a neutral data structure for data exchange among different CAD/CAM systems. The basic concept of IGES was accepted in 1981 as American Standard ANSI Y14.26M. The IGES/PDES Organization of the National Institute of Standards and Technology is constantly updating the specification. [1,16]

The study synthesizes the method of automatic data generation and neutral format of data transfer. It realizes a practical method of building oriented which is independent of CAD/CAM systems to be used. In the application of the proposed method, users are only required to input certain parameters describing the objects. A user-friendly program, developed in this research,

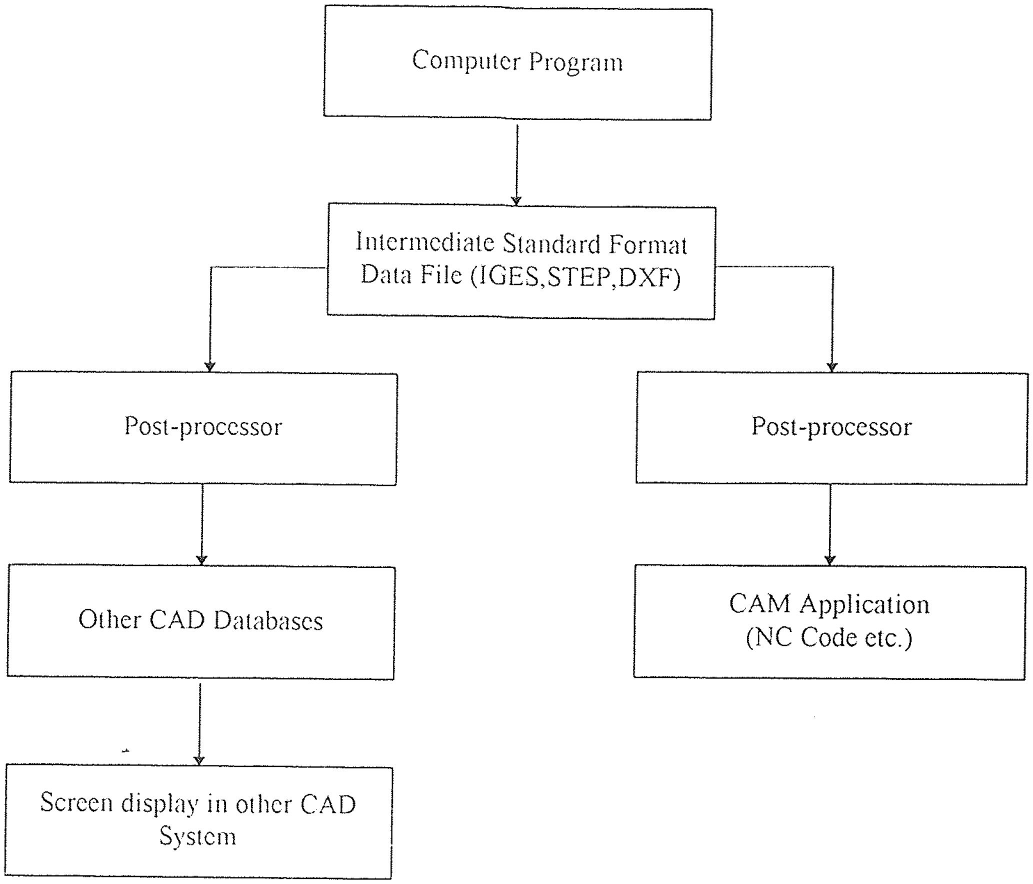

Computer Program
Intermediate Standard Format Data File (IGES,STEP,DXF)
Post-processor
Post-processor
Other CAD Databases
CAM Application (NC Code etc.)
Screen display in other CAD System

Figure 1.3 Proposed Use with CAD/CAM generates automatically a neutral graphic database. Thus the man-hours of the design process in surface generation is reduced significantly, so the design cost . The process is shown in Figure 1.3.

The scope of this research is to develop an algorithm which can be used to generate neutral graphic databases for import in various CAD/CAM systems. The methodology for realization of the proposed algorithm is based on the computer graphics technology, numerical analysis method, and IGES structure. The neutral graphic database in IGES format were pilot-tested on Auto-CAD and I-DEAS MS systems. The most important "downstream" use of the CAD/CAM is to complete the manufacturing processes. The proposed research discusses the steps used in the Manufacturing Model in I-DEAS to accomplish the integration of CAD and CAM.

CHAPTER 2

CURRENT PRACTICE

Reflecting the amount, the form and the quality of the information stored, different CAD systems offered in the market worldwide can vary considerably in terms of the following five elements[2]:

Model philosophy: Mainly, there are four geometric models used in CAD systems, Multiple-View 2-D Input, Wire Frame Geometry Model, Surface Model, and Solid Model. Just for the Surface Model, there are different construction techniques to be presented, Tesselated Modeling, Hermite Surfaces, Bezier Surfaces, B-Spline Surfaces and so on. Each different CAD vendor has its own choice of the model method(s) to use to fit the needs of the specific requirement.

Volume and selection of application-specific entities: An entity can be categorized as geometry and nogeometry. Geometry entities represent the definition of the physical shape and include points, curves, surfaces, solids and relations which are collections of similarly structured entities. Different entities used in CAD systems results from the different model philosophy. In

AutoCAD, for example, referring to Parameter Spline Surface, it uses Polygon Entity to realize the surface.

Data structure: The order of object storage in CAD database. It depends on the model to be put in CAD to stand for geometry graphics.

Data and storage formats: This part follows the concept of the designing team. Each team has its own ideas to arrange the format.

Accuracy: Different CAD vendors offer the accuracy according to their own specifications, considering acquirements and purposes of the package.

Even in the process of generating a surface, different CAD system has some advantages and disadvantages. But the interactive drawing is the main method used in various CAD graphics generation.

In Auto CAD, Draw / 3D Surfaces Submenu is a typical method to generate 3D surfaces. Mainly it consists of four different techniques, Edge Defined Patch, Ruled Surface, Surface of Revolution, and Tabulated Surface, to be used. Also, it provides access to Auto LISP programs that automate the creation of basic surface modeling primitives, such as cones, wedges and sphere.[4]

In I-DEAS, the designer can use skin groups, which are groups of wire frames or profile geometry used to create complex sculpted objects or surfaces, to complete the designing project. There are basically two types of skin groups in I-DEAS. The most common method of skinning is to define a group of profiles that represent cross sections through an object. The other type of skin group is defined by a group of wire frame geometry such as a "mesh of points", or a "mesh of curves". [5]

After the graphics are generated, the data exchange is a significant problem to be considered. The above mentioned limitations constitute the basic problem of data exchange between CAD systems. The problem is difficult to be solved by standardization of the systems. Due to the difficulty of achieving unification of the systems, neutral specification of the various CAD data structure is apparently the most practical method for solving the problem of data exchange between CAD systems. There are two approaches to overcoming data transfer problem in CAD systems[3]. One of them is the direct-translator approach. The translator was originally designed to avoid problems. Writing direct translators between four different systems requires n(n-1) or 12 different translators (see Figure 2.1). Adding a fifth system adds eight additional translators, and the number of translators continues to go up geometrically with the number of systems. Conversely, translation using a neutral file is done from one native format to the neutral file and then to another native format (see Figure 2.2.). For four systems, 2n or eight translators are required. Each system added will require only two more translators. IGES is based on the neutral data file exchange concept. The main goal is to facilitate the transfer of product definition data between different CAD/CAM systems.

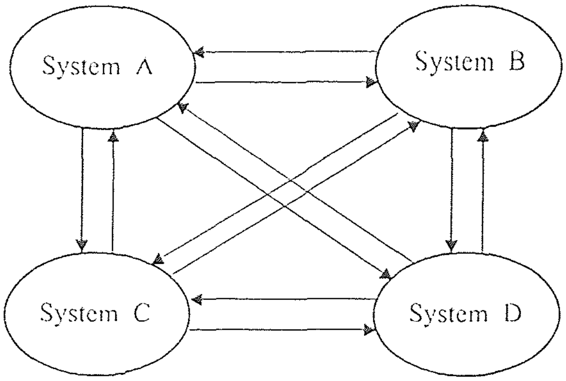


Figure 2.1 Direct-translator Approach

There is a new benefit of neutral files which was overlooked when standards were originally designed. The benefit is that the general data structure founded a situation for the use of the building-oriented parametric method in CAD/CAM systems. This is very useful and efficient method for CAD/CAM users.

In order to use a CAD system, especially in the design process, users need the system to be 'idle design' process. The building oriented method demonstrates a latent energy to counter the tendency. It can be designed to fit the need of users' demands, without the need to run the CAD/CAM system.

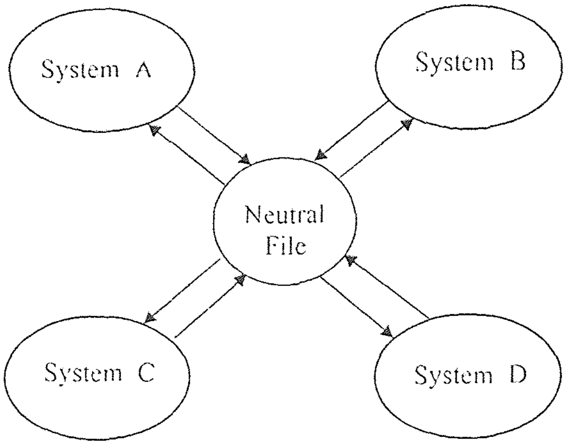


Figure 2.2 Neutral-translator Approach

The user still can get certain complex objects on neutral data file only by input the value of the parameters about the objects.

Due to the importance in CAD/CAM system applications, generating a useful tool to make it user-friendly is a wide attention along with the development of CAD/CAM. Henderson and Anderson took a different approach in which a part is presented as a set of feature cavities in a boundary-representation format [6]. Bauchat, Caignaert, David, Defretin, and Wattellier, who work on a multidisciplinary research team in the field of CAD/CAM of complex surfaces, define criteria to help to identify the best geometric model to describe surfaces. They present the applications in the fields of turbomachinery and biomechanics [7]. Wang and Chang developed an algorithm for automatically extracting the surface features of symmetrical rotational parts in one 2D view [8]. Abdou described a method and a implementation to permit the user to interactively define a complex rotational part [9] and presented the integrated approach to develop a CAM database system building-oriented and to automate the development of the process plan [10]. Filipe developed interpolator curve algorithms that can give aesthetically pleasant curves for use in CAD [11]. Woodward developed a set of B-spline modeling and visualization methods to support interactive free-form shape design with the computer. The swinging method is defined as a free-form generalization of the standard rotational sweep [12].

The research is not only limited in terms of production process, but also related to extensive interests. McCartney and Hinds applied a digitized 3 dimensional surfaces in CAD system for garment designing [13]. Perng, Chen, and Wu developed a system for automatic verification of the exactness of the mechanical part with planar and cylindrical faces through 3D part reconstruction [14]. Harrison, Cheshire, and Butler prosecuted an application with a major ceramic whiteware producer in the distortion of a 3D CAD surface model for the design of tooling in the ceramic industry[15].

The achievements mentioned above have the success in CAD/CAM applications but are limited because the methods or practices are created in special CAD/CAM system. Not each CAD system can accept the information in a specific data form. Because the methods were developed in a specific CAD/CAM system, they can not directly be received by the other systems due to the specific data file structure. Although some of researches are based on the building concept, the application can be converted into IGES files by a pre-processor. However, the quality of IGES processors varies widely depending on the vendors, the conversion may be impossible to transfer into another CAD situation properly. At the same time, the situation in which the computer is used may be a hindrance for the popularization of the achievements due to the variety of operating systems.

CHAPTER 3

RESEARCH OBJECTIVES

The main objective of the research is to develop algorithms on generating complicated surfaces through neutral files in CAD systems to achieve more efficient solutions than those already existing methods mentioned in the literature. Thus, the intention is to review the research done in the area of surfaces generated in CAD systems and address the unsolved problems. At the same time, the pre-manufacturing process is considered in the research for completing the integrated process in CAD/CAM systems.

The emphasis of the research is on the 3-D surfaces of a second degree equation with three or fewer variables. The proposed method employs mathematical and heuristic approaches, taking into account the Initial Graphics Exchange Specification format, IGES V5.0. With respect to the assumption mentioned above, the following objectives are considered in the research:

- Through the realization of the practical procedure, the research expects to obtain the beneficial objective with two important features in computer application: I) reduce the time in surface design by automatically generating the surfaces or the surface component, and II) deduce the memory size to a much lower level than the one generated by the traditional designing application process in CAD systems, by directly generating a neutral data format using the developed FORTRAN program.

In order to achieve the above objectives, the procedures below have been followed:

- Develop an efficient method to generate specific complicated surfaces directly. The method can be interfaced with any CAD systems. In various CAD applications, such surface is called a subfigure, block, cell, or ditto depending on the system.

- Generate the standard data structure for ruled surfaces following IGES specification format, improve information transfer to different applications, enhance the value of the designing file in various CAD systems.

- Design of complex 3D surfaces as subfigures, accomplish product processes for pre-manufacturing. At the same time, a complete Cutter Location, CL, file is generated. The actual part can be then machined from the CL file through the post-processor in the 3-D Numerical Control Milling Machines.

CHAPTER 4

METHODOLOGY OF CAD/CAM INTERFACE

Concerning the shortpoint in CAD/CAM applications, the proposed research selects certain ruled complicated surfaces as its research objective. The surfaces can be expressed in a Second Degree Equation in three or fewer variable(s). The general equation is

$$AX^2 + BY^2 + CZ^2 + DXY + EXZ + FYZ +GX + HY + IZ + J = 0$$

X,Y,Z ___ variables; A,B,C,...J ___ parameters.

For the realization of the surfaces automatically in CAD systems, the research has considered Computer Graphics, Math Iteration Model, and Initial Graphics Exchange Specification those mentioned in this chapter.

4.1 Computer Graphics

Computer graphics is a base for CAD/CAM packages. It is concerned with theories and techniques to input, output, generate, transform, manipulate, and transmit pictures (or, more generally, visually meaningful data) with the aid of computers; its objects are artifacts obtained by synthesis. In contrast, picture or image processing deals with images obtained from the real world; it is a field quite distinct from computer graphics although some overlap exists.

A good definition of computer graphics might be the following: "Computer graphics is the art or science of producing graphical images with the aid of a computer."

According to the classification by application area, computer graphics can be divided into several fields. They are Scientific and Statistical Graphics, Command and Control, Computer Aided Design, Simulation, Geometric Design and so on. Geometric design, the category represents the most challenging segment of computer graphics. Not only does an object have to be represented in three-dimensions (3-D), but it usually has to be rotated to allow the user to observe different views of an object. This is required in applications that display structures (such as a bridge), curved surfaces, or even small mechanical parts. Usually applications in this category require a complete graphics system to support the high-speed display.

Computer Graphics can provide the analyst with several benefits. It reduces the time required to interpret results, simplifies the communication of results to others, and enhances formal reports. Another benefit is that graphic output is much easier to use in decision making than is tabular output. Visual information is presented clearly.

Generally speaking, different basic pictures, whatever the points, lines, curves, surfaces, or texts are, depend on the position of pixels in Cardinal Coordination. The definition for basic entities (like point, line circle) is relatively simple in the expression of pixel positions and directly develops the surfaces and solid models generation. Furthermore, graphics becomes especially powerful through the ability to compose complicated pictures from other previously drawn pictures suitably transformed. As indicated in the figures below, the two-dimensional examples of the most used types are: translation (Figure 4.1.1), rotation

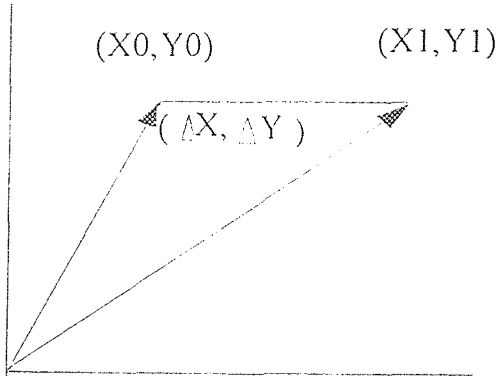


Figure 4.1.1 Translation

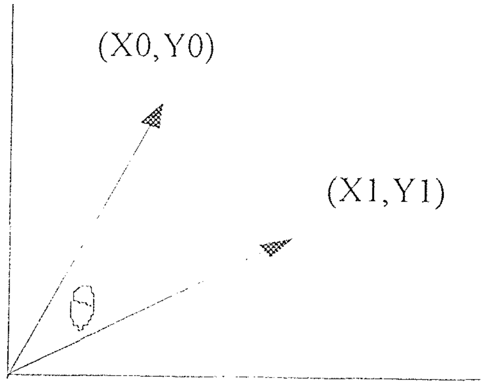


Figure 4.1.2 Rotation of a Point about Origin

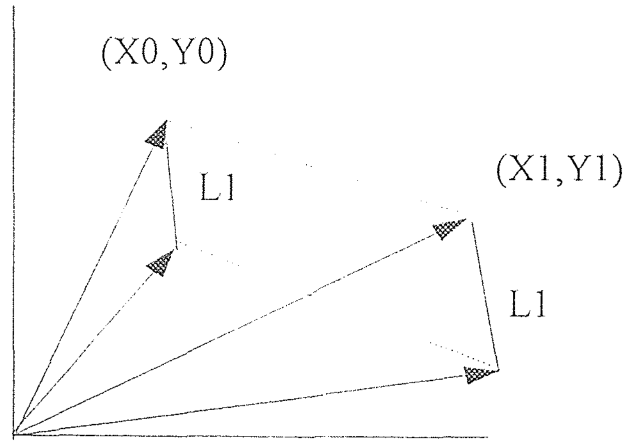


Figure 4.1.3 Scaling (Scaling by Deferent Amounts in x and y (L1 by(A,B)))

(Figure 4.1.2), and scaling (Figure 4.1.3).

Curves and surfaces used in computer graphics are often described by parametric equations. (The x- and y-coordinates are computed as a function of a third variable, called a parameter.) Certain mathematical calculations are needed to arrange the database for a reasonable structure. Because a surface is a component of curves, the basic idea mentioned bellow only refers to curves.

Curves may be created by smoothly connecting a series of specified points, P_0, P_1, P_2, ... P_n, called control points. The most obvious way to create such a curve is to require that it pass through each of the points. This is called interpolation.

A spline curve, flexible nods used by draftmen to draw a smooth curve through a series of points, $C_{(u)}$, is composed of cubic polynomials that interpolate the points P_0, P_1, P_2, ... P_n, on an interval [0,n] into n intervals by using the following technique. Divide the interval [0,n] into n internals [u_{i-1}, $u_i u_i$], for i=1 to n. The numbers u_i are called knots. On each of these intervals define a polynomial q_i such that $C_{(u)}$:= $q_{i(u)}$ for u in [u_{i-1}, u_i]. The value of $C_{(u)}$ for each u is a point.

To simplify this discussion, you will look at only one coordinate of each point generated by C. All properties that hold for one coordinate will hold for the second. For example, using p_i to represent a single coordinate P_i, you can describe the properties you desire for a spline:

$q_{i(u_i-1)} = p_{i-1}$, and $q_{i(u_i)} = p_i$ for i:=1 to n

$q'_{i(u_i)} = q'_{i+1(u_i)}$ for i:=1 to n-1

$q''_{i(u_i)} = q''_{i+1(u_i)}$ for i:=1 to n-1

The fact that this curve interpolates the points is given in the first two equations; the remaining two equations guarantee smoothness. In addition to these requirements at the knots, requirements are imposed on q_1 and q_n at 0 and n. Either their derivatives at the end points must be constant, or the second derivatives must be zero.

Each polynomial q_i is given by $q_{i(u)} = a_i u^3 + b_i u^2 + c_i u + d_i$. The conditions indicated above lead to the following equations:

$$a_i u_{i-1}^3 + b_i u_{i-1}^2 + c_i u_{i-1} + d_i = p_{i-1}$$
$$a_i u_i^3 + b_i u_i^2 + c_i u_i + d_i = p_i$$
$$3a_i u_i^2 + 2b_i u_i + c_i = 3a_{i+1} u_i^2 + 2b_{i+1} u_i + c_{i+1}$$
$$6a_i u_i + 2b_i = 6a_{i+1} u_i + 2b_{i+1}$$

If you add the extra conditions on the polynomials q_1 and q_n, you get 4n linear equations in 4n unknowns. These equations may be simplified to make them easily solved.

4.2. Structure of IGES

IGES (Initial Graphics Exchange Specification) is a graphic-image storage and transfer standard of specific interest to users of CAD/CAM systems. Its objective is to describe not only graphical objects but also completely annotated drawings and engineering information on defined parts and assemblies.

The IGES file consists of six sections which must appear in order as follows:

- Flag Section (in the case of the binary or compressed ASCII form and not always present).

- Start Section: Provides a human-readable prologue to the file. There must be at least one start record.

- Global Section: Describes the preprocessor and information needed by the post processor to handle the file. The parameters for the Global Section are input in free format.

- Directory Entry Section: Directory entry for each entity in the file. The directory entry for each entity is fixed in size and contains twenty fields of eight characters each, spread across two consecutive eighty-character lines.

- Parameter Data Section: The file contains the parameter data associated with each entity. The data are placed in free format with the first field always containing the entity type number. Two groups of parameters are defined at the end of the specified parameters for each entity. Any desired comment may be added after the record delimiter.

- Terminate Section: There is only one line in the section of the file. It is divided into ten fields of eight columns each. The Terminate Section must be the last line of the file.

The fundamental unit of data in the IGES file is the entity. Entities are categorized as geometry and non geometry. Geometry entities represent the definition of the physical shape and include points, curves, surfaces, solids, and relations which are collections of similarly structured entities. Non geometry entities typically serve to enrich the model by providing a viewing perspective in which a planar drawing may be composed and by providing annotation and dimensioning appropriate to the drawing.

Each type of entity is given an identification number. Each type of entity may also be specified in a variety of forms, as in the case of the 32 finite elements. The descriptive information in the directory entry for an entity is brief, however, and always in a fixed format common to all entities. The corresponding parameter-data entries, by comparison, may be very lengthy, and refer not only to the corresponding directory entry but also to a number of other associated entities and "property" entities that further describe the original entity.

There are, in effect, two entries for each entity: one in the directory section, and a second in the parameter-data section. The sequential order of entries in the directory section serves as an index for referencing the parameter-data entities.

There are two types of data formats in the standard. One is a fixed (80 character) line length ASCII format, for user-readable records; the other is a binary format and compressed ASCII which includes an initial binary section that defines how the data is to be interpreted with the aim of creating smaller files.

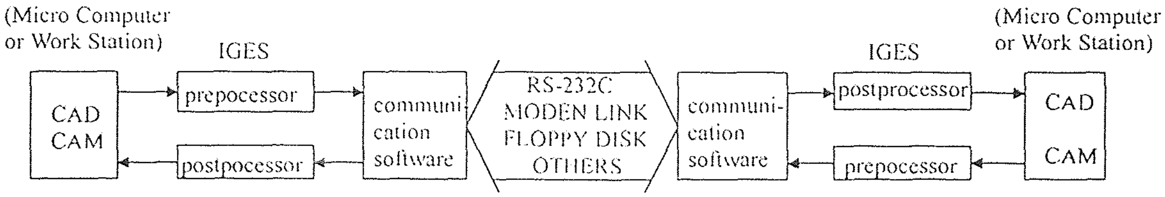


Figure 4.2.1 IGES Communication Model

The specification addresses the task of storing graphical data in a form that can be transferred from one computer installation to another --- of the same or different type -- or regenerated by the original system at a later data (Figure 4.2.1) . IGES, with its roots in CAD/CAM, features a much wider variety of primitives designed to describe efficiently complex mechanical and electrical parts and assemblies.

4.3 Parametric Spline Surface

Parametric Spline Surface Entity 114 in IGES consists of a grid of parametric bicubic polynomial patches. Parameter data includes the number and type of guideline splines (linear, quadratic, cubic, Wilson-Fowler, modified Wilson-Fowler, or B-spline); breakpoints between columns of patches; 16 coefficients for each of three polynomial equations for each patch; the type of surface (Coons, Bezier, B-spline, Ferguson, or Cartesian product); and dummy terminate patches at the end of each row and column.

The parametric spline surface is a grid of parametric polynomial patches. PTYPE in the Parameter Data Section indicates the type of patch under consideration.

The M*N grid of patches is defined by the u breakpoints TU(1), ..., TU(M+1) and the v breakpoints TV(1), ..., TV(N+1). The coordinates of the points in each of the patches are given by the general bicubic polynomials (given here for the (i,j) patch).

```
X(u,v) = AX(i,j)+BX(i,j)*s+CX(i,j)*s*s+DX(i,j)*s*s*s+
        EX(i,j)*t+FX(i,j)*t*s+GX(i,j)*t*s*s+HX(i,j)*t*s*s*s+
        KX(i,j)*t*t+LX(i,j)*t*t*s+MX(i,j)*t*t*s*s+NX(i,j)*t*t*s
        *s*s+PX(i,j)*t*t*t+QX(i,j)*t*t*t*s+RX(i,j)*t*t*t*s*s+SX
        (i,j)*t*t*t*s*s*s
Y(u,v) = ...
Z(u,v) = ...

        where
                TU(i)<u<TU(i+1), i=1, ..., M
                s=u-TU(i)
        and
                TV(j)<v<TV(j+1), j=1, ..., N
                t=v-TV(j)
```

Post-processors shall ignore parameters with the indices 7+M+N+48*(k*N+(k-1)) through 6+M+N+48*(k*(N+1)), where k=1,2,3, ..., M as well as 7+M+N+48*(M*(N+1)) through 6+M+N+48*(M+1)*(N+1).

The spline surface is a grid of parametric bicubic patches defined by:

1. M: The number of grid lines in u,
2. TU(1), ..., TU(M+1): The breakpoints in u (u values of grid lines),
3. N: The number of grid lines in v,
4. TV(1), ..., TV(N+1): The breakpoints in v (v values of grid lines),
5. Ax(i,j),Bx(i,j), ..., Ay(i,j), ...,Az(i,j), ..., for i=1, ..., M; j=1, ..., N:

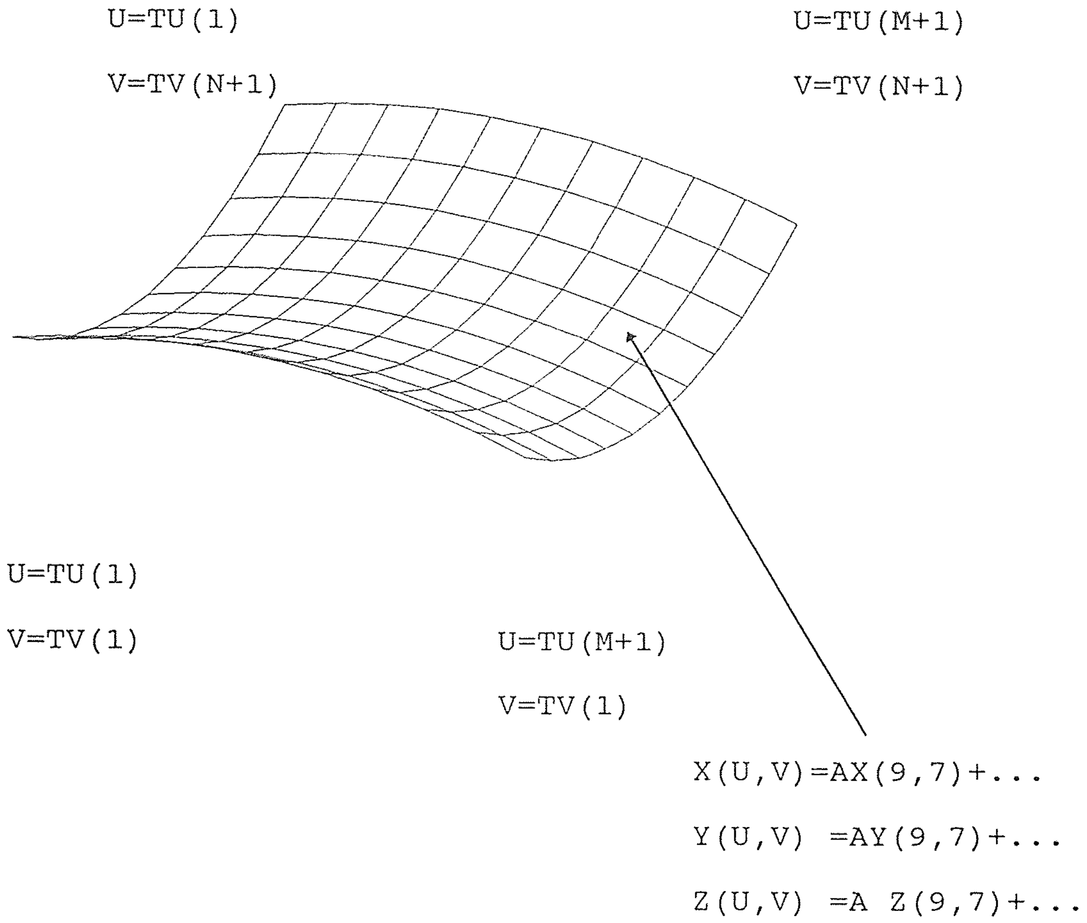
   The M*N sets of 3*16 coefficients define the bicubic polynomial for each of the three coordinates of the patch,
6. CTYPE: The spline type (1=linear, 2=quadratic, 3=cubic, 4=Wilson-Fowler, 5=Modified Wilson-Fowler, 6=B-spline), and point "u,v" in the parameter grid, i.e., the patch "i,j" such that TU(i)<u<TU(i+1) and TV(j)<v<TV(j+1), then evaluate the bicubic polynomial in that patch, i.e.,

compute:

SURFACE = (X(U,V), Y(U,V), Z(U,V))

M=10

N=10



4.4 Solution by Iteration

For solving the above linear multi-variable equations, the Iteration is an efficient method to apply. Also for simplifying the algorithm, there is an analysis which creates a shortcut this will also be mentioned in this section.

4.4.1 Gauss-Seidel iteration (successive corrections)

Concerning the general bicubic polynomials discussed ahead, for a single point which is in the surface, there are 3 linear equations each consisting of 16 parameters waiting to be solved. To figure the tides problem out, Gauss-Seidel iteration is introduced :

If we know the matrix formula is

$\mathbf{A}\mathbf{x} = \mathbf{b}$

we may write $\mathrm{A} = \mathrm{I} + \tilde{\mathrm{L}} + \tilde{\mathrm{U}}$, where I is the n-rowed unit matrix

$\tilde{\mathrm{L}}$and $\tilde{\mathrm{U}}$ are respectively lower and upper triangular matrices with null principal diagonals.

set $\tilde{\mathrm{L}} = -\mathrm{L}$ and $\tilde{\mathrm{U}} = -\mathrm{U}$, we obtain the Grauss-Seidel formula:

$(\mathrm{I} - \mathrm{L})\mathbf{x}_{(m+1)} = \mathrm{b} + \mathrm{U}\mathrm{x}_{(m)}$ (m=0,1,...)

Solving the formula for $\mathrm{x}_{(m+1)}$ we have

$\mathrm{x}_{(m+1)} = (\mathrm{I} - \mathrm{L})^{-1}\mathrm{b} + \mathrm{C}\mathrm{x}_{(m)}$ where $\mathrm{C} = (\mathrm{I} - \mathrm{L})^{-1}\mathrm{U}$

Following the iteration, the algorithm can be setup to realize the database of the parameter spline surface in the IGES standard file. Defining certain arrays is a way to generate matrixes and vectors respectively.

4.4.2 Shortcut

Considering there are 16 valuables in the parameter equation for a patch of a surface, it is possible to get an algorithm following the Gauss-Seidel iteration, but it will create complexity for the programmer in the program realization. In the research, there is a shortcut to arrive at the same precise result using the math method but with no more complexity.

In the general parameter spline surface equations, certain patches are used to generate a whole surface and each patch is divided into 16 partials. Respectively, the values of parameter 's' and 't' will be 0, .25, .50, .75, and 1 in a patch. On the other hand, considering each partial as a patch and not dividing a patch into partials, the proposed research suggests analyzing a surface only by patches. The values of 's' and 't' will be only 0, and 1 respectively. The equations can be changed to the form:

$$X(u,v) = AX(i,j)+BX(i,j)*s+EX(i,j)*t+FX(i,j)*t*s$$

$$Y(u,v) = AY(i,j)+BY(i,j)*s+EY(i,j)*t+FX(i,j)*t*s$$

$$Z(u,v) = AZ(i,j)+BZ(i,j)*s+EZ(i,j)*t+FZ(i,j)*t*s$$

This form of equations can be solved by Kerchiefs law, and it is easy to be realized in the programming process. The research is based on the math method.

Because the preciseness of the expression in the longitudinal and latitudinal for a surface depends on the number of segments in the different directions, the accuracy of a function for a surface using nine units of patches is entirely the same as using a patch deviated into nine partial sections by 16 points. There is a very important condition here that, whether the surface stood by a patch with 16 points or nine patches, the deviated lines in the different expressions have to be in the same direction. For the condition to be easy to realize, the research uses longitudinal or latitudinal direction by X or Y axis in analyzing the problem in the parameter spline surface model and in realizing the surface by the shortcut method. The deviated lines in different directions are perpendicular. There is only one difference between the formal and shortcut expressions which is that there are no more lines except the outline if using a patch to stand for a surface by the formal expression but there are eight lines (including the outline, or say, nine patches) to express the same surface by the shortcut method.

As mentioned above, realizing a surface in a program using the shortcut is much easier than using the formal method. This is the reason for choosing it in the research.

4.5 Proposed Algorithm

To achieve the proposal in a FORTRAN program, the algorithm of the program is shown in this section. Much more important to understand is the data structure in the neutral file. It is mentioned in the third part of this section.

4.5.1 Basic Structure of Proposed Algorithm

A crude classification of surface priority ordering algorithms can be based on how often the priority is computed. (1) Some algorithms compute the priority at every pixel (or even more often for some anti-aliasing schemes).

(2) Other algorithms organize the data so that the priority need only to be calculated at those points along a scan line

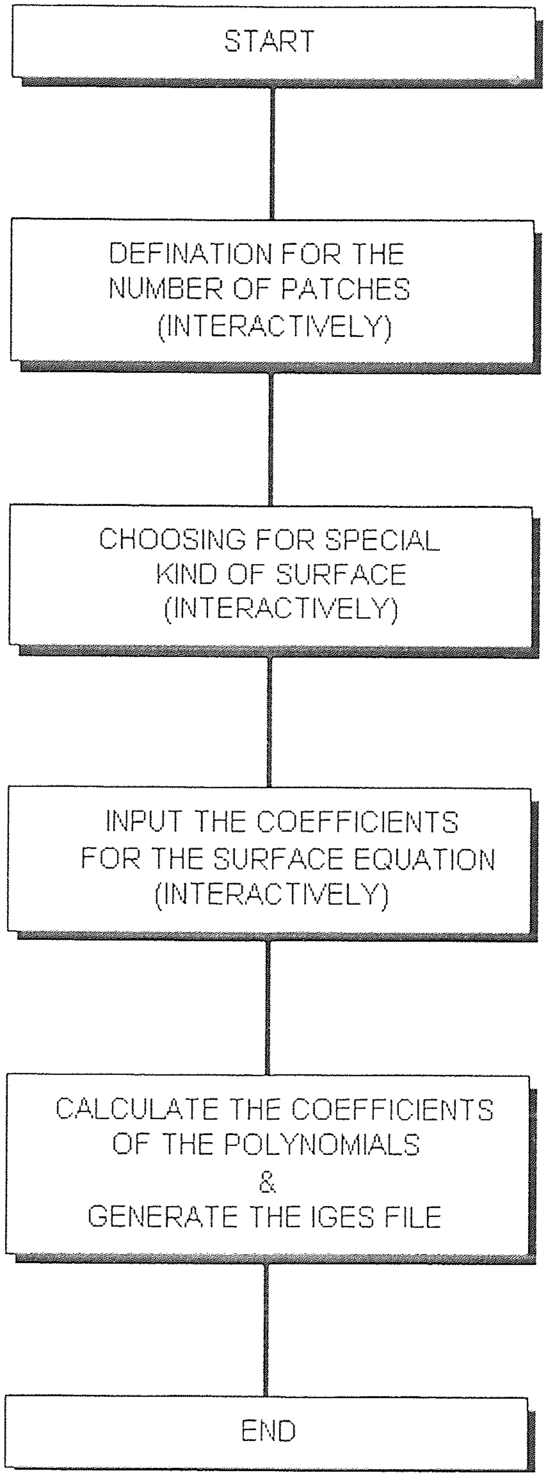


Figure 4.5.1 Basic Structure of the System

where a surface begins or ends, a scan segment. (3) Still other algorithms base the ordering on an entire surface element, a polygon or nonlinear patch.

The flowing graphics (Figure 4.5.1) shows the basic structure of the system. According to the classification above, it belongs to the third kind of algorithm of surface.

4.5.2 FORTRAN Program

Following the algorithm, A FORTRAN program has been developed to realize the IGES file for automatic drawing. The language was developed for the IBM 704 computer by John Backus and a team of thirteen other programmers at IBM over a three-year period (1954-1957).

There has been a considerable effort to standardize the structure of FORTRAN, so that programs written in the higher-level language are "portable", that is , so that they can be processed on several different machines with little or no alternation. In this research, the FORTRAN program is used to realize the algorithm compiled and executed by DOS or UNIX system commands.

In the proposal, the FORTRAN program is used to achieve the following purposes:

- Generate an interactive to certain initial parameters for successive purposes.
- Calculate the sets of coordination with the equation.

- Setup the neutral file following the data structure of IGES.

Running the program, and inputting the coefficients, the user can easily obtain the different complicated graphics generated by the program. It can be used on DOS, UNIX or other operating systems. Also it can work in a single-user or multi-user situation (or we can say on a personal computer or a network).

In the Sun Workstation situation, the FORTRAN program can be compiled and linked by the command "f77 filename(s)". After the program has been compiled, the user can run the executable file named "a.out" to start the graphics drawing. Appendix A is one of the IGES files generated by the program.

Step 1 Get into your UNIX system. You need an account in the system you plan to use. Use Login and password to enter your account.

Step 2 At the UNIX prompt, typing a.out, then Enter, if the FORTRAN program is compiled already.

Step 3 According to the instruction of the program, input the number of longitudinal segment and the number of latitudinal segments.

Step 4 Input the number behind the name of the graphics on the graphics menu you want to generate the respective surface.

Step 5 Input the coefficients of the graphics equation following the instructions the program shows on your screen.

Step 6 Input certain parameters the program asks for. These are some figures concerning the size or form of the surface you want to create.

Step 7 Get the IGES file named fort.8 in your home direction after you can see the word “congratulation” on the screen.(Appendix B)

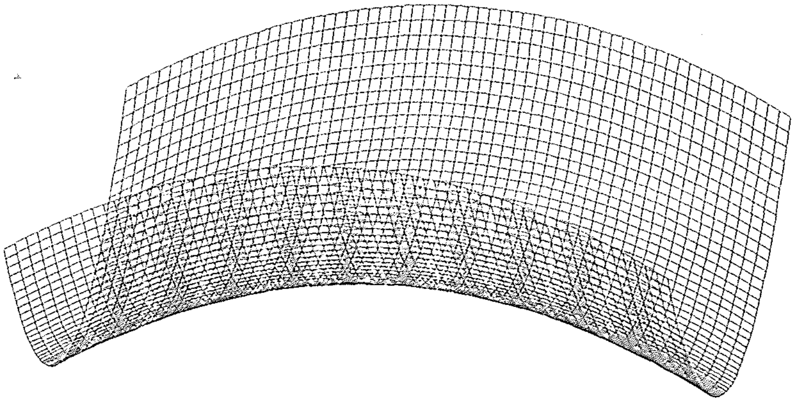


Figure 4.5.1 (HYPERBOLIC PARABOLOID)

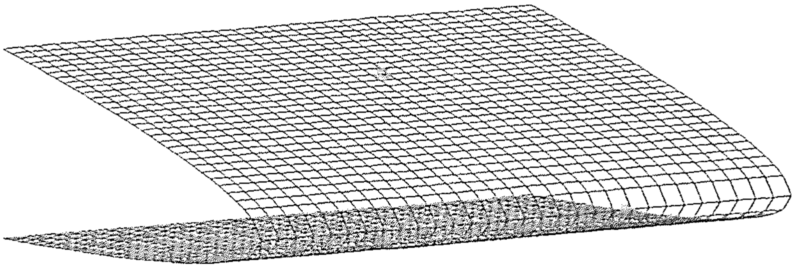


Figure 4.5.2 (PARABOLA)

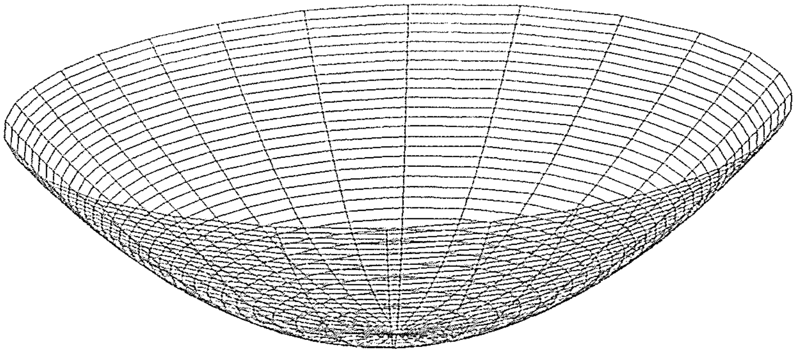


Figure 4.5.3 (ELLIPTIC PARABOLOID)

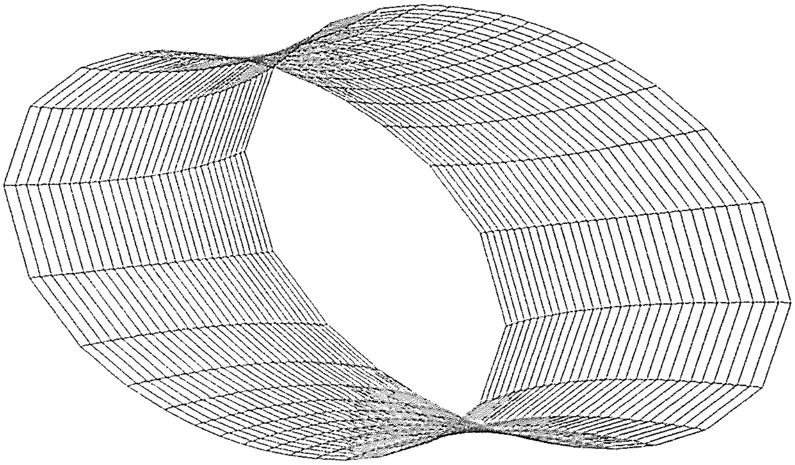


Figure 4.5.4 (ELLIPTIC PARABOLOID OF ONE SHEET)

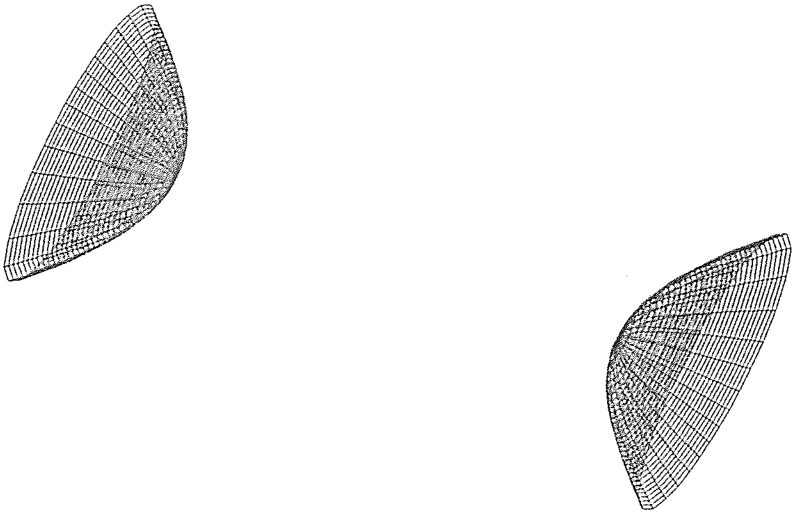


Figure 4.5.5 (ELLIPTIC HYPERBOLOID OF TWO SHEETS)

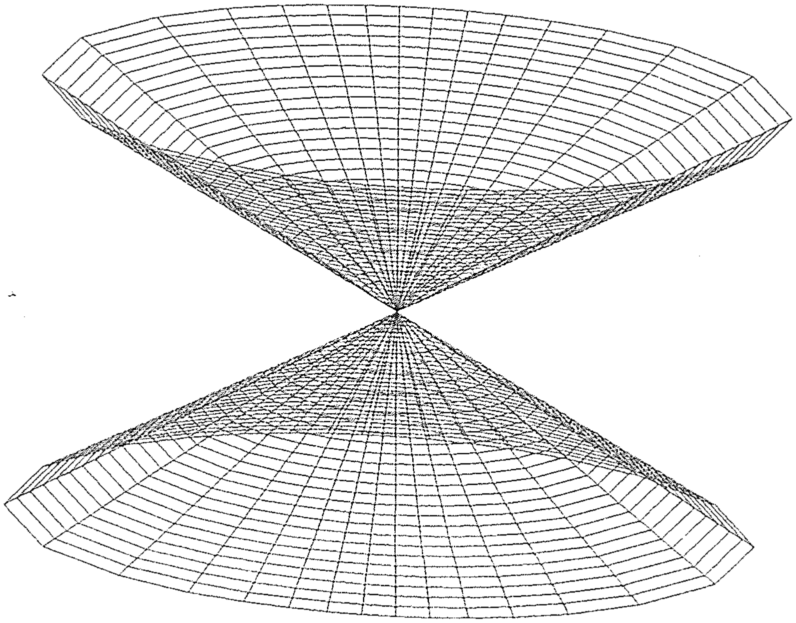


Figure 4.5.6 (ELLIPTIC CONE)

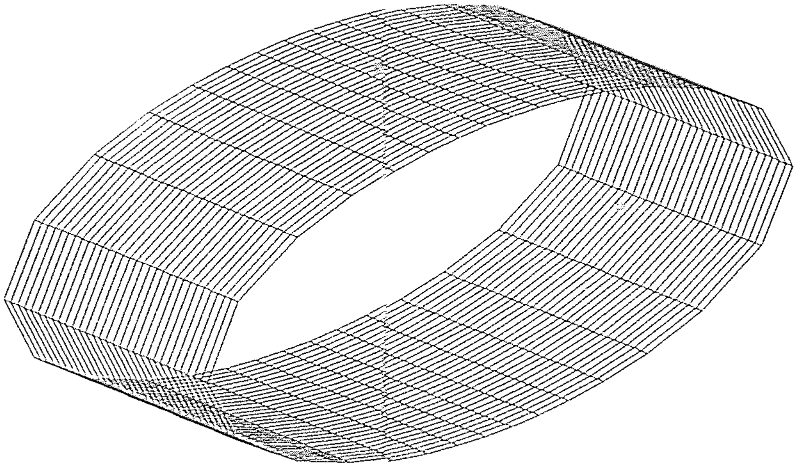


Figure 4.5.7 (ELLIPSE)

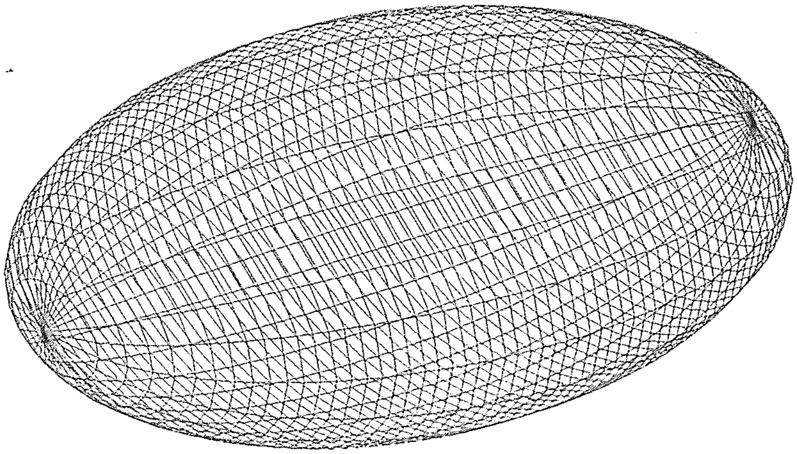


Figure 4.5.8 (ELLIPSOID)

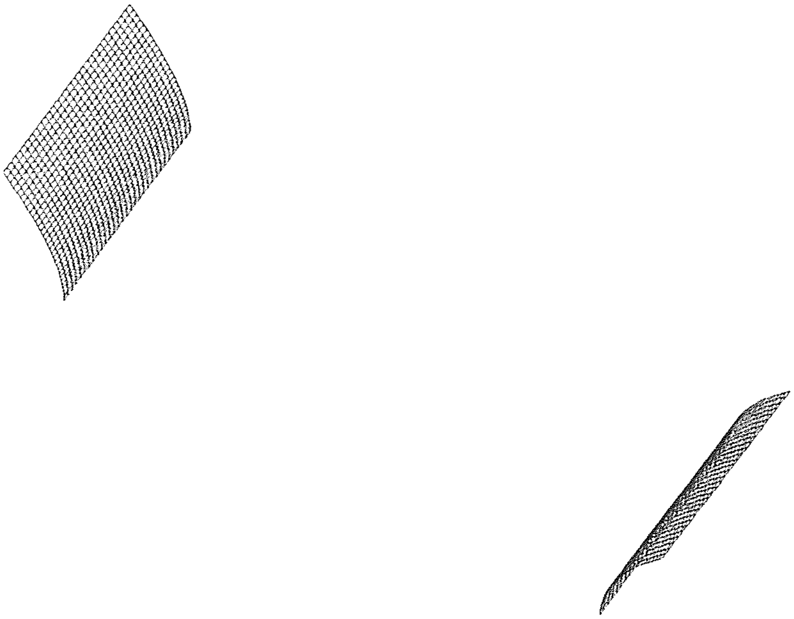


Figure 4.5.9 (HYPERBOLA)

Figure 4.5.1 to Figure 4.5.9 are the complicated surfaces that are obtained through the post-processor to transfer the IGES files generated by the program into real graphics. In the DOS operation system situation, after compiled, the program can complete the same tasks that are shown in the figures. The difference processes between UNIX and DOS is that there is no a.out and fort.8 file in the DOS system. Instead, there are an executable file and an IGES file that the user will be asked to name after inputting every parameter. The user can name the IGES file and define which drive and direction it will take.

4.5.3 Data Format of the Output File

In the ASCII 80 character format, the IGES file consists of lines, each of 80 ASCII characters. The character position in a line is referred to as the "column". To distinguish between the five sections of the file, each section has its own identification character (letter). "S", "G", "D", "P" and "T" are used as identification letters for the start, global, directory, parameter data and terminate sections respectively. The section identification letter occupies column 73 of each line. Columns 74 to 80 are used to specify the sequence number of each line. The other data in a line occupy columns 1 to 72.

The format of the Start Section is shown in Table 4.5.2.1. There must be at least one start record. All records in the section shall have the letter S in Column 73 and a sequence number in Columns 74 through 80. The information in Columns 1 through 72 need not be formatted in any special way except that the ASCII character set must be used.

Table 4.5.3.1[16]Format of Start Section

1 72	73 80
This section is a human-readable prologue to the file.	S0000001
It can contain an arbitrary number of lines	S0000002
:	:
using ASCII characters in columns 1 - 72	S000000N

In the Global Section , all records shall contain the letter G in Column 73 and a sequence number. The first two global parameters are used to define the parameter delimiter and record delimiter characters if necessary. The default characters are "comma" and "semicolon" respectively.

The Global Section contains the information needed by the post-processor at the other end to handle the IGES file. The parameters for the Global Section are input in free format.

The Directory Entry Section is fixed in size and contains twenty fields of eight characters each, spread across two consecutive eighty-character lines. Data are right justified in each field. Table 4.5.2.2 shows the format of the Directory Entry (DE) Section in the ASCII form.

Table 4.5.2.2[16]Format of Directory Entry Section

1 8	9 16	17 24	25 32	33 40	41 48	49 56	57 64	65 72	73 80
(1) Entity type number #	(2) Para-meter data	(3) Structure #, =>	(4) Line font ppattern #, =>	(5) Level #, =>	(6) View 0, =>	(7) Transfor-mation matrix 0, =>	(8) Label display assoc. 0, =>	(9) Status number #	(10) Sequence number D #
(11) Entity type number #	(12) Line weight number #	(13) Color number #, =>	(14) Para-meter line count #	(15) Form number #	(16) Reserved	(17) Reserved	(18) Entity label	(19) Entity subscript number #	(20) Sequence number D # + 1

Nomenclature:

(n) -Field number n
# -Integer
=> -Pointer
#,=> -Integer or pointer (pointer has negative sign)
0,=> -Zero or pointer

The format of the Parameter Data (PD) Section in the ASCII Form is different for each type of entity, with at least one line for each entity. The first parameter in a parameter data entry is always the entity type number. In the parameter data entry of each entity, the parameter delimiter character is used to separate two concessive notes by the record delimiter character. Table 4.5.2.3 shows the format of the Parameter Data (PD) Section in the ASCII form.

The set of parameters for each entity in each section is referred to as a "record". The relationship between an entity's records in both sections is established through bi-directional pointers.

Table 4.5.2.3[16]Format Parameter Data Section

1 64	66 72	73 80
Entity type number followed by parameter delimiter followed by parameters separated by parameter delimiters	DE Pointer	P0000001
Parameters separated by parameter delimiters followed by record delimiter	DE Pointer	P0000002
⋮	⋮	⋮

Note: The DE pointer is the sequence number of the first directory entry line for this entity

The format of the Terminate Section in the ASCII Form contains the total number of lines in each of the previous sections. In the Terminate Section there is only one line, which is divided into 10 fields of 8 columns each. The first 4 fields contain the section-identification character followed by the last sequence number used in the Start, Global, Directory and Parameter Data Sections respectively.

Table 4.5.2.4 shows the format of the Terminate Section in the ASCII format.

Table 4.5.2.4[16]Format of Terminate Section

1 8	9 16	17 24	25 32	33 40	41 48	49 56	57 64	65 72	73 80
S0000020	G0000003	D0000500	P0000261	Not used					T0000001

4.6 Steps in Manufacturing Model

This is a very important process in the application of CAD/CAM. Each step, including getting the IGES file from a certain direction (or from a floppy disk and so on) using the I-DEAS MS package to complete the manufacturing process, is shown:

Step 1 Get into I-DEAS by inputting the command. (At the Mechanical Computer Lab in NJIT Room 1403, Info-Tech, the user can use command “ideasms” in the UNIX system to get into the package.)

Step 2 Use the task of IGES (View Independent) in the Geometry Translator to import the IGES file by following the instructions in different windows.

Step 3 Choose the Master Modular task in the Manufacturing Model, move the surface, generate a block for the surface, then pick the surface as cutter and block as it is to be cut in order to get a solid with the specific surface.

Step 4 Choose the Generative Machining task in the Manufacturing Model, click Pick Part icon in NC Job Specification, pick the part to be in the machining process. This will give the user a part name and job name.

Step 5 Choose the objectives in the Operation Selection. There are two different machining processes in the package (Category in Operation Selection window). One is Milling and the other is Drilling. Also in the Milling process, there are three types for the process, Volume Clear, Copy Mill, and Profiled. In this case, the Copy Milling process is the one chosen.

Step 6 Name the operation in Operation Specification, and define the surface to be machined by clicking the surface after clicking the surface icon in Operation Specification. Then, create a tool for the operation in Cutting Tool Specification. It is necessary to define Identifier, Holder Diameter, Shank Diameter, Holder To Tip Dist, Max Depth Of Cut, Cutter Diameter, Nose Radius and so on.

Step 7 Set the tool motion and cutting parameters for the operation in Machining Parameters.

Step 8 Set the process of the tool path.

Step 9 Choose Animate icon to show the simulation of the process of the tool. The file animated in the Animate Tool window is the Cutter Location (CL) file.

Step 10 Click the Output CL File icon to output the Cutter Location File.(Appendix C)

CHAPTER 5

CASE STUDY

A case study to illustrate the proposed method is applied in I-DEAS MS 1.1. It includes the creating process of the independent sophisticated 3-D surfaces and the pre-manufacturing process to generate a Cutter Location File for use in Numerical Control Machine.

Table 5.1 Surfaces generated programatically

Name of the Graphics	Equation of the Graphics
Hyperbolic Paraboloid	$X^2/A^2-Y^2/B^2=Z/C$
Ellipiptic Paraboloid	$X^2/A^2+Y^2/B^2=Z/C$
Elliptic Hyperboloid of one Sheet	$X^2/A^2-Y^2/B^2+Z^2/C^2=1$
Elliptic Hyperboloid of two Sheets	$X^2/A^2-Y^2/B^2-Z^2/C^2=1$
Elliptic Cone	$X^2/A^2-Y^2/B^2+Z^2/C^2=0$
Ellipse	$X^2/A^2 +Z^2/C^2=1$
Parabola	$Z^2=X/A$
Hyperbola	$X^2/A^2 -Z^2/C^2=1$
Ellipsoid	$X^2/A^2+Y^2/B^2+Z^2/C^2=1$

Table 5.1 shows the equations and respective names of geometry graphics generated automatically by the proposed program. As a case study, two surfaces of Hyperbolic

Paraboloid is illustrated in Figure 5.1. The parameters of the equation are shown:

M(number of longitudinal segment)=10

N(number of latitudinal segment)=10

$a_1=7$; $a_2=5$

$b_1=5$; $b_2=5$

$c_1=3$; $c_2=5$

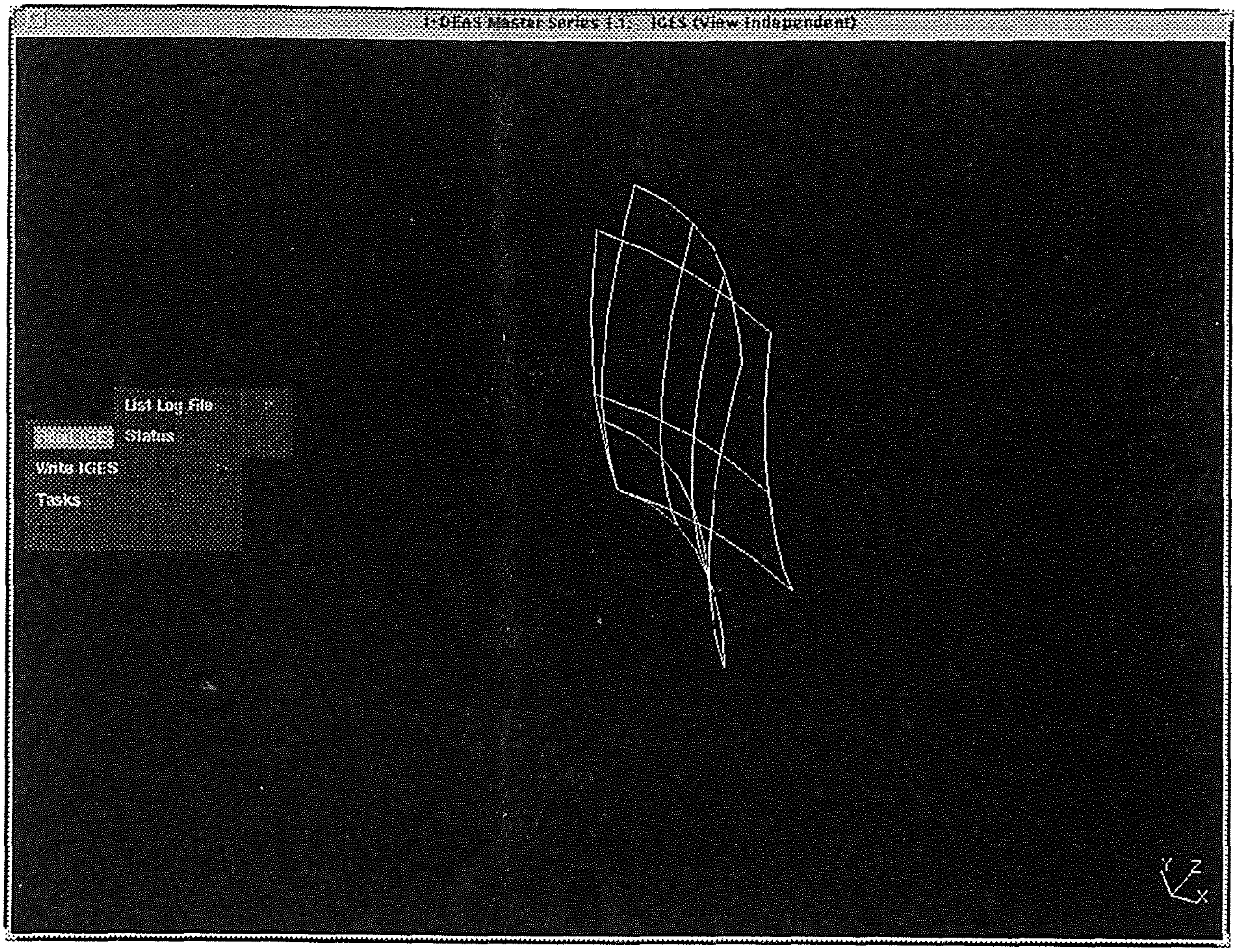


Figure 5.1 Surfaces of IGES File

the number of patches=100

After the graphics are generated, in 3-D CAD/CAM system(s), different solid models can be generated by using certain existing methods in CAD. The typical method used in the case study is to make a block and put the sophisticated surfaces on the block, then "cut" the block. Figure 5.2 is the result of this process.

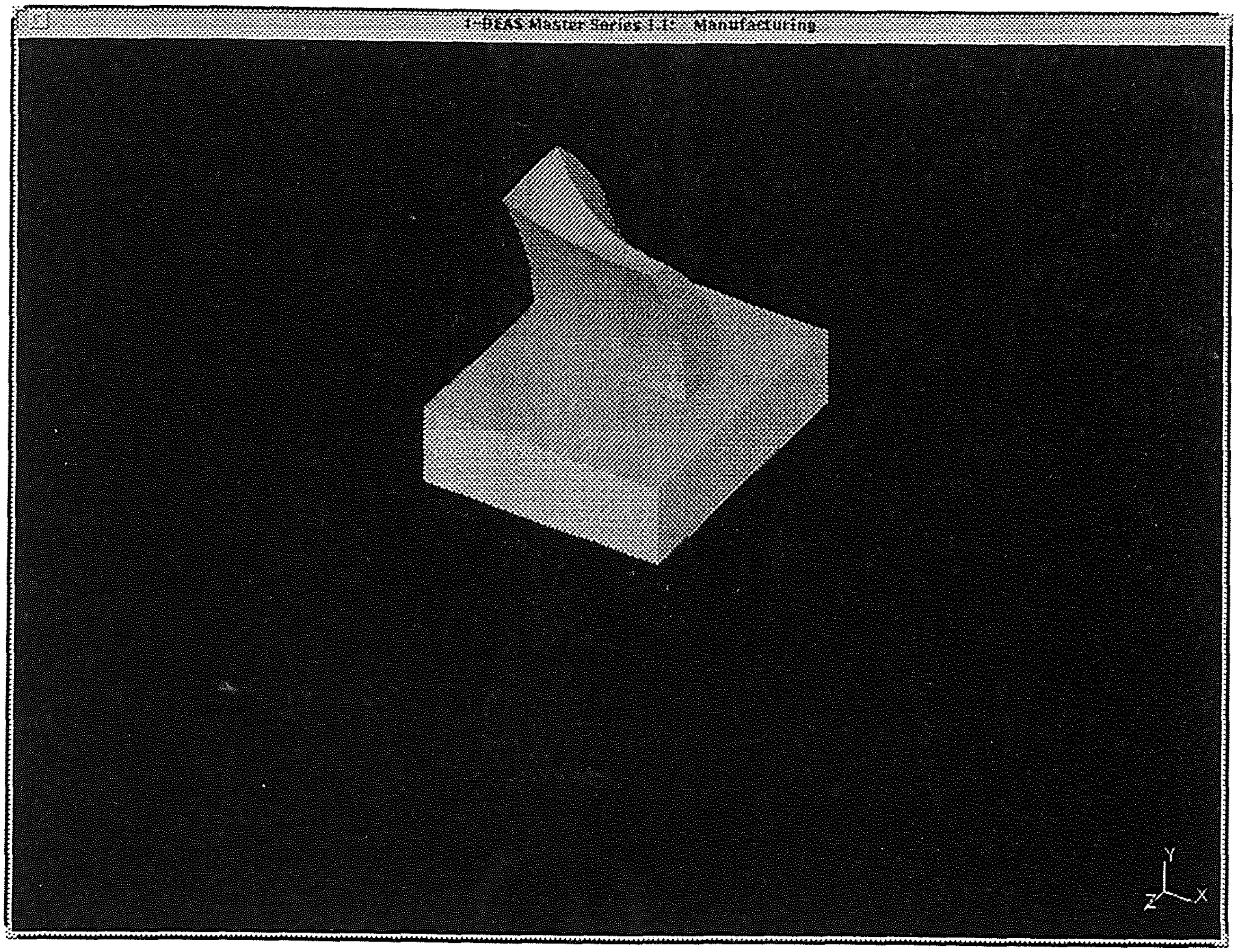


Figure 5.2 Part with the Surfaces

Following the process introduced in Chapter 4 Methodology of CAD/CAM Interface, the research defined the parameters of the machining procedure as below:

Cat/Type	Milling/Copy Mill
Constant Step	20
Zig Zag Angle	0
Cut Type	Bi-Directional
Units	IN

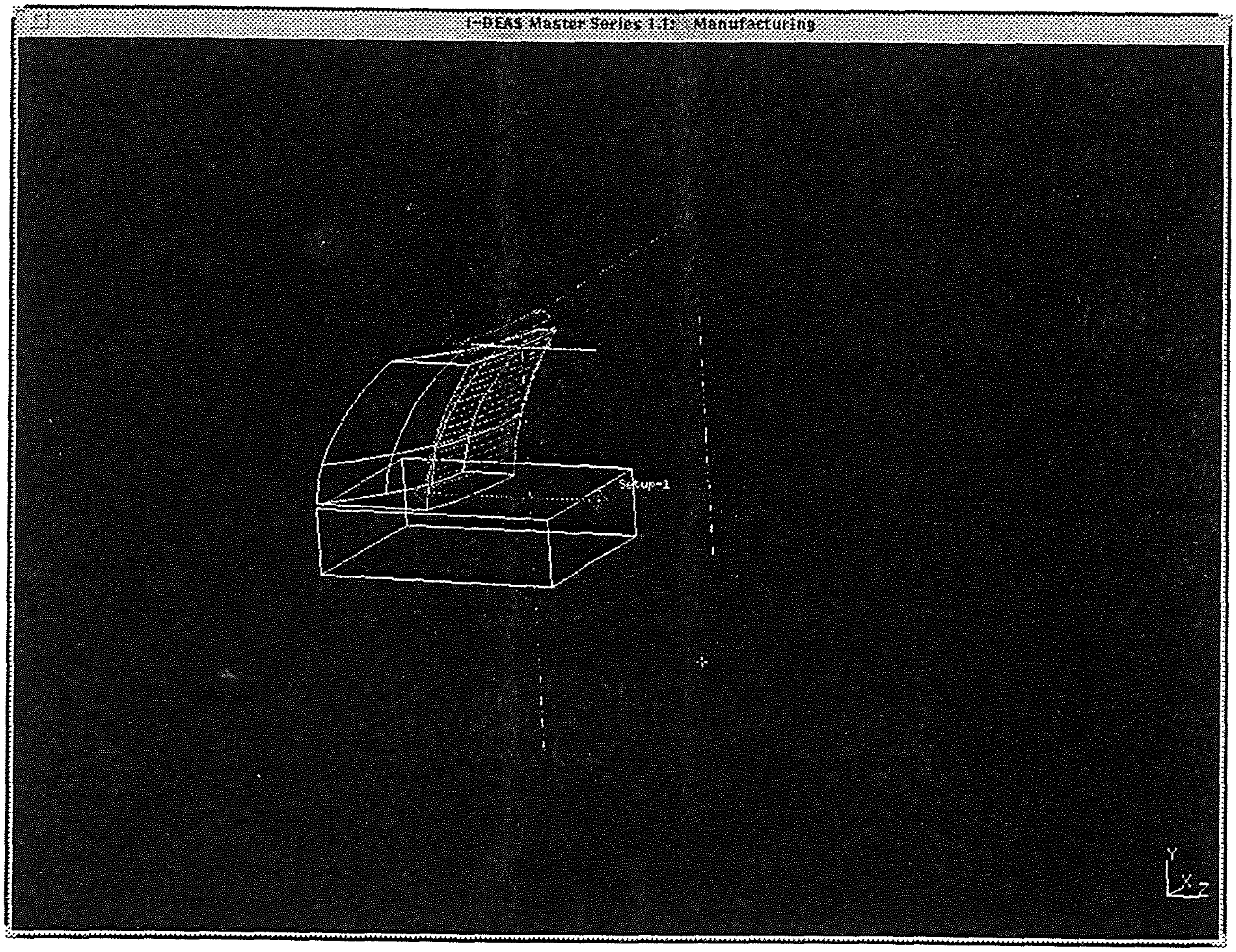


Figure 5.3 Tool Path on the Surface

Style	Ball Mill
Holder Diameter	3
Shank Diameter	0.75
Holder To Tip Dist	4.5
Mas Depth Of Cut	4
Cutter Diameter	0.75
Nose Radius	0.375
Taper Angle	0

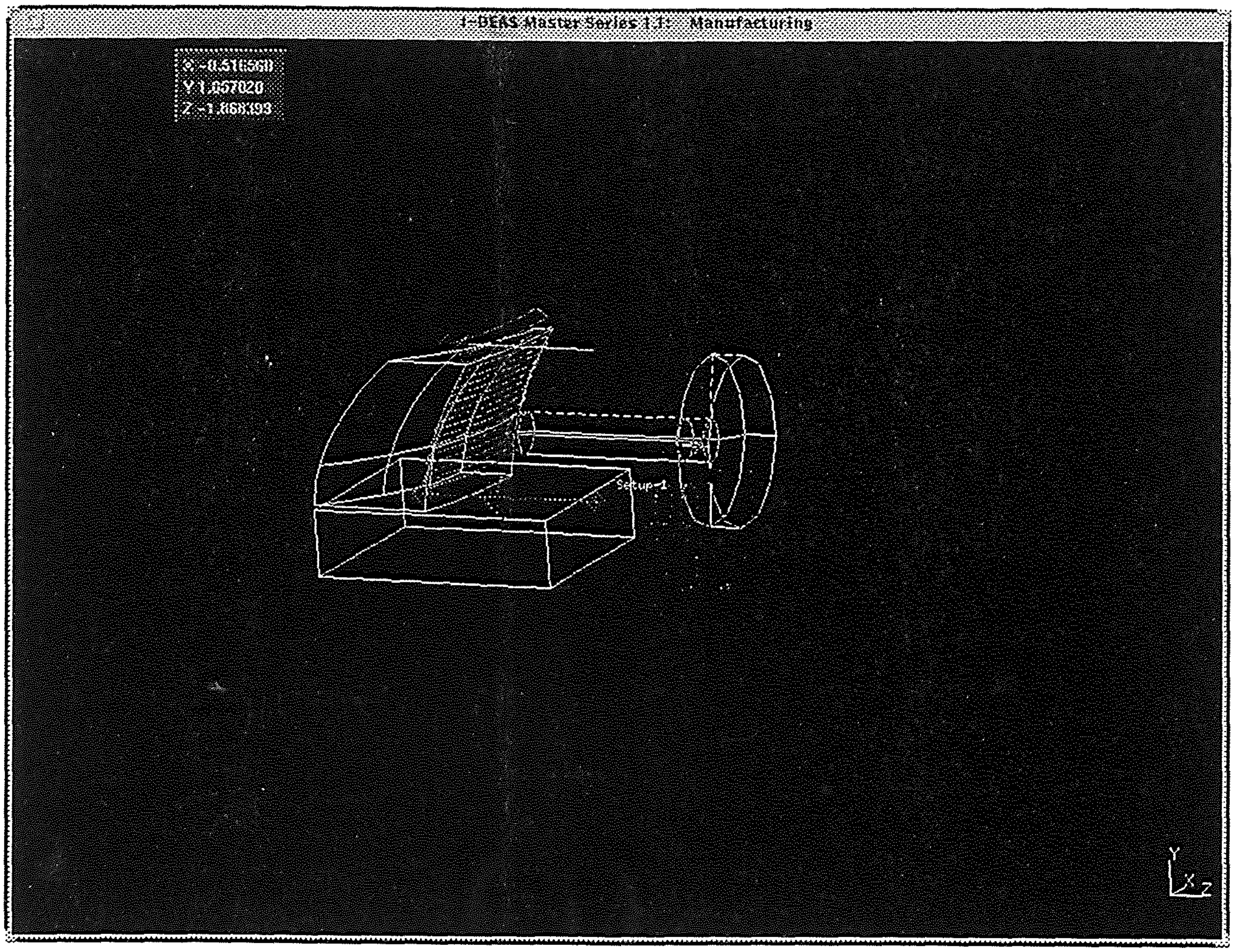


Figure 5.4 Illustrution of Animate Tool

By finishing the machining process, the tool path is generated by the Cutter Location File. Figure 5.3 shows the tool path on the machined surface. Figure 5.4 illustrates the animate tool on the surface to be machined. The entire pre-manufacturing process is completed by using Generative Machining in Manufacturing Model. The respective CL file has been generated for Numerical Control Machine.

CHAPTER 6

ANALYSIS OF RESULTS

The most important feature of the new method is that it saves a great deal of designing time for certain sophisticated surfaces and it suggests a new application direction to using CAD/CAM for greater productivity. This is the purpose to be followed.

The outcome of running the program is successful execution in different CAD systems. The typical packages are Auto-CAD version 12 (in IBM Compatible Computer 486/50MHz), I-DEAS Master Series 1.1 and Pro-Engineering Release 1.2 (in Sun Workstation, Local Network). A comparison of calculation time in different systems automatically and manually is listed in Table 6.1. The comparison is based on drawing a 45*45 patch Hyperbolic Paraboloid Surface where the parameters are A equal to 7, B equal to 5 and C equal to 3. Total 3-D variables (X,Y,Z) are 2116 sets.

Table 6.1 Calculating Time in Different Packages automatically and manually

# of Patches	Manually	Automatically(Program)	
		486DX/50M	SUN SPARCstation LX
10*10	9.2 hours	0.82”	0.0167”
45*45	564.27 hours	7.607”	0.2”

* the calculation in manual based on 1 set/4 min

From the table, the advantage of the new method is made obviously by the different process times.

The other important feature of computer applications is how much memory space will be taken. It is hard to say that the utilization in memory space is superior. Table 6.2 shows the byte number of the files in the same surface have taken in different CAD systems.

Table 6.2 Number of Byte of Files in CAD Systems

	SUN SPARCstation LX	I-DEAS MS		486DX/50M	AutoCAD
Kind of File	.igs	.mf1	.mf2	.igs	.dwg
# of bytes	995976	794624	99112	1008272	816110

In I-DEAS, The difference between IGES file and the Manufacturing File (1 and 2 together) is 0.1M bytes. A similar conclusion can be obtained by comparing the size of the files with different forms of igs and dwg files to be used in personal computers. This is because that the IGES files use the ASCII code rather than the effective machine codes. Since IGES is an industrial standard, it is mandatory to keep its form to assure a smooth data exchange. In order to save the disk space, standard compressing utilities provided by different operation systems may be used.

The more memory acquirement also exists in the proposed method following general analysis. Analyzing the graphics databases of the same dish surface with 45*45 patches, the igs file generated by Auto-CAD has 663380 bytes, and the file generated by the FORTRAN Program has 1008272 bytes. The reason is in the designing process of the Parameter Data Section. Because the Section is unformated and its form depends on the programmers designing idea. In order to save the CPU time and make the program uncomplicated, giving up memory is reasonable.

However, in light of the entire process of data storage and communication in CAD/CAM systems, it is necessary to keep the independent graphics database and the neutral database in concurrent application. The total memory used in the application is almost twice as much as IGES file itself. Using the proposed method, IGES file can be used for either graphic database or neutral database. Users can apply the IGES file to accomplish drawing graphics on different CAD systems. There is no any more communication block. The proposed method saves almost half of the memory space compared to traditional application. Furthermore, because of the automatic generating function of the proposed method, conserving the program but the data file will obtain the same outcome. It can save much more memory space. The number of bytes of the FORTRAN program, which used to generate Hyperbolic Paraboloid Surface, is 6465 bytes. The relative objective file is 18843 bytes. The executable file is 180924 bytes. The total number of bytes is 206232 to generate the special surface. The program can be used to generate different database for different complicated surfaces. Each database has to have 1000000 bytes as its memory space.. The memory taken in the proposed method is only 20% of using the neutral file in the CAD system, and almost 10% of using the traditional method.

There is a block existed in the neutral database communication between CAD systems. The difference of post-processor is the important reason. It will affect the data-flow and the application of the proposed method, especially in the case of the programmer who unfamiliar with the structure of IGES. For instance, in Auto-CAD, the 'S' and 'G' sections of IGES can be left blank. When the package receives the command 'igesin', it start to transfer the IGES file into the graphics. But such file cannot be accepted by I-DEAS. It needs more specifics in 'G' section, otherwise, there is nothing on the screen and the record file shows no any error in the transferring process.

In the process of generating a CL file, the expected outcome could not be achieved. The process of the tool path cannot be completed. Followed the suggestion made by the vendor, the process of the Topology Method was used but there were still the same outcome. In order to completely solve this problem, the designer(s) of the CAD system needs to be involved, and sufficient time will be required.

CHAPTER 7

CONCLUSIONS

As mentioned in Analysis of Results, using the program ready for the generating file, one can not only reach the same transmission and drawing functions, but also save very big amount of time for data generation (see Table 6.1) and just take 10% memory space used in traditional method. Although a big memory is required in the process of generating certain sophisticated surfaces in the form of IGES, the proposed method, which automatically generate 3-D surfaces, has shown better results. The most important benefit is that the method can save a great deal of working time in generating the surfaces. The proposed method is not limited to the application of the surfaces described in case study. It can be extended into various geometry objects. This is the new practical way that the research illustrates for the users of CAD/CAM systems. The IGES specification offers 22 curve and surface entities and 9 CSG primitive entities to help the programmer to generate the geometry database. It is of great benefit in automatic surface generation and will be applicable for further application in various geometry object generation in different CAD/CAM systems.

The other conclusion drawn from the research is that further development is needed in neutral specifications.

IGES is a data standard format that mainly includes the geometry. There are a broad range of detailed products and customer information. IGES was not designed to meet all the demands. Certain standards are still needed to complete the whole process. There is another specification, STEP [17], to be used with IGES to get the data over the life of the product at different levels: conception, analysis, design, manufacturing and testing. This idea is to be considered for further research in the future.

The proposal which suggests generating building oriented surfaces is only indicating a different method to achieve graphics in a CAD application. It does not mean that the new method will replace the traditional interactive data input used in CAD systems. In the practical situations, the reasonable integrated application of these two different orientations will result in a relatively high productivity of the entire process.

APPENDIX A

FORTRAN PROGRAM

```
C                                                       C
C                                                       C
C          THE PROGRAM IS FOR USER TO GET               C
C          A CERTAIN GRAPHICS FOLLOWING THE             C
C          EQUATION DEMANDED                            C
C                                                       C
C                                                       C

   program main

   print*,'This program is used to help you to get a IGES file'
   print*,'according to your special equation. Please follow'
   print*,'the demands below to get what you want. Thank you.'
   print*,' '
   print*,'Please input the # of longitudial segments (MAX=100)'
   read(*,*) M
   print*,'Please input the # of latitudial segments (MAX=100)'
   read(*,*) N
   print*,' '
   print*,' '
   print*,'At here, you can choose 2D,or 3D equation to get the'
   print*,'IGES file. Please choose the serial # of the graphics '
   print*,'you want to create and input the # from your keyboard'
   print*,' '
   print*,'*********GRAPHICS MENUE**********'
   print*,' '
   print*,'        1.HYPERBOLIC PARABOLOID'
   print*,'        2.ELLIPTIC PARABOLOID'
   print*,'        3.ELLIPTIC HYPERBOLOID OF ONE SHEET'
   print*,'        4.ELLIPTIC HYPERBOLOID OF TWO SHEETS'
   print*,'        5.ELLIPTIC CONE'
   print*,'        6.ELLIPSE'
   print*,'        7.PARABOLA'
   print*,'        8.HYPERBOLA'
   print*,'        9.ELLIPSOID'
   read(*,*)i
   if (i.eq.1) then
```

```
       call hyperbolic(M,N)
      else
       if (i.eq.2) then
        call elliptice(M,N)
       else
        if (i.eq.3) then
         call ellhy(M,N)
        else
         if (i.eq.4) then
          call ellhyt(M,N)
         else
          if (i.eq.5) then
           call ellcon(M,N)
          else
           if (i.eq.6) then
            call ells(M,N)
           else
            if (i.eq.7) then
             call para(M,N)
            else
             if (i.eq.8) then
              call hya(M,N)
             else
              call elsoid(M,N)
             endif
            endif
           endif
          endif
         endif
        endif
       endif
      endif
      print*,'Congraduation! Your IGES file is in present disk driver'
      print*,'Please switch to CAD system to get your graphics.Thanks!'
      end


   subroutine hyperbolic(M,N)
      real ParX,ParY,X,Y
      integer a,b,c,MaxX,MaxY
      dimension r(1:50,1:50,1:3)
      dimension g(1:50,1:50,1:3),h(1:50,1:50,1:3)
      dimension e(1:50,1:50,1:3),f(1:50,1:50,1:3)
      DOUBLE PRECISION G,H,E,F,R
      print*,'Equition of HYPERBOLIC PARABOLOID showes bellow:'
   print*,'-X*X/a*a+Y*Y/b*b=Z/c'
   print*,'Please input integer number of the parameters a, b and c'
   read(*,*) a,b,c
   print*
   print*,'Here, it creats a graphics in the first section.'
   print*,'Please input the MAX integer number of X axis you want'
   read(*,*) MaxX
   print*,'Please input the MAX integer number of Y axis you want'
   read(*,*) MaxY
   X=M
   Y=N
   ParX=MaxX/Y
   ParY=MaxY/X
   PRINT*,'M=',M,'PARY=',PARY
   do 20 i=1,M+1
     do 10 j=1,N+1
       r(i,j,1)=MaxX-(j-1)*ParX
       r(i,j,2)=MaxY-(M-i+1)*ParY
       r(i,j,3)=c*((r(i,j,2)*r(i,j,2))/(b*b)-
 '             (r(i,j,1)*r(i,j,1))/(a*a))
10   continue
20 continue
   do 60 i=1,M
     do 50 j=1,N
       do 45 l=1,3
         g(i,j,l)=r(i,j,l)
         h(i,j,l)=r(i+1,j,l)-r(i,j,l)
         e(i,j,l)=r(i,j+1,l)-r(i,j,l)
         f(i,j,l)=r(i+1,j+1,l)-r(i+1,j,l)-r(i,j+1,l)+r(i,j,l)
45     continue
50   continue
60 continue
   call igestart(M,N)
   call igespf(M,N)
   k=0
   do 95 i=1,M
     do 85 j=1,N
       do 80 l=1,3
         k=k+1
         write(8,70) g(i,j,l),',',h(i,j,l),',,,','1P',M+N+3+k
         k=k+1
         write(8,75) e(i,j,l),',',f(i,j,l),',,,,,,,,,,,','1P',M+N+3+k
70        format (D23.13,A1,D23.13,A3,21X,A2,I7)
75        format (D23.13,A1,D23.13,A11,13X,A2,I7)
80     continue
```

```
 85   continue
        k=k+1
        write (8,90) ',,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,',
   '              '1P',M+N+3+k
 90   format (A48,23X,A2,I7)
 95 continue
      k=k+1
      write (8,100) ';','1P',M+N+3+k
100 format(A1,70X,A2,I7)
      call igest(M,N,K)
      return
      end



subroutine elliptice(M,N)
      dimension r(1:50,1:50,1:3)
      dimension g(1:50,1:50,1:3),h(1:50,1:50,1:3)
      dimension e(1:50,1:50,1:3),f(1:50,1:50,1:3)
      dimension t(1:50)
      real MaxD,ParZ,Z
      integer a,b,c
      double precision R,G,H,E,F
      print*, 'Equition of ELLIPTIC PARABOLOID showes bellow:'
      print*, 'X*X/a*a+Y*Y/b*b=Z/c'
      print*, 'Please input integer numbers of the parameter a, b and c'
      read(*,*) a,b,c
      print*
      Z=N
      ParZ=c/Z
      print*,'Please input the number of degree you want to display'
      print*,'the graphics.'
      read(*,*) MaxD
      do 20 i=1,M+1
        do 10 j=1,N+1
          r(i,j,3)=ParZ*(j-1)
          print*,r(i,j,3)
          t(i)=((i-1)*MaxD/M)*(3.1415926/180.0)
          w=r(i,j,3)/((a*a*sin(t(i))*sin(t(i))+
   '              b*b*cos(t(i))*cos(t(i)))*c)
          rt=a*b*sqrt(w)
          r(i,j,1)=rt*cos(t(i))
          r(i,j,2)=rt*sin(t(i))
 10   continue
 20 continue
```

```
      do 65 i=1,M
       do 60 j=1,N
        do 50 l=1,3
         g(i,j,l)=r(i,j,l)
         h(i,j,l)=r(i+1,j,l)-r(i,j,l)
         e(i,j,l)=r(i,j+1,l)-r(i,j,l)
         f(i,j,l)=r(i+1,j+1,l)-r(i,j+1,l)-r(i+1,j,l)+r(i,j,l)
  50     continue
  60    continue
  65 continue
      CALL IGESTART(M,N)
      CALL IGESPF(M,N)
      k=0
      do 95 i=1,M
       do 85 j=1,N
        do 80 l=1,3
         k=k+1
         write(8,70) g(i,j,l),',',h(i,j,l),',,,','1P',M+N+3+k
         k=k+1
         write(8,75) e(i,j,l),',',f(i,j,l),',,,,,,,,,,,','1P',M+N+3+k
  70      format (D23.13,A1,D23.13,A3,21X,A2,I7)
  75      format (D23.13,A1,D23.13,A11,13X,A2,I7)
  80     continue
  85    continue
       k=k+1
       write (8,90) ',,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,',
   '             '1P',M+N+3+k
  90    format (A48,23X,A2,I7)
  95 continue
      k=k+1
      write (8,100) ';','1P',M+N+3+k
 100 format(A1,70X,A2,I7)

      return
      end


subroutine ellhy(M,N)
      real ParY,X,MaxD
      integer a,b,c,MaxY
      dimension r(1:50,1:50,1:3)
      dimension g(1:50,1:50,1:3),h(1:50,1:50,1:3)
      dimension e(1:50,1:50,1:3),f(1:50,1:50,1:3)
      dimension t(1:360)
      DOUBLE PRECISION G,H,E,F,R
  print*, 'Equition of ELLIPTIC HYPERBOLOID OF ONE SHEET showes
 '       bellow:'
  print*, 'X*X/a*a-Y*Y/b*b+Z*Z/c*c=1'
  print*, 'Please input integer numbers of the parameter a, b and c'
  read(*,*) a,b,c
  print*
  print*,'Please input the number of degree you want to display'
  print*,'the graphics.'
  read(*,*) MaxD
  print*,'Please input the MAX integer number of Y axis you want'
  read(*,*) MaxY
  X=M
  ParY=MaxY/X
  do 20 i=1,M+1
   do 10 j=1,N+1
    r(i,j,2)=ParY*(i-1)-MaxY/2
    t(j)=((j-1)*MaxD/N)*(3.1415926/180.0)
    w=(1+(r(i,j,2)*r(i,j,2))/(b*b))/(a*a*sin(t(j))*sin(t(j))+
 '           c*c*cos(t(j))*cos(t(j)))
    rt=a*c*sqrt(w)
    r(i,j,1)=rt*cos(t(j))
    r(i,j,3)=rt*sin(t(j))
10   continue
20 continue
  do 65 i=1,M
   do 60 j=1,N
    do 50 l=1,3
    g(i,j,l)=r(i,j,l)
    h(i,j,l)=r(i+1,j,l)-r(i,j,l)
    e(i,j,l)=r(i,j+1,l)-r(i,j,l)
    f(i,j,l)=r(i+1,j+1,l)-r(i,j+1,l)-r(i+1,j,l)+r(i,j,l)
50    continue
60   continue
65 continue
  CALL IGESTART(M,N)
  CALL IGESPF(M,N)
  k=0
  do 95 i=1,M
   do 85 j=1,N
    do 80 l=1,3
     k=k+1
     write(8,70) g(i,j,l),',',h(i,j,l),',,,','1P',M+N+3+k
     k=k+1
     write(8,75) e(i,j,l),',',f(i,j,l),',,,,,,,,,,,','1P',M+N+3+k
70      format (D23.13,A1,D23.13,A3,21X,A2,I7)
```

```
  75      format (D23.13,A1,D23.13,A11,13X,A2,I7)
  80    continue
  85   continue
       k=k+1
       write (8,90) ',,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,',
  '             '1P',M+N+3+k
  90   format (A48,23X,A2,I7)
  95 continue
     k=k+1
     write (8,100) ';','1P',M+N+3+k
 100 format(A1,70X,A2,I7)
     call IGEST(M,N,K)
     return
     end


subroutine ellhyt(M,N)
     real ParX,X,Y,MaxD
     integer a,b,c,MaxX
     dimension r(1:50,1:50,1:3)
     dimension g(1:50,1:50,1:3),h(1:50,1:50,1:3)
     dimension e(1:50,1:50,1:3),f(1:50,1:50,1:3)
     dimension t(1:360)
     DOUBLE PRECISION G,H,E,F,R
     print*, 'Equition of ELLIPTIC HYPERBOLOID OF TWO SHEETS showes
    '        bellow:'
     print*, 'X*X/a*a-Y*Y/b*b-Z*Z/c*c=1'
     print*, 'Please input integer numbers of the parameter a, b and c'
     read(*,*) a,b,c
     print*
     print*, 'Please input the Max integer number of X axis:'
     read(*,*) MaxX
     print*,'Please input the number of degree you want to display'
     print*,'the graphics.'
     read(*,*) MaxD
     X=M
     Y=a
     ParX=(MaxX-a)/X
     do 20 i=1,M+1
       do 10 j=1,N+1
         r(i,j,1)=ParX*(i-1)+Y
         t(j)=((j-1)*MaxD/N)*(3.1415926/180.0)
         w=((r(i,j,1)*r(i,j,1))/(a*a)-1)/(b*b*sin(t(j))*sin(t(j))+
    '           c*c*cos(t(j))*cos(t(j)))
         rt=b*c*sqrt(w)
```

```
        r(i,j,2)=rt*cos(t(j))
        r(i,j,3)=rt*sin(t(j))
 10   continue
 20 continue
      do 65 i=1,M
       do 60 j=1,N
        do 50 l=1,3
        g(i,j,l)=r(i,j,l)
        h(i,j,l)=r(i+1,j,l)-r(i,j,l)
        e(i,j,l)=r(i,j+1,l)-r(i,j,l)
        f(i,j,l)=r(i+1,j+1,l)-r(i,j+1,l)-r(i+1,j,l)+r(i,j,l)
 50     continue
 60   continue
 65 continue
      CALL IGESTART(M,N)
      CALL IGESPF(M,N)
      k=0
      do 95 i=1,M
       do 85 j=1,N
        do 80 l=1,3
         k=k+1
         write(8,70) g(i,j,l),',',h(i,j,l),',,,','1P',M+N+3+k
         k=k+1
         write(8,75) e(i,j,l),',',f(i,j,l),',,,,,,,,,,,','1P',M+N+3+k
 70      format (D23.13,A1,D23.13,A3,21X,A2,I7)
 75      format (D23.13,A1,D23.13,A11,13X,A2,I7)
 80     continue
 85   continue
       k=k+1
       write (8,90) ',,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,',
     '             '1P',M+N+3+k
 90   format (A48,23X,A2,I7)
 95 continue
      k=k+1
      write (8,100) ';','1P',M+N+3+k
100 format(A1,70X,A2,I7)
      call IGEST(M,N,K)
      return
      end


subroutine ellcon(M,N)
      real ParY,X,MaxD
      integer a,b,c,MaxY
      dimension r(1:50,1:50,1:3)
```

```
  dimension g(1:50,1:50,1:3),h(1:50,1:50,1:3)
  dimension e(1:50,1:50,1:3),f(1:50,1:50,1:3)
  dimension t(1:360)
  DOUBLE PRECISION G,H,E,F,R
  print*, 'Equition of ELLIPTIC CONE showes bellow:'
  print*, 'X*X/a*a-Y*Y/b*b+Z*Z/c*c=0'
  print*, 'Please input integer numbers of the parameter a, b and c'
  read(*,*) a,b,c
  print*
  print*,'Please input the MAX integer number of Y axis you want'
  read(*,*) MaxY
  print*,'Please input the number of degree you want to display'
  print*,'the graphics.'
  read(*,*) MaxD
  X=M
  ParY=MaxY/X
  do 20 i=1,M+1
   do 10 j=1,N+1
    r(i,j,2)=ParY*(i-1)
    t(j)=((j-1)*MaxD/N)*(3.1415926/180.0)
    w=((r(i,j,2)*r(i,j,2))/(b*b))/(a*a*sin(t(j))*sin(t(j))+
 '           c*c*cos(t(j))*cos(t(j)))
    rt=a*c*sqrt(w)
    r(i,j,1)=rt*cos(t(j))
    r(i,j,3)=rt*sin(t(j))
10  continue
20 continue
  do 65 i=1,M
   do 60 j=1,N
    do 50 l=1,3
    g(i,j,l)=r(i,j,l)
    h(i,j,l)=r(i+1,j,l)-r(i,j,l)
    e(i,j,l)=r(i,j+1,l)-r(i,j,l)
    f(i,j,l)=r(i+1,j+1,l)-r(i,j+1,l)-r(i+1,j,l)+r(i,j,l)
50    continue
60  continue
65 continue
  CALL IGESTART(M,N)
  CALL IGESPF(M,N)
  k=0
  do 95 i=1,M
   do 85 j=1,N
    do 80 l=1,3
     k=k+1
     write(8,70) g(i,j,l),',',h(i,j,l),',,,','1P',M+N+3+k
```

```
          k=k+1
          write(8,75) e(i,j,l),',',f(i,j,l),',,,,,,,,,,,','1P',M+N+3+k
 70        format (D23.13,A1,D23.13,A3,21X,A2,I7)
 75        format (D23.13,A1,D23.13,A11,13X,A2,I7)
 80       continue
 85     continue
        k=k+1
        write (8,90) ',,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,',
     '              '1P',M+N+3+k
 90     format (A48,23X,A2,I7)
 95 continue
      k=k+1
      write (8,100) ';','1P',M+N+3+k
100 format(A1,70X,A2,I7)
      call IGEST(M,N,K)
      return
      end


subroutine ells(M,N)
      real ParY,X,MaxD
      integer a,c,MaxY
      dimension r(1:50,1:50,1:3)
      dimension g(1:50,1:50,1:3),h(1:50,1:50,1:3)
      dimension e(1:50,1:50,1:3),f(1:50,1:50,1:3)
      dimension t(1:360)
      DOUBLE PRECISION G,H,E,F,R
      print*,'Equition of ELLIPSE showes bellow:'
      print*,'X*X/a*a+Y*Y/b*b=1'
      print*,'Please input integer number of the parameters a, and c'
      read(*,*) a,c
      print*
      print*,'Please input the MAX integer number of Y axis you want'
      read(*,*) MaxY
      print*,'Please input the real number of degree you want to display
     '        the graphics.'
      read(*,*) MaxD
      X=M
      ParY=MaxY/X
      do 20 i=1,2*M+1
        do 10 j=1,N+1
          r(i,j,2)=ParY*(i-1)-MaxY
          t(j)=((j-1)*MaxD/N)*(3.1415926/180.0)
          w=1/(a*a*sin(t(j))*sin(t(j))+
     '              c*c*cos(t(j))*cos(t(j)))
```

```
       rt=a*c*sqrt(w)
       r(i,j,1)=rt*cos(t(j))
       r(i,j,3)=rt*sin(t(j))
   10  continue
   20 continue
     do 65 i=1,M
      do 60 j=1,N
       do 50 l=1,3
       g(i,j,l)=r(i,j,l)
       h(i,j,l)=r(i+1,j,l)-r(i,j,l)
       e(i,j,l)=r(i,j+1,l)-r(i,j,l)
       f(i,j,l)=r(i+1,j+1,l)-r(i,j+1,l)-r(i+1,j,l)+r(i,j,l)
   50    continue
   60  continue
   65 continue
     CALL IGESTART(M,N)
     CALL IGESPF(M,N)
     k=0
     do 95 i=1,M
      do 85 j=1,N
       do 80 l=1,3
        k=k+1
        write(8,70) g(i,j,l),',',h(i,j,l),',,,','1P',M+N+3+k
        k=k+1
        write(8,75) e(i,j,l),',',f(i,j,l),',,,,,,,,,,,','1P',M+N+3+k
   70     format (D23.13,A1,D23.13,A3,21X,A2,I7)
   75     format (D23.13,A1,D23.13,A11,13X,A2,I7)
   80    continue
   85  continue
      k=k+1
      write (8,90) ',,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,',
    '           '1P',M+N+3+k
   90  format (A48,23X,A2,I7)
   95 continue
     k=k+1
     write (8,100) ';','1P',M+N+3+k
  100 format(A1,70X,A2,I7)
     call IGEST(M,N,K)
     return
     end


 subroutine para(M,N)
     real ParX,X,ParY,Y
     integer a,MaxX,MaxY
  dimension r(1:50,1:50,1:3)
  dimension g(1:50,1:50,1:3),h(1:50,1:50,1:3)
  dimension e(1:50,1:50,1:3),f(1:50,1:50,1:3)
  DOUBLE PRECISION G,H,E,F,R
  print*,'Equition of PARABOLA showes bellow:'
  print*,'Z*Z=X/a'
  print*,'Please input integer number of the parameter a'
  read(*,*) a
  print*
  print*,'Please input the MAX integer number of Y axis you want'
  read(*,*) MaxY
  print*,'Please input the MAX integer number of X axis you want'
  read(*,*) MaxX
  X=M
  Y=N
  ParX=MaxX/X
  ParY=MaxY/Y
  do 20 i=1,M+1
   do 10 j=1,N+1
    r(i,j,1)=MaxX-ParX*(j-1)
    r(i,j,2)=(i-1)*ParY
    r(i,j,3)=(-1)*SQRT(r(i,j,1)/a)
10  continue
20 continue
  do 65 i=1,M
   do 60 j=1,N
    do 50 l=1,3
    g(i,j,l)=r(i,j,l)
    h(i,j,l)=r(i+1,j,l)-r(i,j,l)
    e(i,j,l)=r(i,j+1,l)-r(i,j,l)
    f(i,j,l)=r(i+1,j+1,l)-r(i,j+1,l)-r(i+1,j,l)+r(i,j,l)
50   continue
60  continue
65 continue
  CALL IGESTART(M,N)
  CALL IGESPF(M,N)
  k=0
  do 95 i=1,M
   do 85 j=1,N
    do 80 l=1,3
     k=k+1
     write(8,70) g(i,j,l),',',h(i,j,l),',,,','1P',M+N+3+k
     k=k+1
     write(8,75) e(i,j,l),',',f(i,j,l),',,,,,,,,,,,','1P',M+N+3+k
70     format (D23.13,A1,D23.13,A3,21X,A2,I7)
```

```
 75      format (D23.13,A1,D23.13,A11,13X,A2,I7)
 80     continue
 85   continue
      k=k+1
      write (8,90) ',,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,',
    '             '1P',M+N+3+k
 90   format (A48,23X,A2,I7)
 95 continue
     k=k+1
     write (8,100) ';','1P',M+N+3+k
100 format(A1,70X,A2,I7)
     call IGEST(M,N,K)
     return
     end


subroutine hya(M,N)
     real ParZ,Z,ParY,Y
     integer a,c,MaxZ,MaxY
     dimension r(1:50,1:50,1:3)
     dimension g(1:50,1:50,1:3),h(1:50,1:50,1:3)
     dimension e(1:50,1:50,1:3),f(1:50,1:50,1:3)
     DOUBLE PRECISION G,H,E,F,R
     print*,'Equition of HYPERBOLA showes bellow:'
     print*,'X*X/a*a-Z*Z/c*c=1'
     print*,'Please input integer number of the parameters a, and c'
     read(*,*) a,c
     print*
     print*,'Please input the MAX integer number of Z axis you want'
     read(*,*) MaxZ
     print*,'Please input the MAX integer number of Y axis you want'
     read(*,*) MaxY
     Z=N
     Y=M
     ParZ=MaxZ/Z
     ParY=MaxY/Y
     do 20 i=1,M+1
       do 10 j=1,N+1
         r(i,j,3)=ParZ*(j-1)
         r(i,j,2)=(i-1)*ParY
         r(i,j,1)=a*SQRT(1+(r(i,j,3)*r(i,j,3))/(a*a))
 10   continue
 20 continue
     do 65 i=1,M
       do 60 j=1,N
```

```
        do 50 l=1,3
        g(i,j,l)=r(i,j,l)
        h(i,j,l)=r(i+1,j,l)-r(i,j,l)
        e(i,j,l)=r(i,j+1,l)-r(i,j,l)
        f(i,j,l)=r(i+1,j+1,l)-r(i,j+1,l)-r(i+1,j,l)+r(i,j,l)
 50      continue
 60    continue
 65 continue
      CALL IGESTART(M,N)
      CALL IGESPF(M,N)
      k=0
      do 95 i=1,M
       do 85 j=1,N
        do 80 l=1,3
         k=k+1
         write(8,70) g(i,j,l),',',h(i,j,l),',,,','1P',M+N+3+k
         k=k+1
         write(8,75) e(i,j,l),',',f(i,j,l),',,,,,,,,,,,','1P',M+N+3+k
 70       format (D23.13,A1,D23.13,A3,21X,A2,I7)
 75       format (D23.13,A1,D23.13,A11,13X,A2,I7)
 80      continue
 85    continue
       k=k+1
       write (8,90) ',,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,',
  '               '1P',M+N+3+k
 90    format (A48,23X,A2,I7)
 95 continue
      k=k+1
      write (8,100) ';','1P',M+N+3+k
100 format(A1,70X,A2,I7)
      call IGEST(M,N,K)
      return
      end


subroutine elsoid(M,N)
      dimension r(1:50,1:50,1:3)
      dimension g(1:50,1:50,1:3),h(1:50,1:50,1:3)
      dimension e(1:50,1:50,1:3),f(1:50,1:50,1:3)
      dimension t(1:50)
      integer a,b,c
      real ParX,X,MaxD
      double precision R,G,H,E,F
      print*,'Equition of ELLIPSOID showes bellow:'
      print*,'X*X/a*a+Y*Y/b*b+Z*Z/c*c=1'
  print*,'Please input integer number of the parameters a, b and c'
  read(*,*) a,b,c
  print*
  print*,'Please input the real number of degree you want to display
'       the graphics.'
  read(*,*) MaxD
  X=N
  ParX=a/X
  do 20 i=1,M+1
   do 10 j=1,N+1
    r(i,j,1)=a-ParX*(j-1)
    t(i)=((i-1)*MaxD/M)*(3.1415926/180.0)
    w=(1-(r(i,j,1)*r(i,j,1))/(a*a))/(b*b*sin(t(i))*sin(t(i))+
'              c*c*cos(t(i))*cos(t(i)))
    rt=b*c*sqrt(w)
    r(i,j,2)=rt*cos(t(i))
    r(i,j,3)=rt*sin(t(i))
10   continue
20 continue
  do 65 i=1,M
   do 60 j=1,N
    do 50 l=1,3
    g(i,j,l)=r(i,j,l)
    h(i,j,l)=r(i+1,j,l)-r(i,j,l)
    e(i,j,l)=r(i,j+1,l)-r(i,j,l)
    f(i,j,l)=r(i+1,j+1,l)-r(i,j+1,l)-r(i+1,j,l)+r(i,j,l)
50     continue
60   continue
65 continue
  CALL IGESTART(M,N)
  CALL IGESPF(M,N)
  k=0
  do 95 i=1,M
   do 85 j=1,N
    do 80 l=1,3
     k=k+1
     write(8,70) g(i,j,l),',',h(i,j,l),',,,','1P',M+N+3+k
     k=k+1
     write(8,75) e(i,j,l),',',f(i,j,l),',,,,,,,,,,,','1P',M+N+3+k
70      format (D23.13,A1,D23.13,A3,21X,A2,I7)
75      format (D23.13,A1,D23.13,A11,13X,A2,I7)
80     continue
85   continue
   k=k+1
   write (8,90) ',,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,',
  '           '1P',M+N+3+k
 90   format (A48,23X,A2,I7)
 95 continue
    k=k+1
    write (8,100) ';','1P',M+N+3+k
100 format(A1,70X,A2,I7)
    call IGEST(M,N,K)
    return
    end


subroutine IGESTART(M,N)
     write(8,5) 'S0000001'
   5 format(72X,A8)
    write(8,6) ',,',4,'HIGES,',6,'Hfort.8,',12,'HAUTO_DRAWING,',
   '7,'HPROGRAM,',32,',',38,',',6,',',99,',',15,',','G0000001'
   6 format (A2,I1,A6,I1,A8,I2,A14,I1,A9,I2,A1,I2,A1,I1,A1,
   'I2,A1,I2,A1,14X,A8)
    WRITE(8,7) 1,'HI,',1.0,',',1,',',4,'HINCH,',32767,',',3.276D1,
   ",',13,'H890705.193000,',7.0D-9,',',7.0,',','G0000002'
   7 format (I1,A3,F3.1,A1,I1,A1,I1,A6,I5,A1,D9.4,A1,I2,A15,D7.1,
   'A1,F3.1,A1,10X,A8)
    write(8,8) 12,'H SELF-GREATE,',5,'H NJIT,',6,',',0,';','G0000003'
   8 format (I2,A14,I1,A7,I1,A1,I1,A1,44X,A8)
    write(8,20) 114,1,1,1,'00000000','D0000001'
  20 format(4I8,32X,2A8)
    write(8,30) 114,((6*N+1)*M+M+N+4),'D0000002'
  30 format(I8,16X,I8,40X,A8)
    return
    end


subroutine IGESPF(M,N)
    write (8,1) 114,',',1,',',1,',',M,',',N,',','1P',1
   1 format (I3,A1,I1,A1,I1,A1,I3,A1,I3,A1,55X,A2,I7)
    x=1.0
    do 10 i=1,M+1
      write(8,5) x,',','1P',i+1
   5   format(F5.1,A1,65X,A2,I7)
      x=x+1.0
  10 continue
    x=1.0
    do 20 j=1,N+1
      write(8,15) x,',','1P',M+2+j
  15   format(F5.1,A1,65X,A2,I7)
```

```
      x=x+1.0
  20 continue
    return
    end


subroutine IGEST(M,N,K)
    write(8,10) 'S',1,'G',3,'D',2,'P',(M+N+3+K),'T',1
  10 format(A1,I7,A1,I7,A1,I7,A1,I7,40X,A1,I7)
    return
    end
```

APPENDIX B

IGES FILE

```
                                                                        S0000001
,,4HIGES,6Hfort.8,12HAUTO_DRAWING,7HPROGRAM,32,38,6,99,15,              G0000001
1HI,1.0,1,4HINCH,32767,.3276D+02,13H890705.193000,0.7D-08,7.0,          G0000002
12H SELF-GREATE,5H NJIT,6,0;                                            G0000003
     114       1       1       1                                00000000D0000001
     114                      67                                        D0000002
114,1,1,  3,  3,                                                       1P      1
  1.0,                                                                 1P      2
  2.0,                                                                 1P      3
  3.0,                                                                 1P      4
  4.0,                                                                 1P      5
  1.0,                                                                 1P      6
  2.0,                                                                 1P      7
  3.0,                                                                 1P      8
  4.0,                                                                 1P      9
    0.0000000000000D+00,    0.0000000000000D+00,,,                     1P     10
    0.4041451931000D+01,   -0.5582241296768D+01,,,,,,,,,,,             1P     11
    0.0000000000000D+00,    0.0000000000000D+00,,,                     1P     12
    0.0000000000000D+00,    0.2668725013733D+01,,,,,,,,,,,             1P     13
    0.0000000000000D+00,    0.0000000000000D+00,,,                     1P     14
    0.1000000000000D+01,    0.0000000000000D+00,,,,,,,,,,,             1P     15
    0.4041451931000D+01,   -0.5582241296768D+01,,,                     1P     16
    0.1674024105072D+01,   -0.2312239646912D+01,,,,,,,,,,,             1P     17
    0.0000000000000D+00,    0.2668725013733D+01,,,                     1P     18
    0.0000000000000D+00,    0.1105421781540D+01,,,,,,,,,,,             1P     19
    0.1000000000000D+01,    0.0000000000000D+00,,,                     1P     20
    0.1000000000000D+01,    0.0000000000000D+00,,,,,,,,,,,             1P     21
    0.5715476036072D+01,   -0.7894480943680D+01,,,                     1P     22
    0.1284523963928D+01,   -0.1774244308472D+01,,,,,,,,,,,          1P     23
    0.0000000000000D+00,    0.3774146795273D+01,,,                  1P     24
    0.0000000000000D+00,    0.8482205867767D+00,,,,,,,,,,,          1P     25
    0.2000000000000D+01,    0.0000000000000D+00,,,                  1P     26
    0.1000000000000D+01,    0.0000000000000D+00,,,,,,,,,,,          1P     27
,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,                        1P     28
    0.0000000000000D+00,    0.0000000000000D+00,,,                  1P     29
   -0.1540789365768D+01,    0.4768371582031D-06,,,,,,,,,,,          1P     30
    0.0000000000000D+00,    0.0000000000000D+00,,,                  1P     31
    0.2668725013733D+01,   -0.5337450265884D+01,,,,,,,,,,,          1P     32
    0.0000000000000D+00,    0.0000000000000D+00,,,                  1P     33
    0.1000000000000D+01,    0.0000000000000D+00,,,,,,,,,,,          1P     34
   -0.1540789365768D+01,    0.4768371582031D-06,,,                  1P     35
   -0.6382155418396D+00,    0.2384185791016D-06,,,,,,,,,,,          1P     36
    0.2668725013733D+01,   -0.5337450265884D+01,,,                  1P     37
    0.1105421781540D+01,   -0.2210843563080D+01,,,,,,,,,,,          1P     38
    0.1000000000000D+01,    0.0000000000000D+00,,,                  1P     39
    0.1000000000000D+01,    0.0000000000000D+00,,,,,,,,,,,          1P     40
   -0.2179004907608D+01,    0.7152557373047D-06,,,                  1P     41
   -0.4897203445435D+00,    0.0000000000000D+00,,,,,,,,,,,          1P     42
    0.3774146795273D+01,   -0.7548293828964D+01,,,                  1P     43
    0.8482205867767D+00,   -0.1696440935135D+01,,,,,,,,,,,          1P     44
    0.2000000000000D+01,    0.0000000000000D+00,,,                  1P     45
    0.1000000000000D+01,    0.0000000000000D+00,,,,,,,,,,,          1P     46
,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,                        1P     47
    0.0000000000000D+00,    0.0000000000000D+00,,,                  1P     48
   -0.1540788888931D+01,    0.5582240819931D+01,,,,,,,,,,,          1P     49
    0.0000000000000D+00,    0.0000000000000D+00,,,                  1P     50
   -0.2668725252151D+01,    0.2668725958781D+01,,,,,,,,,,,          1P     51
    0.0000000000000D+00,    0.0000000000000D+00,,,                  1P     52
    0.1000000000000D+01,    0.0000000000000D+00,,,,,,,,,,,          1P     53
   -0.1540788888931D+01,    0.5582240819931D+01,,,                  1P     54
   -0.6382153034210D+00,    0.2312239408493D+01,,,,,,,,,,,          1P     55
   -0.2668725252151D+01,    0.2668725958781D+01,,,                  1P     56
   -0.1105421781540D+01,    0.1105422074236D+01,,,,,,,,,,,          1P     57
    0.1000000000000D+01,    0.0000000000000D+00,,,                  1P     58
    0.1000000000000D+01,    0.0000000000000D+00,,,,,,,,,,,             1P     59
   -0.2179004192352D+01,    0.7894480228424D+01,,,                     1P     60
   -0.4897203445435D+00,    0.1774244308472D+01,,,,,,,,,,,             1P     61
   -0.3774147033691D+01,    0.3774148033017D+01,,,                     1P     62
   -0.8482203483582D+00,    0.8482205729514D+00,,,,,,,,,,,             1P     63
    0.2000000000000D+01,    0.0000000000000D+00,,,                     1P     64
    0.1000000000000D+01,    0.0000000000000D+00,,,,,,,,,,,             1P     65
,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,                       1P     66
;                                                                      1P     67
S      1G      3D      2P      67                                       T      1
```

The patches of the file listed above is only 3*3 and the surface is Elliptic Paraboloid for the format illustration only.

APPENDIX C

CL FILE

```
MACHIN/AIMILL,0,161,0,LINCIR
PARTNO/Part2
FROM/ 0.000000,0.000000,0.000000
COOLNT/FLOOD
LOADTL/0, 0.000000, 1.000000
GOHOME
ROTABL/ 0.000000
SPINDL/RPM, 2200.000000, CLW
RAPID
GOTO/-4.828288, -1.715545, 4.072218
FEDRAT/21.999956, IPM
RAPID
GOTO/-4.828288, -1.715545, 2.646837
FEDRAT/21.999956, IPM
GOTO/-5.033318, -1.715545, 2.546837
FEDRAT/21.999956, IPM
GOTO/-4.871573, -1.715545, 2.398864
GOTO/-4.804594, -1.715545, 2.339304
GOTO/-4.358182, -1.715545, 1.970077
GOTO/-4.307489, -1.715545, 1.928580
GOTO/-3.733285, -1.715545, 1.510123
GOTO/-3.729775, -1.715545, 1.507890
GOTO/-3.491860, -1.715545, 1.361642
GOTO/-3.487987, -1.709771, 1.367945
GOTO/-3.486675, -1.707816, 1.374086
GOTO/-3.478595, -1.695773, 1.402765
GOTO/-3.468932, -1.681369, 1.429167
GOTO/-3.457265, -1.663979, 1.454037
GOTO/-3.444046, -1.644276, 1.476052
GOTO/-3.429376, -1.622411, 1.495044
GOTO/-3.421753, -1.611048, 1.502521
GOTO/-3.420274, -1.608844, 1.504303
GOTO/-3.418060, -1.605545, 1.506143
GOTO/-3.412446, -1.597176, 1.511649
GOTO/-3.405665, -1.587069, 1.516448
GOTO/-3.401430, -1.580757, 1.519969
GOTO/-3.401430, -1.580757, 1.519445
GOTO/-3.394167, -1.569931, 1.524585
GOTO/-3.394167, -1.569931, 1.520581
GOTO/-3.388958, -1.562166, 1.529057
GOTO/-3.623050, -1.562166, 1.672875
GOTO/-4.190448, -1.562166, 2.086433
GOTO/-4.192627, -1.562166, 2.088064
GOTO/-4.691775, -1.562166, 2.501090
GOTO/-4.699419, -1.562166, 2.507603
GOTO/-4.900633, -1.562166, 2.691789
```

```
GOTO/-4.898782, -1.554652, 2.693810
GOTO/-4.895779, -1.542457, 2.701092
GOTO/-4.889165, -1.515599, 2.713658
GOTO/-4.882522, -1.488621, 2.722728
GOTO/-4.877203, -1.467022, 2.727676
GOTO/-4.867764, -1.428691, 2.731721
GOTO/-4.865907, -1.421147, 2.731856
GOTO/-4.864170, -1.414093, 2.731622
GOTO/-4.862863, -1.408788, 2.733050
GOTO/-4.662294, -1.408788, 2.549453
GOTO/-4.655765, -1.408788, 2.543895
GOTO/-4.157968, -1.408788, 2.131989
GOTO/-4.157132, -1.408788, 2.131367
GOTO/-3.591921, -1.408788, 1.719405
GOTO/-3.359666, -1.408788, 1.576711
GOTO/-3.359514, -1.394783, 1.576959
GOTO/-3.359138, -1.360074, 1.579419
GOTO/-3.358561, -1.306901, 1.578510
GOTO/-3.358002, -1.255409, 1.579418
GOTO/-3.590691, -1.255409, 1.722443
GOTO/-4.157252, -1.255409, 2.135521
GOTO/-4.659047, -1.255409, 2.550789
GOTO/-4.860718, -1.255409, 2.735394
GOTO/-4.860718, -1.102030, 2.735394
GOTO/-4.659047, -1.102030, 2.550789
GOTO/-4.157252, -1.102030, 2.135521
GOTO/-3.590691, -1.102030, 1.722443
GOTO/-3.358002, -1.102030, 1.579418
GOTO/-3.358002, -0.948651, 1.578714
GOTO/-3.590691, -0.948651, 1.722443
GOTO/-4.157252, -0.948651, 2.135521
GOTO/-4.659047, -0.948651, 2.550789
GOTO/-4.860718, -0.948651, 2.735394
GOTO/-4.860718, -0.795272, 2.735394
GOTO/-4.659047, -0.795272, 2.550789
GOTO/-4.157252, -0.795272, 2.135521
GOTO/-3.590691, -0.795272, 1.722443
GOTO/-3.358002, -0.795272, 1.579418
GOTO/-3.358002, -0.641894, 1.579418
GOTO/-3.590691, -0.641894, 1.722443
GOTO/-4.157252, -0.641894, 2.135521
GOTO/-4.659047, -0.641894, 2.550789
GOTO/-4.860718, -0.641894, 2.735394
GOTO/-4.860718, -0.488515, 2.735394
GOTO/-4.659047, -0.488515, 2.550789
GOTO/-4.157252, -0.488515, 2.135521
GOTO/-3.590691, -0.488515, 1.722443
GOTO/-3.358002, -0.488515, 1.579418
GOTO/-3.358002, -0.335136, 1.579418
GOTO/-3.590691, -0.335136, 1.722443
GOTO/-4.157252, -0.335136, 2.135521
GOTO/-4.659047, -0.335136, 2.550789
GOTO/-4.860718, -0.335136, 2.735394
GOTO/-4.860718, -0.181757, 2.735394
```

```
GOTO/-4.659047, -0.181757, 2.550789
GOTO/-4.157252, -0.181757, 2.135521
GOTO/-3.590691, -0.181757, 1.722443
GOTO/-3.358002, -0.181757, 1.579418
GOTO/-3.358002, -0.028379, 1.578714
GOTO/-3.590691, -0.028379, 1.722443
GOTO/-4.157252, -0.028379, 2.135521
GOTO/-4.659047, -0.028379, 2.550789
GOTO/-4.860718, -0.028379, 2.735394
GOTO/-4.860718, 0.125000, 2.735394
GOTO/-4.659047, 0.125000, 2.550789
GOTO/-4.157252, 0.125000, 2.135521
GOTO/-3.590691, 0.125000, 1.722443
GOTO/-3.358002, 0.125000, 1.579418
GOTO/-3.358002, 0.278379, 1.578714
GOTO/-3.590691, 0.278379, 1.722443
GOTO/-4.157252, 0.278379, 2.135521
GOTO/-4.659047, 0.278379, 2.550789
GOTO/-4.860718, 0.278379, 2.735394
GOTO/-4.860718, 0.431758, 2.735394
GOTO/-4.659047, 0.431758, 2.550789
GOTO/-4.157252, 0.431758, 2.135521
GOTO/-3.590691, 0.431758, 1.722443
GOTO/-3.358002, 0.431758, 1.579418
GOTO/-3.358002, 0.585137, 1.579418
GOTO/-3.590691, 0.585137, 1.722443
GOTO/-4.157252, 0.585137, 2.135521
GOTO/-4.659047, 0.585137, 2.550789
GOTO/-4.860718, 0.585137, 2.735394
GOTO/-4.860718, 0.738515, 2.735394
GOTO/-4.659047, 0.738515, 2.550789
GOTO/-4.157252, 0.738515, 2.135521
GOTO/-3.590691, 0.738515, 1.722443
GOTO/-3.358002, 0.738515, 1.579418
GOTO/-3.358002, 0.891894, 1.579418
GOTO/-3.590691, 0.891894, 1.722443
GOTO/-4.157252, 0.891894, 2.135521
GOTO/-4.659047, 0.891894, 2.550789
GOTO/-4.860718, 0.891894, 2.735394
GOTO/-4.860718, 1.045273, 2.735394
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GOTO/-4.157252, 1.045273, 2.135521
GOTO/-3.590691, 1.045273, 1.722443
GOTO/-3.358002, 1.045273, 1.579418
GOTO/-3.358002, 1.198652, 1.579418
GOTO/-3.590691, 1.198652, 1.722443
GOTO/-4.157252, 1.198652, 2.135521
GOTO/-4.659047, 1.198652, 2.550789
GOTO/-4.860718, 1.198652, 2.735394
GOTO/-4.860718, 1.352031, 2.735394
GOTO/-4.659047, 1.352031, 2.550789
GOTO/-4.157252, 1.352031, 2.135521
GOTO/-3.590691, 1.352031, 1.722443
GOTO/-3.358002, 1.352031, 1.579418
```

```
GOTO/-3.358002, 1.505409, 1.578714
GOTO/-3.590691, 1.505409, 1.722443
GOTO/-4.157252, 1.505409, 2.135521
GOTO/-4.659047, 1.505409, 2.550789
GOTO/-4.860718, 1.505409, 2.735394
GOTO/-4.861427, 1.565271, 2.734619
GOTO/-4.862003, 1.613962, 2.735148
GOTO/-4.862238, 1.633770, 2.733733
GOTO/-4.862534, 1.658788, 2.733410
GOTO/-4.744659, 1.658788, 2.625510
GOTO/-4.655377, 1.658788, 2.544260
GOTO/-4.160342, 1.658788, 2.134445
GOTO/-3.593494, 1.658788, 1.721008
GOTO/-3.359411, 1.658788, 1.577127
GOTO/-3.359984, 1.661895, 1.576195
GOTO/-3.363090, 1.678750, 1.575152
GOTO/-3.368844, 1.709975, 1.570548
GOTO/-3.370330, 1.718038, 1.568516
GOTO/-3.371086, 1.722141, 1.567823
GOTO/-3.372514, 1.729892, 1.565528
GOTO/-3.374056, 1.738258, 1.563419
GOTO/-3.375157, 1.744231, 1.561283
GOTO/-3.376199, 1.749885, 1.559609
GOTO/-3.377299, 1.755857, 1.557124
GOTO/-3.379122, 1.765749, 1.553585
GOTO/-3.381081, 1.776380, 1.548584
GOTO/-3.382284, 1.782908, 1.545867
GOTO/-3.384010, 1.792272, 1.541108
GOTO/-3.384010, 1.792272, 1.537107
GOTO/-3.387676, 1.812167, 1.531142
GOTO/-3.623914, 1.812167, 1.676387
GOTO/-4.192141, 1.812167, 2.090830
GOTO/-4.352048, 1.812167, 2.223173
GOTO/-4.689790, 1.812167, 2.502676
GOTO/-4.781105, 1.812167, 2.585695
GOTO/-4.898980, 1.812167, 2.693595
GOTO/-4.901538, 1.815259, 2.690800
GOTO/-4.905783, 1.820389, 2.690165
GOTO/-4.929105, 1.848575, 2.682867
GOTO/-4.945970, 1.868956, 2.673513
GOTO/-4.966877, 1.894223, 2.656349
GOTO/-4.993007, 1.925802, 2.623317
GOTO/-4.993007, 1.925802, 2.590875
GOTO/-5.019095, 1.957330, 2.562375
GOTO/-5.019095, 1.957330, 2.566386
GOTO/-5.020756, 1.959338, 2.560560
GOTO/-5.025893, 1.965546, 2.554949
GOTO/-4.907991, 1.965546, 2.447079
GOTO/-4.809627, 1.965546, 2.357870
GOTO/-4.387423, 1.965546, 2.008522
GOTO/-4.302877, 1.965546, 1.938950
GOTO/-3.761519, 1.965546, 1.544247
GOTO/-3.721933, 1.965546, 1.515966
GOTO/-3.486102, 1.965546, 1.371011
```

```
FEDRAT/21.999956, IPM
GOTO/-3.486102, 1.965546, 1.746011
FEDRAT/21.999956, IPM
RAPID
GOTO/-3.486102, 1.965546, 4.072218
GOHOME
END
FINI
```

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