A Distributed Structural Design Graphics System

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Introduction

The FASTDRAW/3 distributed graphics system includes commands to generate points and elements in local coordinate systems, perform simple construction of arcs, circles and create arbitrary space curves and surfaces. FASTDRAW/3 can automatically create a mesh of elements on a defined surface after control points along the boundaries have been selected. Also, elements can be duplicated by any combination of translation, rotation, and scaling in two or three dimensions. FASTDRAW/3 supports user defined elements that allow a design to be accomplished in parts and the parts then combined to build the final geometric model.

The FASTDRAW/3 distributed processing system is compared with alternative systems on large mainframe computers, standalone mini-computers, and desktop computers. The distributed processing system is part of the MCAUTO network of remote job entry stations. It is a mini-computer implementation of FASTDRAW/3 with enhancements to provide better service. Local plotting from a high speed pen and ink plotter that is directly attached to the mini-computer gives the engineer fast turnaround on plots of his design at intermediate steps. Error free communications between the user's graphic CRT and the FASTDRAW/3 system occurs at speeds higher than available from conventional remote timesharing services.

The structural design engineer today has a choice of computer programs and systems which are supposed to reduce the work required to create the input data used by finite element analysis programs such as STRUDL, EASE, ANSYS, etc.

The manner in which the engineer uses these preprocessing systems varies from one program to another. Some are simple prompting programs that create card files to be scanned and subsequently plotted on a graphics CRT.

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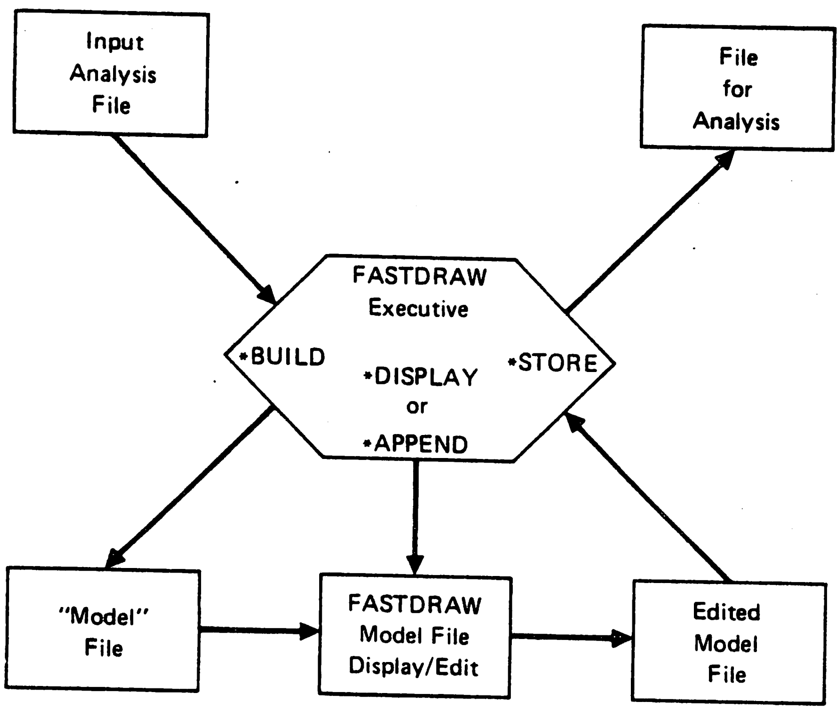
These prompters are usually specific for a single analysis input format and are cumbersum if used in an interactive design process. The programs that allow interactive design and editing do not all satisfy reasonable expectations for ease of use, understandable conventions, and good response.

This paper describes the FASTDRAW/3 interactive graphics system as it is implemented in the McDonnell Douglas Automation Company distributed processing network.

The system provides interactive finite element design pre and postprocessing as well as access to analysis programs such as STRUDL, NASTRAN, ANSYS, EASE, SAP which execute on MCAUTO's large IBM and CDC remote job entry computers.

FASTDRAW/3 Features

FASTDRAW/3 allows the finite element designer to create, display, and modify a special data file known as the model file. The interactions with the program are performed from an interactive graphics CRT. The FASTDRAW/3 Executive (see Fig. 1) interfaces the engineer with the model manipulation command subsystem and with the conversion interfaces for STRUDL, NASTRAN, ANSYS, EASE2, and SAP5.



FASTDRAW/3 ORGANIZATION
Figure 1

1.1 The FASTDRAW/3 Model File

Using FASTDRAW/3 in finite element design consists of creating and modifying data kept in the model file. A model file contains points, local coordinate system definitions, elements, boundaries, and regions. Let's briefly descirbe each of these.

Point data consists of the x,y,z coordinates, a reference to a local coordinate system, an identifying label, force constraints, a count of the number of elements that use the point and the number of times the point is used by boundaries. Points attached to a boundary are called control points because they control the mesh that is generated on a region formed with that boundary.

A local coordinate system has a label, the coordinates of its origin, and a type(rectangular, cylindrical, or spherical).

FASTDRAW/3 elements are either finite elements specific for an analysis program or are user-defined elements. A user-defined element is constructed in its own model file, and consists of application finite elements. In another model file, instances (incidences) of the entire user-defined element can be created by locating the definition points to be used in the new model, and by also indicating which user-defined element is required.

Boundaries are used to create a mesh of points and elements on a region. A boundary can be a straight line, a circular arc, or a space curve. Points are created along a boundary to influence the generation of a mesh and in some cases to aid in the creation of additional boundaries. A temporary boundary consisting of several other connected bounaries can be specified with the PATH command.

The last FASTDRAW/3 data type is the region. A region is a surface or part of a surface. The region is speified by three or four sides which are one or several boundraies. The region is used to generate a mesh of finitie elements such that the points in the mesh are on the region.

The values of these data types is easily printed for inspection on the CRT by using the PRINT command.

1.2 Command Usage.

Commands will usually be shown with their optional parameters. When a required parameter is left off of the command line, FASTDRAW/3 will request the user to enter the missing parameter values. This is an important feature for someone unfamiliar with a specific command.

When using the FASTDRAW/3 model file editor all commands are always available.

What this means is that the user is not required to make command selections that limit what operations can be done at a particular stage of the design.

1.3 Label, PRINT Command

The first example is the LABEL command. It is used to print the labels of model file data entities which are currently displayed. Its full syntax is:

```
LABEL type[(list)],[type...] [REACTIONS][MESH]
```

LABEL will label Points, elements, regions, systems, and boundaries, or all types of data as well as reactions(i.e., constraints) and meshs. If no parameters are specified, then the data type choices are printed on the CRT and the user selects one of the types. FASTDRAW/3 will then label all of the occurences of that type in the picture. An example of LABEL which will label all the regions, and the points numbered between 10 and 50:

```
LABEL R,P(10-50)
```

The values of the FASTDRAW/3 data types that were described in the preceeding section can be displayed very simply by using the PRINT command:

```
PRINT [type[(list)]]... [PATH] [SWITCH]
```

So, to print the model file's point data, this command would be used:

```
PRINT P
```

1.4 Display Control

FASTDRAW/3 has several commands which control the display of the model file. They do not change values of the model data, only change the picture that is visible on the CRT. Two of these commands, LABEL and PRINT, have already been described.

The REORIENT command lets the user select three viewing angles which causes the picture to be redrawn in the desired orientation:

```
REO ANG(thetaz,thetay,thetax)
```

If no angles are specified, the command prompts the user to enter the angles.

Portions of the picture can be magnified for closer inspection(zoom) by using the WINDOW command. WINDOW lets the user pick two points from the model or two points on the CRT screen(using a cross-hair cursor) which define opposite corners of a rectangle that is to be enlarged to fill the CRT screen.

2.0 Model file Data Creation

The different model file data types (points, elements, systems, regions, boundaries) each have their own set of commands that are used to construct new occurrences of these data types. In addition, points and elements can be duplicated using four special duplication commands. There is also a command to generate a mesh of points and elements on a region.

2.1 Creating Points

There are nine commands that will create points in the model file. These are:

POINT DIGITIZE
POINT at the intersection of 2 boundaries
POINT KEYIN
POINT HORIZONTAL
POINT VERTICAL
POINT on a BOUNDARY
POINT on a PATH
POINT on a REGION

Keyed-in points may be specified in a user-defined local coordinate system (rectngular, cylindrical, or spherical). As an example, if local system number 1 is a spherical system, the FASTDRAW/3 command

```
POI KEY SYS(1)
```

would prompt by printing

```
ENTER   R,THETA,PHI
```

Then coordinate triples could be entered, with an empty line terminating the input.

The POINT ON A BOUNDARY command has five variations which offer different methods for automatically calculating the distances between the new points that are placed on the selected boundary.

2.2 Creating Elements

FASTDRAW/3 uses the same commands to create both user-defined elements and application finite elements. Elements can be constructed one at a time or by using the duplication commands or the MESH command.

A FASTDRAW/3 user selects which application or user-defined elements are going to be used and assigns the element a number. To add a single element instance to the model file the ELEMENT command is used. The required definition points are specified by their label or by digitizing each point on the CRT screen

```
ELEMENT BOX(n) P(point list)
   or ELn P(point list)
```

(where "n" is the number that was assigned to the element by the user).

For example, EL2 P(1,7,10,4) could be used to add a new occurrence of the element assigned to box 2 (it has four definition points).

This is the manual method of creating elements.

There are also four element and point generation commands that can create new elements and points from existing points and elements:

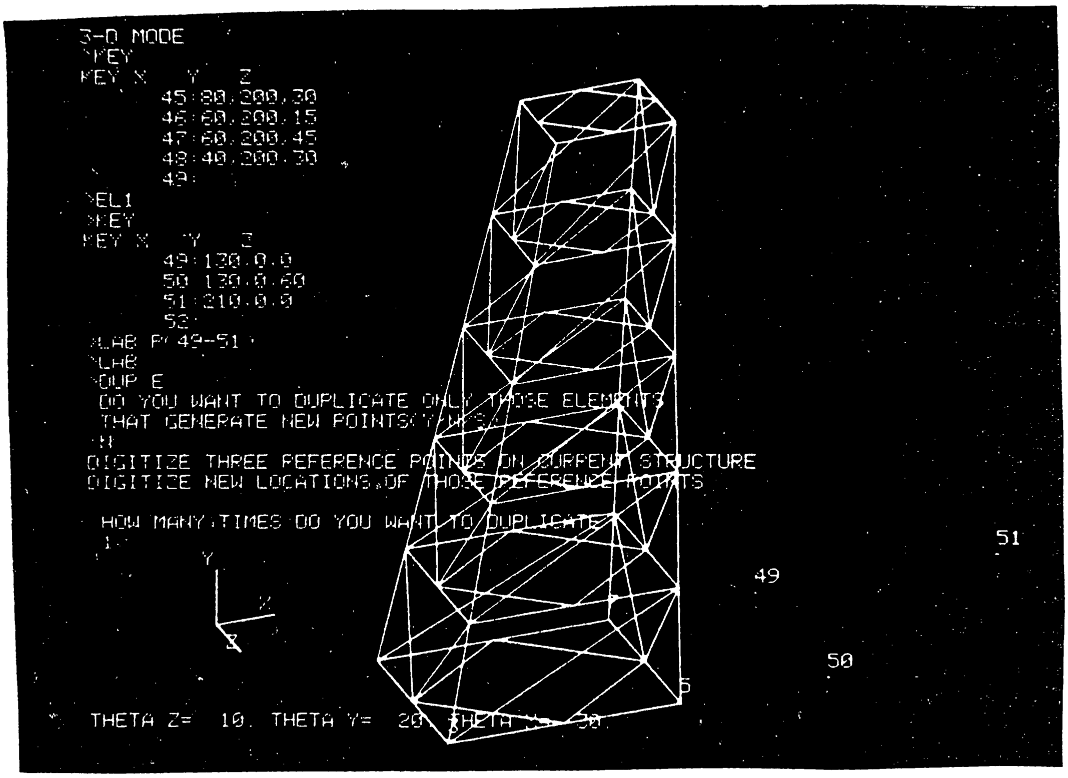
- TRANSLATE
- ROTATE
- TRAVERSE
- DUPLICATE

The TRAVERSE command generates new elements by translating points in the same plane or in a plane parallel to the current plane.

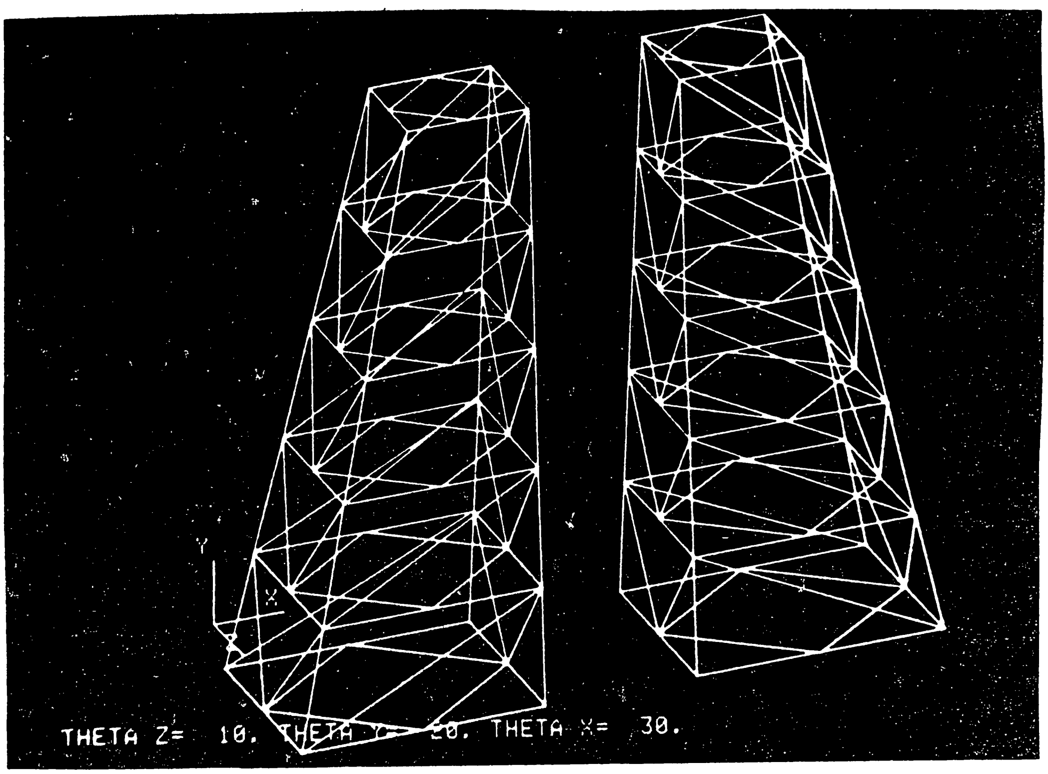
The ROTATE command duplicates the desired elements by rotating the new elements a specified number of degrees about an axis lying in the current plane, or one perpendicular to the current plane.

The TRAVERSE command is specifically designed for truss generation because it generates the duplicates such that the reference lines in the new elements have the same slope as in the original.

The DUPLICATE command works in three dimensions and combines translation, rotation and scaling for creating duplicates. (see Figures 2, 3)



MODEL BEFORE ELEMENT DUPLICATION
Figure 2



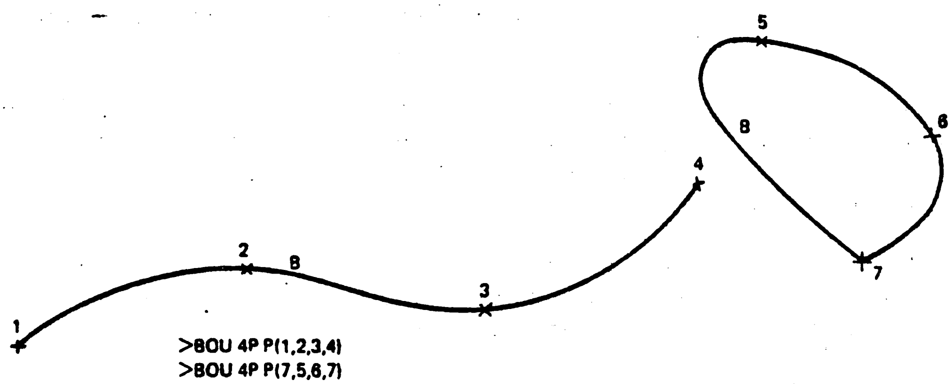
MODEL AFTER ELEMENT DUPLICATION
Figure 3

2.3 Creating Boundaries

There are fifteen boundary creation commands. These commands create standard geometric boundaries:

LINE P	line, given a point and an angle
LINE NP	line through a series of points
LINE LINE	line parallel to another line
ARC 3P	circular arc through 3 points
ARC 2L	arc tangent to 2 lines
ARC 3L	arc tangent to 3 lines
CIRCLE P	circle, center point and radius
CIRCLE 2P	circle, center, circumference pt.
CIRCLE 3P	circle, given 3 points
BOUNDARY 4P	space curve through 4 pts.
BOUNDARY SPLIT	two boundaries by cutting the existing one
BOUNDARY REGION	boundary string through points on a region
BOUNDARY NP	smooth boundary through points

The BOUNDARY 4P command will create a cubic space curve through four model file points (See Figure 4).



BOUNDARY FROM 4 POINTS
Figure 4

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The BOUNDARY NP command uses a series of model file points to create a continuous spline curve. The mathematical technique used by FASTDRAW/3 to represent boundaries is called parametric cubic geometry. (See Ref. 2)

When describing a complex shape with FASTDRAW/3 several different boundaries may be needed to model the geometry of the object.

The PATH command: PATH B(boundary list) lists a set of boundaries that together define a continuous boundary chain. The path is used in creating points along the path, or in creating a region (surface) that follows the path (see REGION PATH).

2.4 Creating Regions(Surfaces)

There are five commands used to create regions with FASTDRAW/3:

```
REGION PATH B(boundary list)
REGION SPHERE RADIUS(r) THETA(tba,tea)
              PHI(pba,pea) SYSTEM(s)
REGION SUBDIVIDE R(r1) B(b1) B(b2) B(b3) B(b4)
REGION 4B B(b11) B(b2) B(b13) B(b4)
REGION RULED B(b11) B(b12)
```

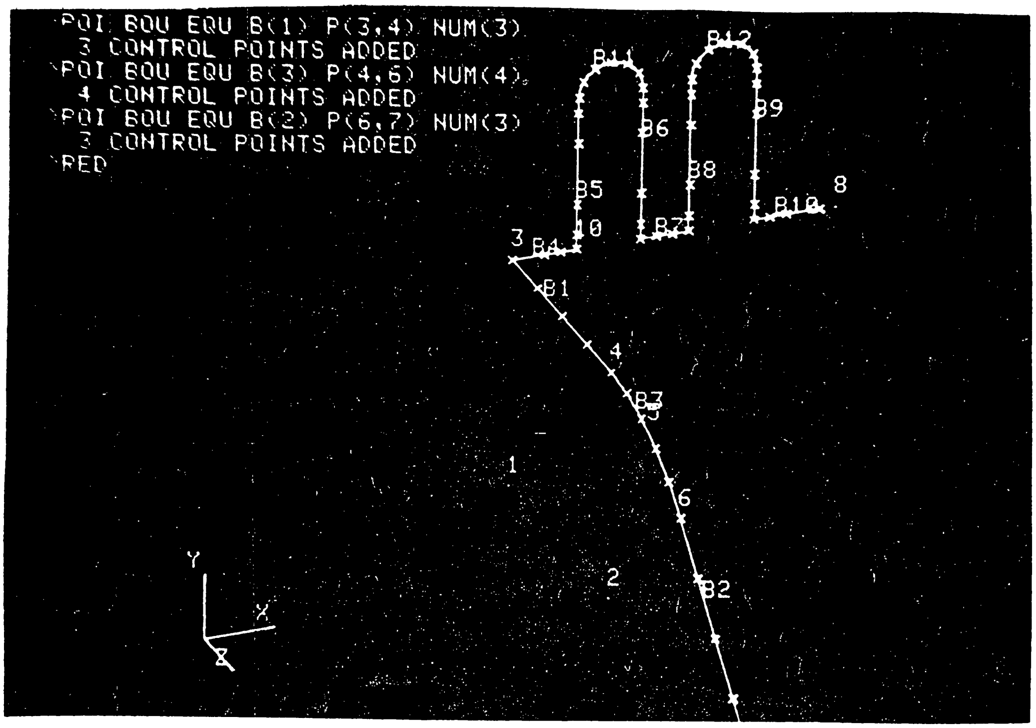
REGION SPHERE is a command to create a spherical surface given the radius and the starting and ending theta and phi angles.

REGION RULED creates a ruled surface by using straight lines to connect two boundary lists that form the opposite edges of the surface.

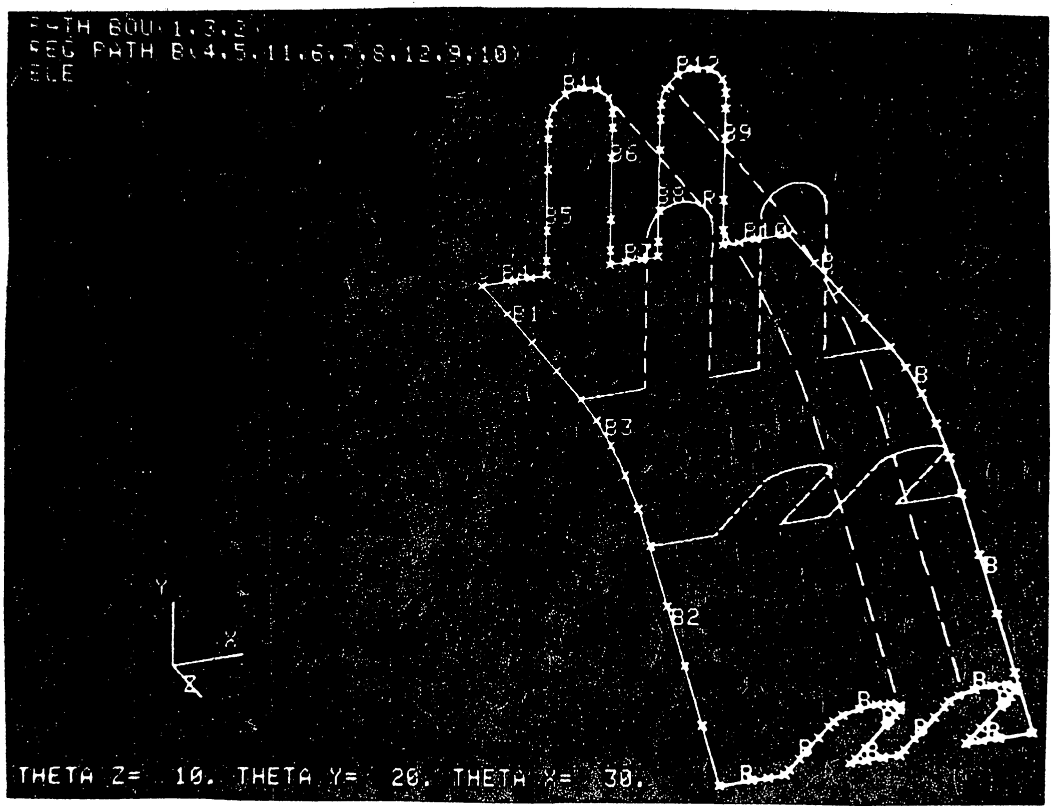
REGION SUBDIVIDE creates a smaller surface from an existing one. Only the limits defining the region change. Typically, REGION SUB is used to form a smaller region for mesh generation.

REGION PATH is used when a surface is desired that can be created by a curve of constant shape which is moved along the specified path.(Figure 5, 6)

REGION 4B is used in creating a region from four boundary lists.



CREATION OF CONTROL POINTS
Figure 5



REGION PATH SURFACE CREATION
Figure 6

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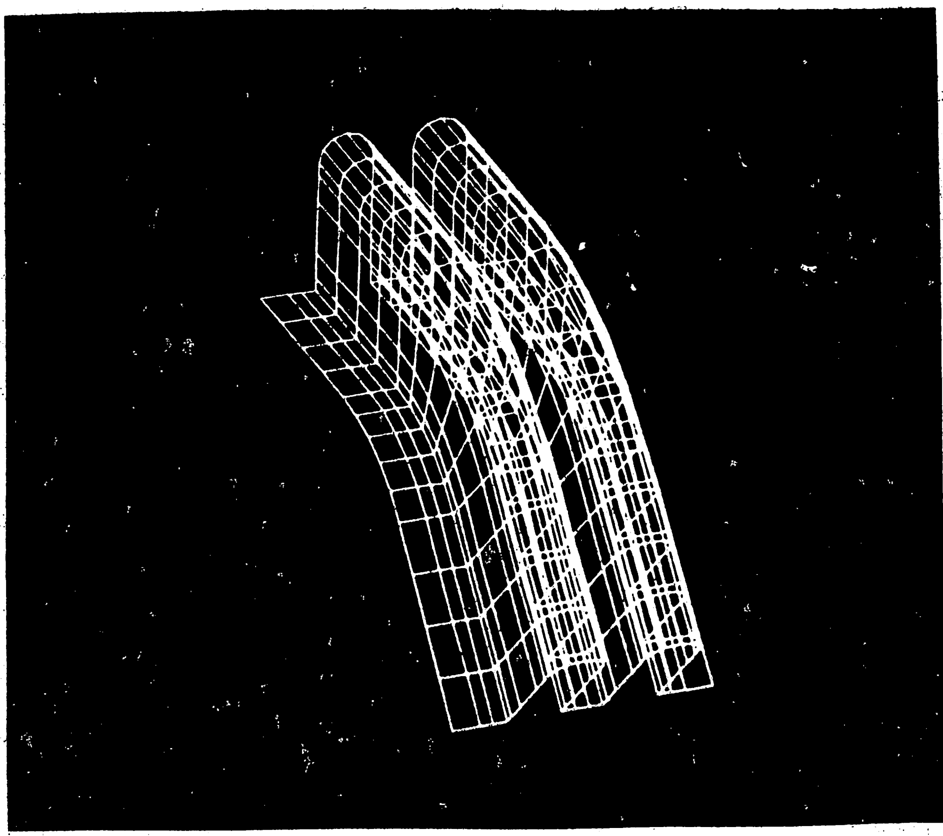
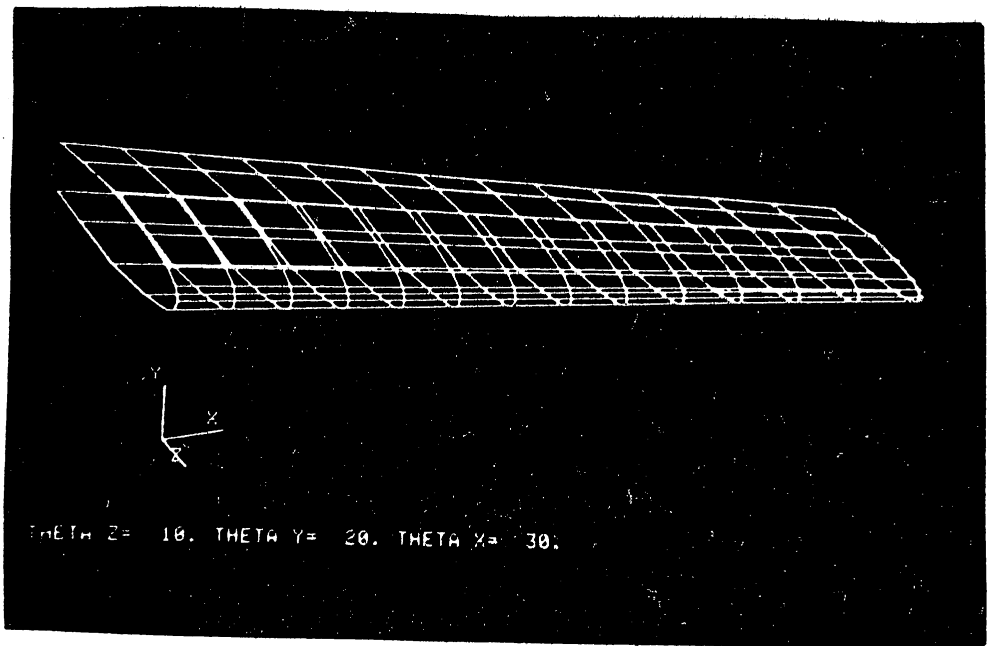
2.5 Creating a Mesh

The MESH command is used to generate a finite element mesh on any FASTDRAW/3 region. Control points placed along the region's boundaries with the POINT creation commands are the way that the user has to adjust the mesh density. A separate command, MSET, is used to control the label generation sequencing and the type of mesh elements to be used. FASTDRAW/3 will automatically create transition row elements if the proper number of control points are present on opposite sides of the region.

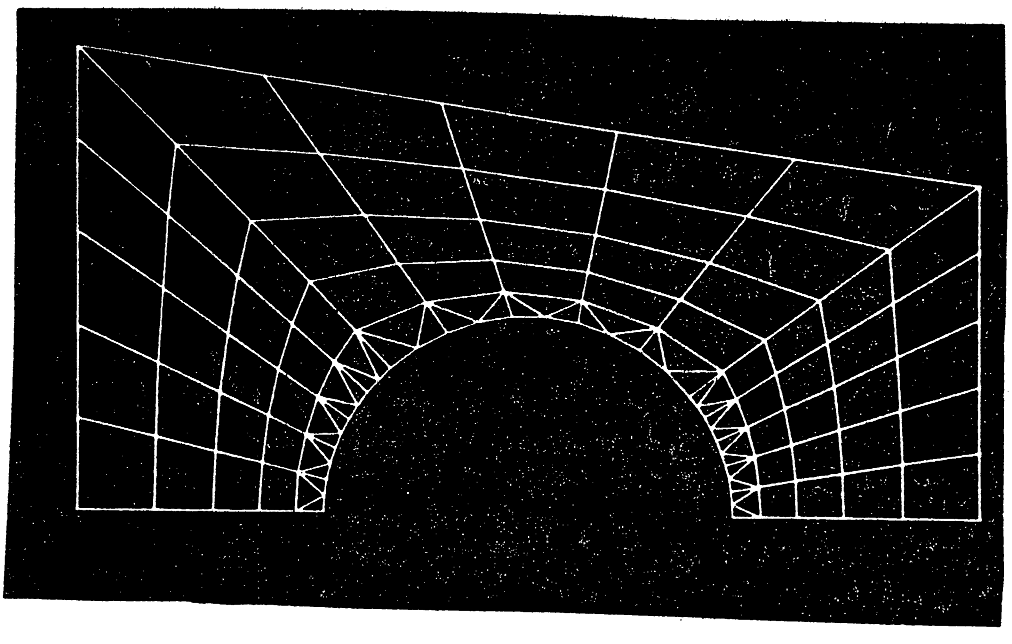
The optimum use and selection of boundaries and regions for mesh generation is extensively covered in "FASTDRAW/3: Interactive Graphic Mesh Generation" (Reference 3). (Examples of meshs produced by FASTDRAW/3 are shown in Figures 7, 8, 9.)



MESH ON SURFACE AFTER REGION PATH
Figure 7



MESH ON SURFACE FORMED BY REGION RULED
Figure 8



MESH WITH TRANSITION ROWS
Figure 9

3.0 Distributed System Design

All the display and model editing features of FASTDRAW/3 have been incorporated in a multiple user mini-computer system. This implementation strategy was chosen over several other possibilities:
- -timeshared large mainframe
- -single user mimi-computer
- -desktop computer

FASTDRAW/3 was already available on MCAUTO's timeshared system and it was desired to reduce the cost of the computer system that hosted FASTDRAW/3, and to also provide service enhancements that were difficult to do on the CDC equipment being used.

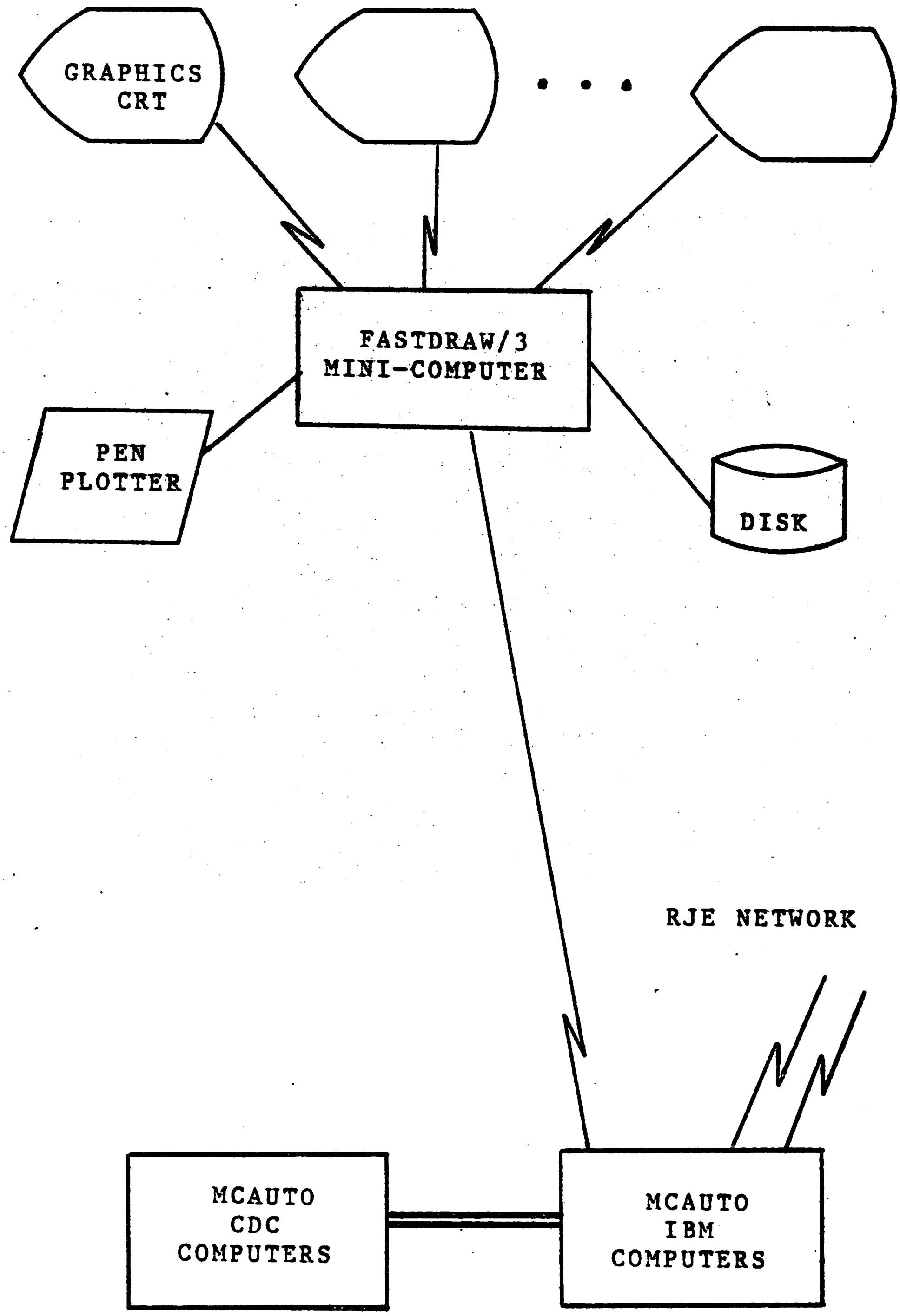
Small, single user mini-computers had several strikes against them in spite of their low cost. The small memory space on these mini's would have made it difficult to implement FASTDRAW/3. Another important consideration was that important peripherals (disks, plotters) are a significant fraction of the cost of the system. To keep the cost low for a user's workstation, these devices should be shared and easily accessable. A final point to be mentioned is that to ask a customer to purchase their own mini-computer imposses a large capital expenditure and one which is quickly obsoleted or at least soon surpassed in value by new equipment.

The last strategy considered was to use a desktop computer. All of the implementation problems found with small mimi-computers existed with desktop systems as well. The expense of non-shared peripherals was also still a problem.

What finally evolved was a multi-user timeshared mini-computer. The restriction on memory space was overcome by using a mini-computer with virtual memory management hardware and software. This virtual memory allows for large programs and sharing of a single copy of a program by all users.

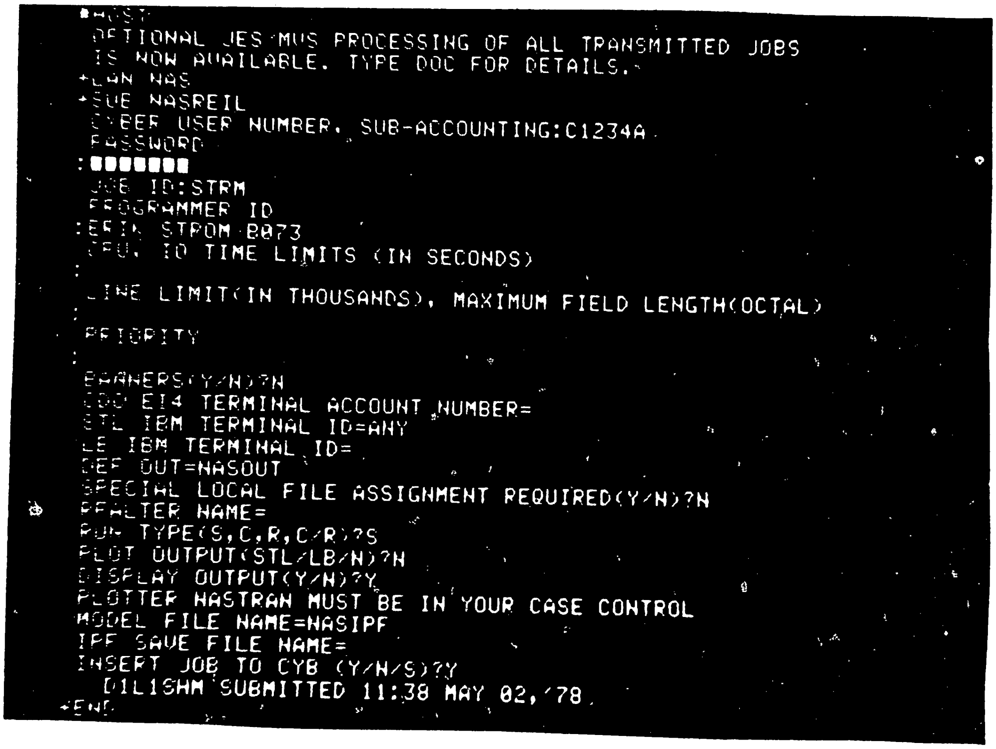
The distributed FASTDRAW/3 system does not rely on any special operating system modifications. This keeps the software portable and makes it possible to respond to improvements in hardware cost or performance as they become available.

The FASTDRAW/3 distributed processing system is a node in the MCAUTO network of remote job entry terminals and computers. (see Figure 10) The multi-user mini-computer allows several FASTDRAW/3 users to access the FASTDRAW/3 model editing features while the computer system is concurrently processing plots spooled to an on-line pen and ink plotter, and also communicating to the MCAUTO RJE complex of IBM and CDC computers.



DISTRIBUTED PROCESSING SYSTEM NETWORK
Figure 12

FASTDRAW/3 has a subsystem called HOST that makes the communication between the mini-computer and the MCAUTO IBM and CDC systems a simple matter of answering questions. (Figure 11) HOST then creates the correct batch job control card images and submits them to the proper host computer in the MCAUTO network.



EXAMPLE OF HOST OPERATION
Figure 11

4.0 Summary

FASTDRAW/3's superior features such as local coordinate systems. flexible point creation, element duplication, and boundary, region and mesh generation have been enhanced by implementing FASTDRAW/3 on a multi-user mini-computer system. Now on-line pen and ink plotting of intermediate and final design steps can be performed with the plotted output quickly available. Terminal drawing speeds 2-8 times faster than what is available from remote timesharing mainframes is a standard feature. A successful distribution of tasks has been accomplished by placing the interactive problem modeling software on a shared mini-computer that has a link to the MCAUTO large scale batch processing system to execute the model analysis.

References

1. FASTDRAW/3 Reference, McDonnell Douglas Automation Company, 1978.

2. Fousek, Daniel P., "An Interactive Mesh Generation System", presented at the ASCE Annual Convention, Chicago, Illinois; October 1978.

3. Fousek, Daniel P., "FASTDRAW/3: Interactive Graphic Mesh Generation", to be presented at the Seventh Conference on Electronic Calculation, ASCE, St. Louis, Missouri; August 1979.

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