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Photomask and Pattern Programming Manual

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National Aeronautics and Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

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PREFACE

The work described herein was perfomed by the Applied Mechanics Division and the Earth and Space Sciences Division of the Jet Propulsion Laboratory.

ACKNOWLEDGMENTS

The mask program described in Chapters IV and VI was originally obtained from the Electronics Development Division of Marshall Space Flight Center. J. M. Gould, T. M. Edge, W. R. Feltner, E. C. Lentz and D. L. Bouldin of that group have been extremely helpful during the implementation of the program at JPL, and in many other phases of this work. D. E. Routh and D.-S. Woo (now at the Solid State Technology Center, RCA Corporation) wrote the original version of the program.

Persons at JPL contributing to this work include E. T. Bates and T. W. Griswold, who provided mask and circuit designs and contributed in other ways; J. H. Hix, J. L. Miranda, and D. M. Engler, who provided digitizing and plotting expertise and facilities; C. W. Snyder, N. L. Nickle, and W. El, who made available expertise and facilities for flat-bed plotting; and B. M. Cooper, J. Fuhrman, D. Germann, S. Gold, and J. H. Nicol of the General Purpose Computing Facility who assisted with the programming and computer operations.

I am indebted to E. T. Bates, W. H. Causey, R. H. Cockrum, M. D. Donner, J. Maserjian, P. V. Mason, R. H. Nixon, D. E. Routh, C. H. Savage, and D.-S. Woo for giving the preliminary version of this manual a critical reading and suggesting valuable revisions.

The photo for Figure 2-3 and the masks for Figures 1-1, 2-5 and 6-7 were provided by the Electronics Development Division of Marshall Space Flight Center; the photo for Figure 2-6 was provided by GCA/Burlington Division.

ABSTRACT

This document is a user's manual for a set of computer programs for the layout and generation of photomasks. Also included is a limited amount of related information on photomasks, their design and use. The programs and this manual would be most useful to persons having a moderate need for photomasks for prototype or research purposes.

The source language for the programs is extended FORTRAN. To use the programs, data describing the photomask design is input to the programs; provisions for scaling, repetition, complex geometries, etc., allow simplifications in the preparation of the input data. The possible outputs are plots of the layout and a magnetic tape for controlling generation of the photomask by a pattern generator.

NOTE

The computer programs described herein are available from Computer Software Management and Information Center (COSMIC), University of Georgia, Suite 112, Barrow Hall, Athens, Georgia 30602. Specify NPO-14419.

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SECTION I

INTRODUCTION

The fabrication of many items of modern technology is accomplished by means of photomasks. A photomask is a photographic plate or film which carries a geometrical pattern of transparent and opaque areas that represents a part of the design of the device to be fabricated. Figure 1-1 shows two examples. As one step of the fabrication process the pattern on the photomask is transferred photographically to the device, where it determines in which areas modifications such as deposition or removal of material will take place in subsequent steps. Thus, the photomask can be thought of as a link between design and fabrication.

The use of photomasks is particularly suited to applications involving fine detail, reproducibility, or repetition, and where fabrication can be carried out on the planar surface of a material. Examples of items fabricated by means of photomasks include semiconductor integrated circuits, hybrid circuits, printed circuits, surface acoustic wave devices, magnetic bubble devices, integrated optics circuits, and other devices.

The purposes of this manual are (1) to describe computer programs available at JPL which can serve as aids in designing, verifying, and fabricating photomasks or other graphic patterns, (2) to provide instructions enabling a person to use these programs, and (3) to provide the related information on the fabrication and use of photomasks that is needed for effective use of the programs. Familiarity with use of the computer and peripheral equipment is assumed and is not covered here.

The programs described in this manual provide the mask designer a means of converting drawings and designs into computer data which can control mask-making machines and graphics equipment. They provide for documentation, verification, alteration, and updating of designs. In regard to mask geometry, the programs allow simplified specifications for scaling, repetition, shifting, image reversal, certain complex geometries, alphanumeric characters, alignment marks, and other features.

These programs and this manual do not cover any aspect of computer-aided design, which is the design or simulation of electronic circuits or devices by computer. What is covered here might be called computer-aided graphics or computer-aided layout. The circuit design and initial geometrical layout must be provided by the user.

The information and data in this manual are for programs, procedures, and equipment at JPL and MSFC. Although some of the information may apply in a general way to other installations, it should not be assumed that the information given here is applicable to other installations.

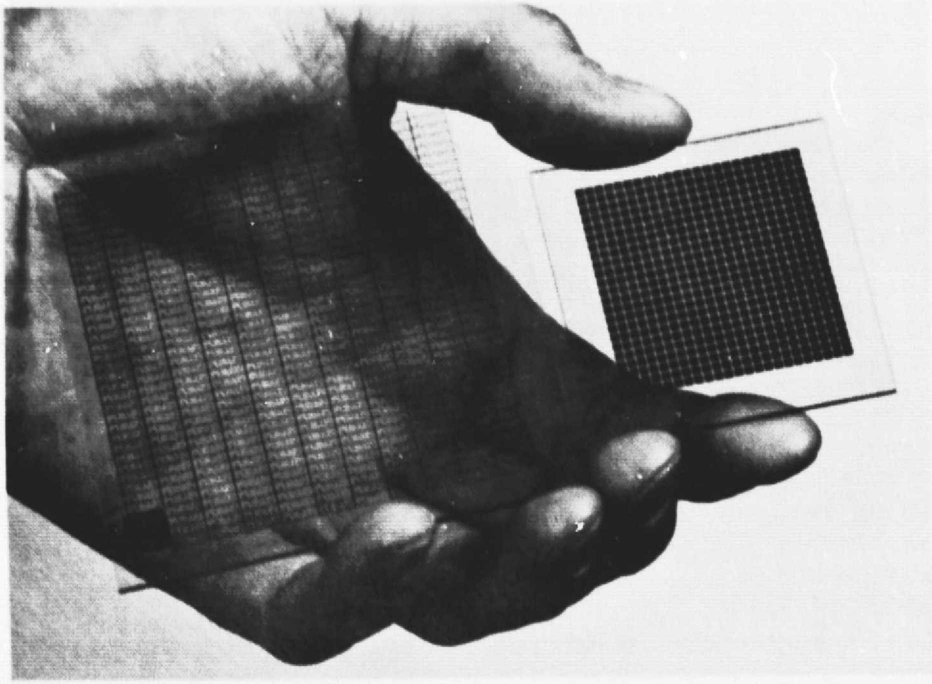

Figure 1-1. Examples of Photomasks (3-in. x 3-in. on left, 2-in. x 2-in. on right; the details of the patterns are too small to be visible in the photograph)

SECTION II

PHOTOMASK DESIGN, GENERATION AND USE

A. OVERALL PROCESS

To use the photomask programs effectively, it is necessary to have an understanding of the overall process of photomask preparation. Thus, the purpose of this section is to describe the complete process, from design idea to completed photomask. There are many ways to prepare photomasks; the methods described here are those applicable to facilities at JPL and MSFC.

The various steps, shown in outline in Figure 2-1, are as follows:

(1) The process begins with a design idea.

(2) The design idea must be translated into data suitable for the computer programs. For these programs the input data must be in the form of punched cards (or their equivalent in a data file). Three ways of doing this are shown:

(a) If the design is fairly simple the data may be prepared directly. This is not the usual practice however.

(b) A drawing is made and data describing the pattern is taken from it by hand.

(c) A drawing is made and data describing the pattern is taken from it by a digitizer. The digitizer resembles a drafting board; it has a cursor which is aligned with various points on the drawing and automatically converts their positions to punched card data.

(3) The data cards are read into a file (file 53) and from there are processed by the MASK program. The program has three possible outputs. One is a printout; the other two are data placed in computer files (magnetic disc storage).

(a) One (file 55) contains data which may be used to plot the pattern for verification purposes. The pattern may be plotted in various ways: on paper, CRT screen, and film. Each method requires executing a small program to translate the file 55 data into a form appropriate for the particular plotting device.

(b) The other (file 57) contains data which may be used to control the actual fabrication of the photomask by a machine called a pattern generator. This also requires an additional program, MASKTRAN, to translate the data into a suitable form.

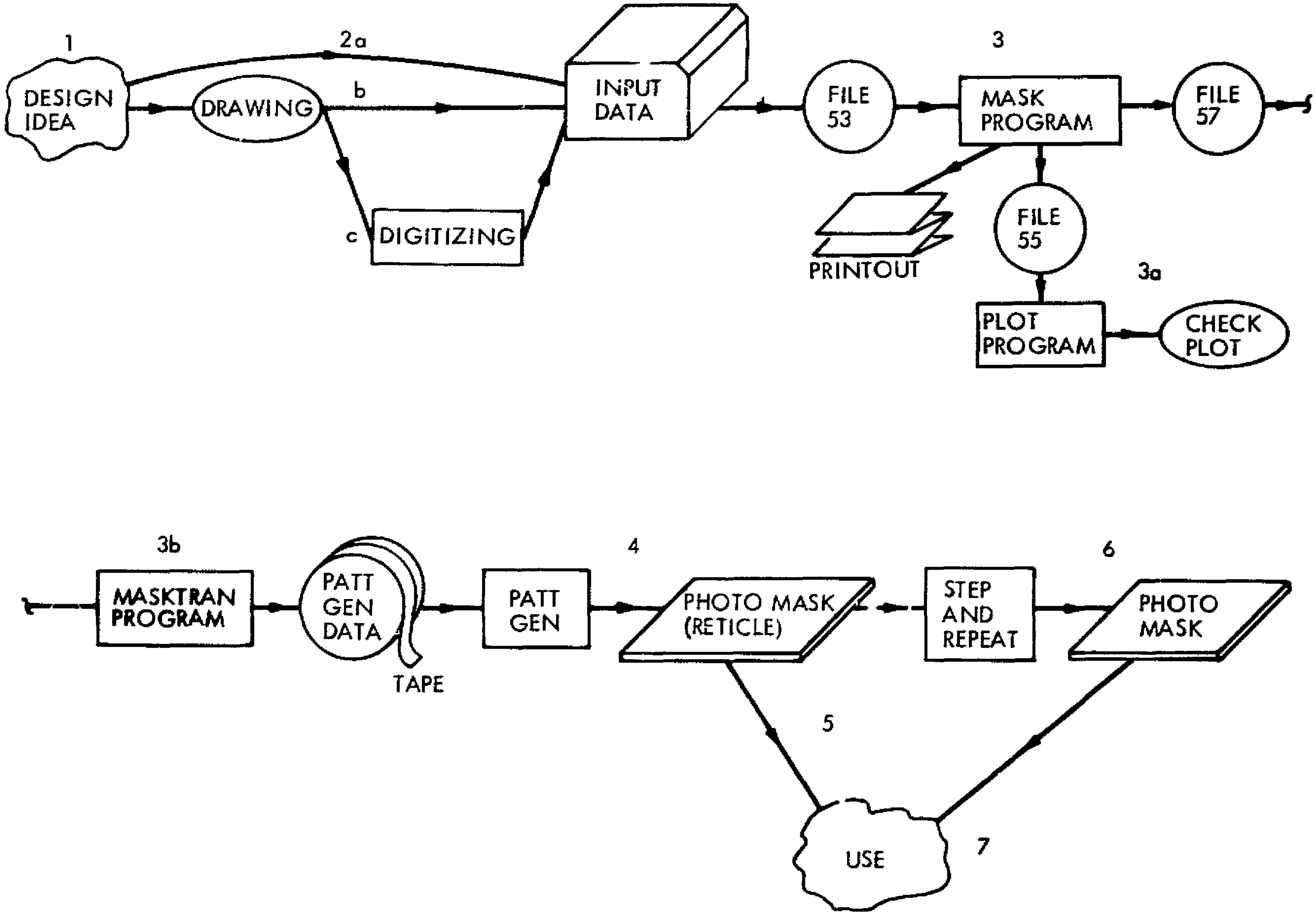

Figure 2-1. Flowchart of Photomask Preparation

(4) The photomask is generated by the pattern generator, an extremely accurate optical/mechanical machine for exposing a photoplate. Its motions are controlled by the numerical data given to it.

(5) For some applications the photoplate will be used as is. For other applications, such as integrated circuit work, an additional step (6) is required.

(6) The photoplate produced by the pattern generator generally contains only one pattern. For many applications, a photomask with an array of patterns is required. It is made in a process called step-and-repeat in which the photoplate, made with the pattern at 10 times required size, is reproduced repeatedly on another plate at required size in an accurately spaced rectangular array. This is done by a step-and-repeat generator, a machine similar to the pattern generator.

(7) The photomask plate from the step-and-repeat generator (the master plate) may be used directly or may be duplicated onto other plates (the working plates), either directly or by means of an intermediate plate (a sub-master plate).

Photomasks are usually used by photographically transferring the pattern they contain to a photoresist, a light-sensitive material which is coated onto the surface of an object. Their use is best explained by a typical sequence of fabrication steps such as the following (see Figure 2-2):

(1) Coat object with photoresist.

(2) Place photomask in contact with resist, emulsion toward resist.

(3) Expose to light (usually ultraviolet); resist is altered where light strikes it.

(4) Develop resist, to leave resist in desired areas.

(5) Process resist-coated object: deposit, etch, etc. - action is confined to areas not coated by resist.

(6) Remove resist.

There are two types of photoresist: positive and negative. This must be taken into account when designing the photomask.

Positive resist. Developing removes resist where it was exposed to light. Thus the resist pattern duplicates the opaque areas on the photomask.

Negative resist. Developing removes resist where it was not exposed to light. Thus the resist pattern duplicates the transparent areas on the photomask.

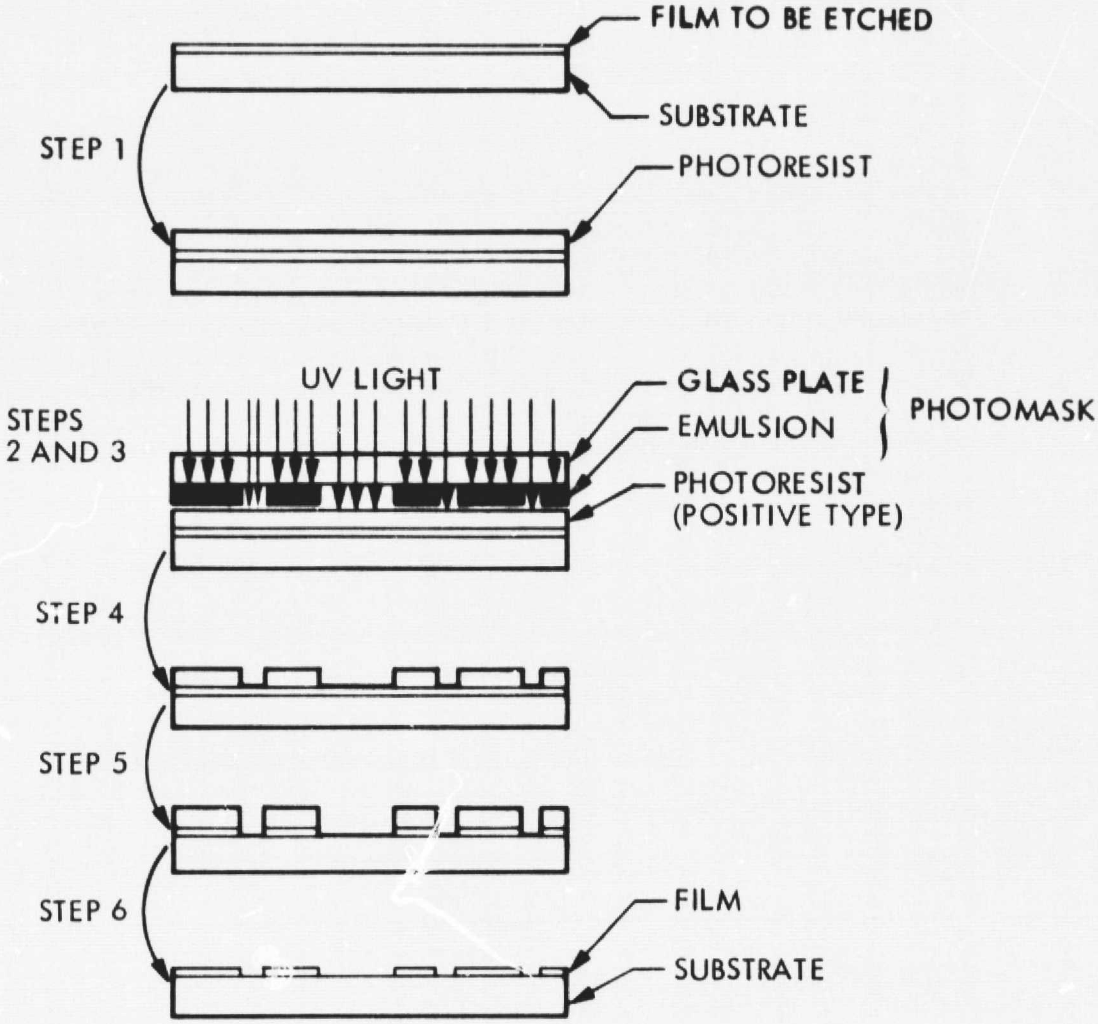

Figure 2-2. Fabrication Sequence Using Photomask and Positive Photoresist

B. MASK DESIGN

The design of photomasks is beyond the scope of this manual; however, a few general guidelines are given here.

(1) Keep the layout simple and organized -- right angle geometry, even spacing, uniformity, etc.

(2) The mask program has the capability of generating circles, rings, sectors, and arcs; however, they should be avoided except where necessary, since they require substantially more pattern generator time than rectangles.

(3) Try to incorporate symmetry and similarity wherever feasible so that repetition can be used as much as possible. Repetition is easily handled by the programs, and using it can save programming time.

(4) Incorporate identification to appear on the mask plates and also on the completed device.

(5) Put alignment and registration marks on the mask. These will be discussed later.

It is a good idea for everyone involved with the mask to get together and decide on the design during the drawing stage, before data processing rather than afterwards.

C. MASK GENERATION

As indicated earlier, the actual mask is made from a blank photographic plate using a <u>pattern generator</u>, a type of high-accuracy machine for exposing photoplates. Specifically, the information in this manual applies to the Mann pattern generator (MPG) at MSFC shown in Figure 2-3. This type of machine is represented schematically in Figure 2-4. A flash tube serves as the light source. A rectangular opening, whose width, height, and angle are determined by input data, is imaged by a system of high-quality lenses onto the plate. The plate is carried on a table which moves along two axes, as determined by input data. The rectangular exposures are made at various locations on the plate and the pattern is gradually built up. A rectangle is the only shape available, all other shapes must be made up from it; thus some shapes like a circle or triangle must be approximated. The MPG is operated in an ultra-clean, vibration-isolated, temperature-controlled area.

The model 1600 MPG at MSFC has the following characteristics:

(1) Motion of the plate along the X axis and along the Y axis is limited to 4,000 mils.

(2) The smallest increment in X and Y motion is 0.25 mil.

(3) The smallest increment in rectangle height and width is 0.5 mil.

(4) The angle increment is 1 degree.

(5) Rectangle height and width are each limited to 120 mils maximum.

(6) The angle must be between 0 and 89 degrees inclusive.

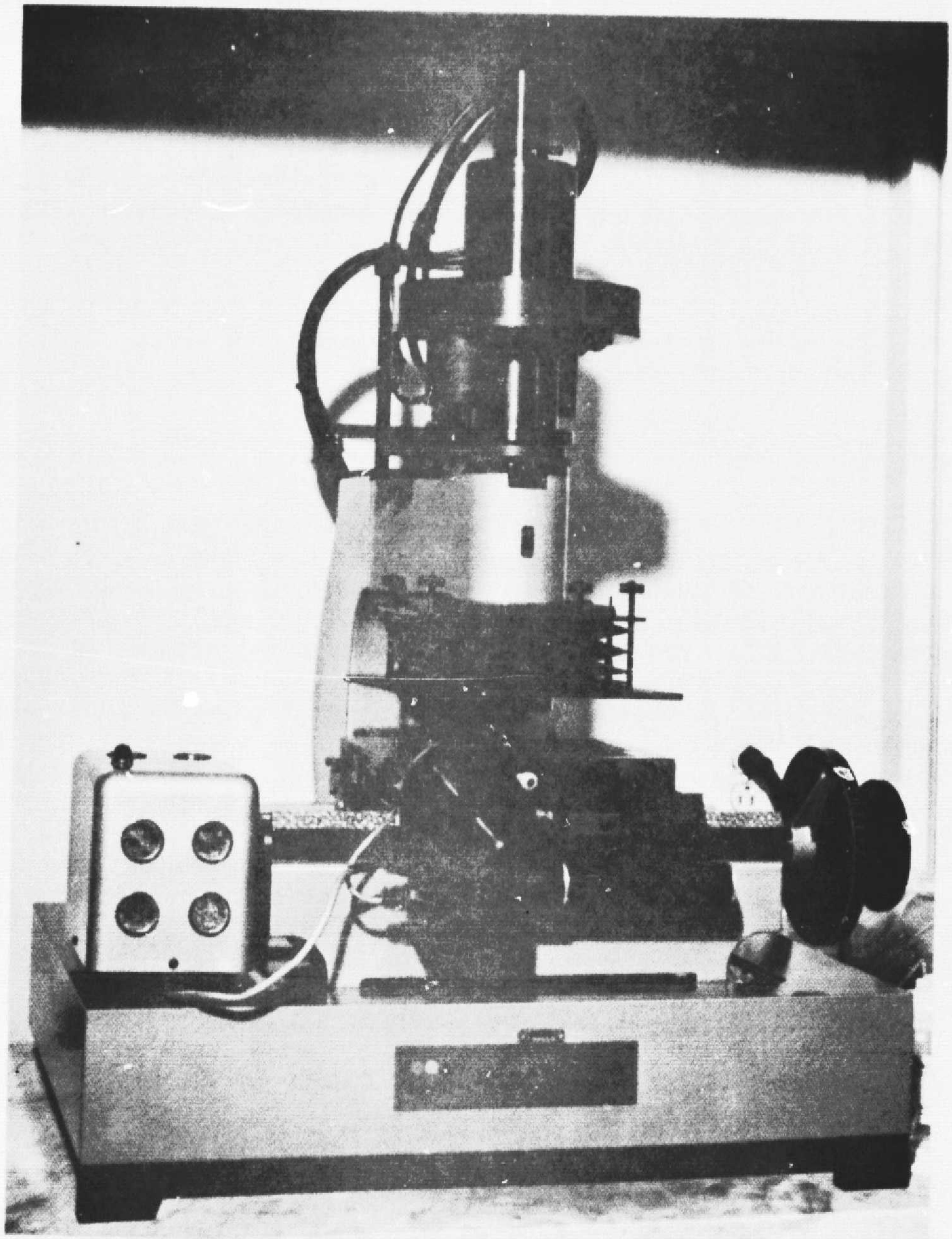

Figure 2-3. The Mann Model 1600 Pattern Generator at MSFC (the control unit and teletype are not shown)

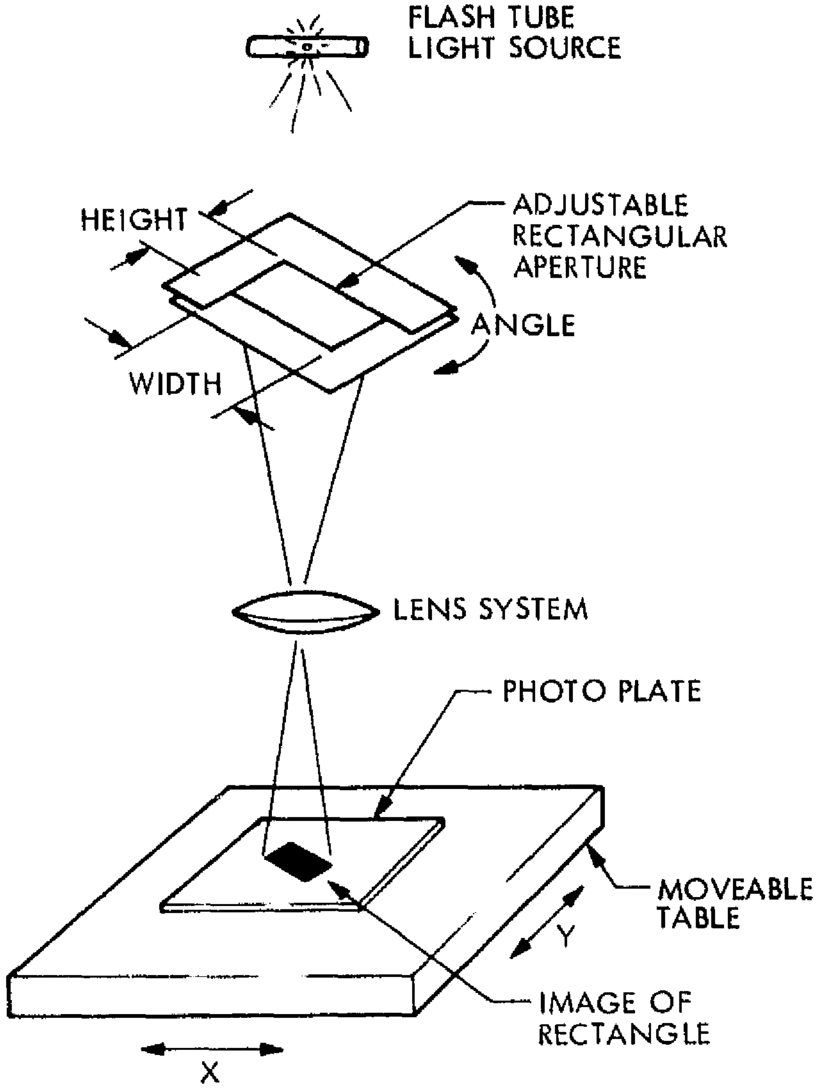

Figure 2-4. Principle of Operation of Mann Pattern Generator

The mask designer need not be concerned with (5) and (6) as they are automatically taken care of by the mask program. If necessary, a rectangle can be made with a height or width having a 0.25 mil increment (for example, 3.75 mils), by making two overlapping exposures, one shifted by 0.25 mil with respect to the other.

The MPG can accept the following plate sizes:

Nominal Size	Useable Pattern Area (approx)
2 in. X 2 in.	1.6 in. X 1.6 in.
3 in. X 3 in.	2.6 in. X 2.6 in.
4 in. X 5 in.*	3.75 in. X 3.75 in.

*Cannot be stepped-and-repeated at MSFC.

After exposure the plate is developed photographically. Depending on the intended use of the plate it may be developed by one of two processes:

<u>Normal processing</u> -- areas exposed to light (rectangles) become opaque.

<u>Reversal processing</u> -- areas exposed to light become transparent.

The completed plate from the MPG is referred to as a <u>reticle</u>. The reticle may be used as is, printed onto other plates, or stepped-and-repeated.

D. STEP-AND-REPEAT

In the step-and-repeat process the pattern from the reticle is imaged onto another plate at a 10X reduction and exposed onto the plate repeatedly in a regularly-spaced, rectangular array (Figure 2-5). This is done in a <u>photorepeater</u> or <u>step-and-repeat generator</u> (Figure 2-6), a machine similar to the MPG. The step-and-repeat generator at MSFC can only accept reticles of 2 in. x 2 in. or 3 in. x 3 in. Step and repeat distances must be in whole mils. A minimum step-and-repeat separation of 50 mils in the X-direction is recommended to allow time for charging of the flash lamp supply on the step-and-repeat generator between exposures.

The 1X plate from the step-and-repeat generator is developed photographically; reversal processing is not possible due to equipment limitations at MSFC. With normal processing, the images on the 1X plate are the photographic negative of the image on the reticle. The

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OF POOR QUALITY

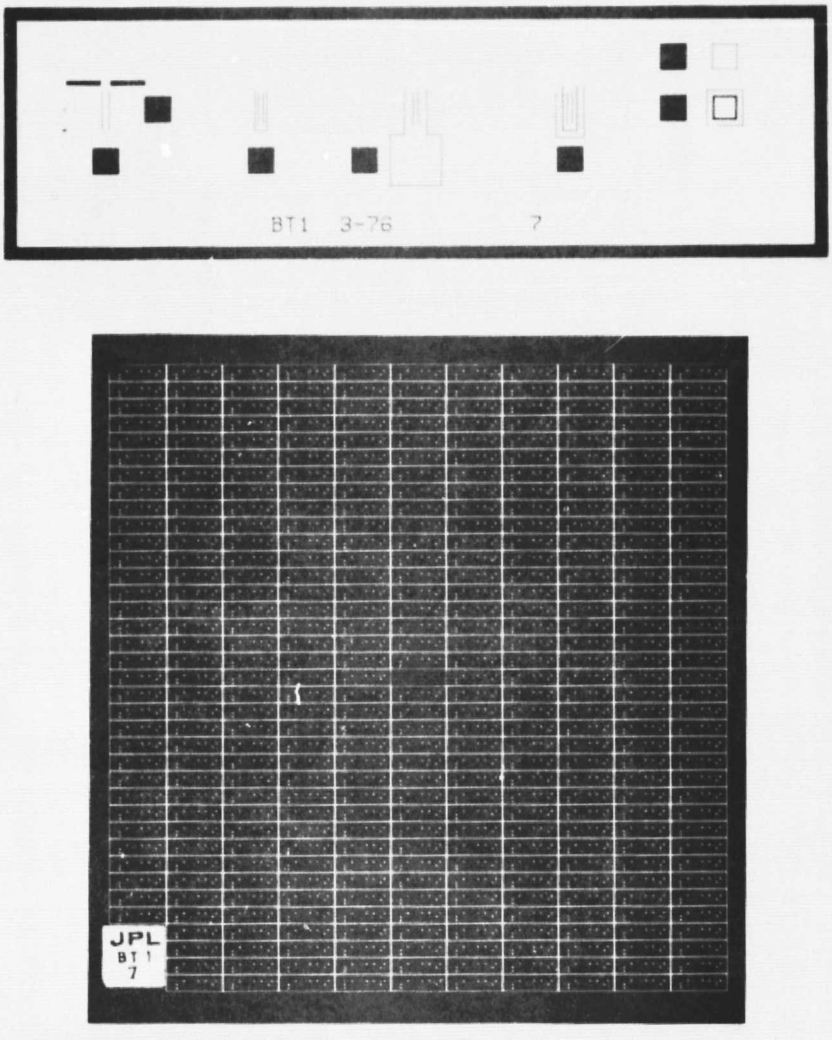

Figure 2-5. Step-and-Repeat (Top: 10X reticle pattern; two small crosses on the left are alignment marks. Bottom: 1X mask made from above reticle pattern by step-and-repeat process; center pattern was omitted to aid in coarse alignment; identification added in lower left)

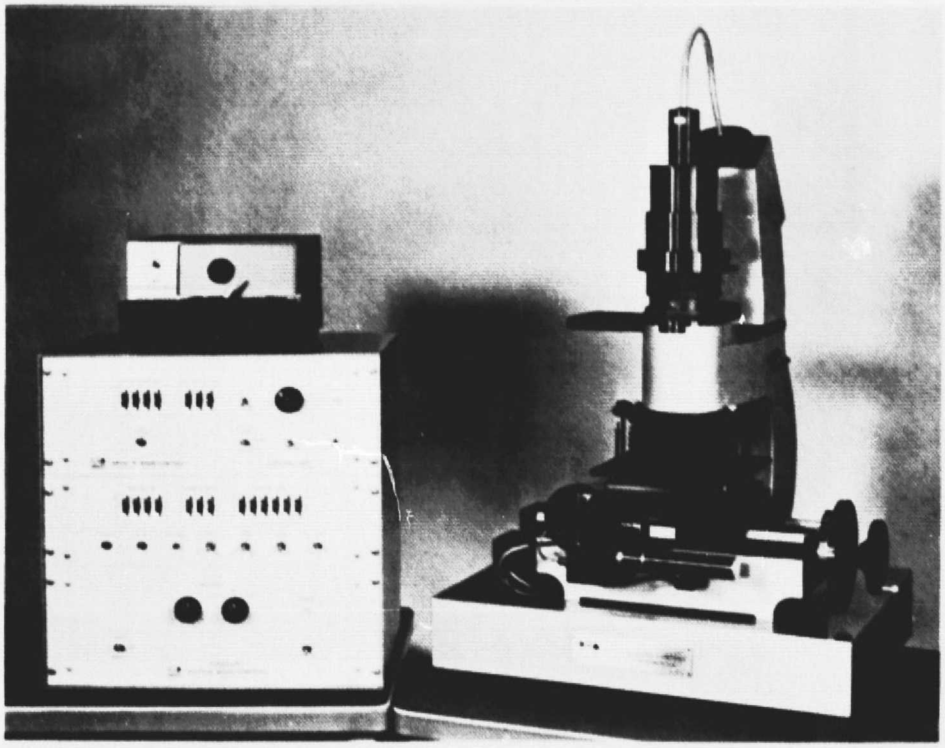

Figure 2-6. A Photorepeater or Step-and-Repeat Generator (Mann Model 1795)

1X mask has the opposite symmetry from the reticle; that is, its patterns are mirror images of the reticle pattern, with the emulsions on both plates facing the same way.

E. BORDER

If the reticle plate is developed normally (exposed areas become opaque), the plate area surrounding the pattern will be transparent. If one were to attempt to step-and-repeat such a reticle, each time a pattern was exposed onto the 1X plate, the surrounding area would also be exposed completely, obliterating any neighboring patterns. To prevent this, a border is added to the reticle mask: the area surrounding the pattern is made opaque. The program automatically provides for a border as specified by the designer, as explained in Section IV. If reversal developing is used on the reticle the border must not be put on. Refer to Section III for further information.

F. ALIGNMENT MARKS

Frequently, during fabrication of a device, the pattern on the mask must be aligned with other patterns or features on the device. This is usually true if more than one mask is used in the fabrication. For this purpose, alignment marks are put on the mask. Nested crosses, squares, or combinations of the two are most common. The mask shown in Figure 2-5 uses two crosses. For masks that have an opaque field (the pattern is transparent), an alignment mark may be made by exposing around the desired shape as shown in Figure 2-7.

If there are special circumstances, for example, a large number of masks to be aligned to each other, optional masks, or close registration requirements, it may be desirable to put several alignment marks on each mask. Marks may also be put on to register the mask with the edges of a wafer or substrate, or to indicate centerlines, etc. In any case, alignment marks should be used generously.

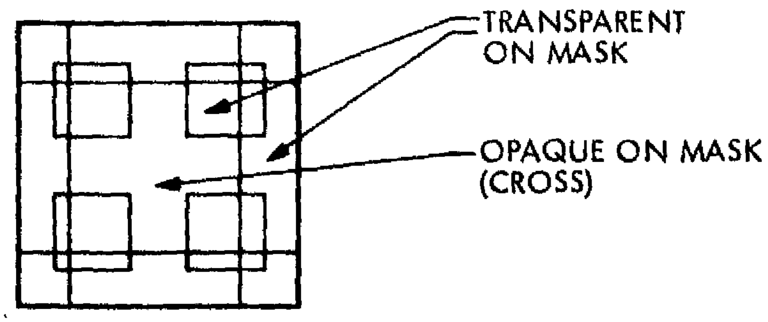

Figure 2-7. Cross Alignment Mark for Opaque Field

SECTION III

MASK EXAMPLES

A. INTRODUCTION

In the previous section the basics of mask generation were discussed. Trying to understand all the processes and their interrelation in general terms is likely to result in complete confusion; a better approach is to consider each design case individually, step by step. Thus, in this section some concrete examples are given to help clarify some of the design steps.

The five examples given are all of masks for typical semiconductor integrated-circuit processing steps, requiring step-and-repeat of the reticle. No examples are given in which the reticle is used directly, since the mask design is relatively straightforward in that case. For all the examples it is assumed that normal processing will be used on the 1X mask, as is the case at MSFC. If reversal processing is also available, the design may be changed to take advantage of this additional degree of freedom. All dimensions given are final size for the device to be fabricated and thus for the 1X mask. For the 10X reticle they must be multiplied by 10. Figure 3-1 shows the layout used in the examples.

B. EXAMPLE 1: POSITIVE PR, OXIDE WINDOWS

The first example is a mask to be used with positive photoresist (PR) for etching windows in an oxide. Typical uses would be for diffusion, gate oxide, or contact windows.

Since the PR is positive type, the final 1X mask will have an opaque background with transparent areas where the oxide windows will be. Consequently, the reticle will have a transparent background with opaque areas corresponding to the windows. In most cases, the window areas rather than the background will be made up of the rectangular MPG exposures. Thus, normal developing will be used on the reticle.

Since the reticle background is transparent, it needs a border. Suppose the pattern occupies a region of 80 mils by 60 mils (800 mils by 600 mils on the 10X reticle) as shown in Figure 3-1. Allow 5 mils clearance all around the pattern and a 4-mil dicing track; the step-and-repeat distances are then 80 + 5 + 5 + 4 = 94 mils by 60 + 5 + 5 + 4 = 74 mils. The opening inside the border could be as large as 94 + 4 + 10 = 108 mils by 74 + 4 + 10 = 88 mils without causing obliteration of adjacent patterns during step-and-repeat. However, this would expose the dicing track region, resulting in oxide being left in the dicing track. Since this is usually undesirable, the opening inside the border should be smaller. An opening of 90 mils by 70 mils would give the desired 4-mil dicing track, free of oxide. Regarding the size of the outside of the border, see IV-C-6, "I" Data Group.

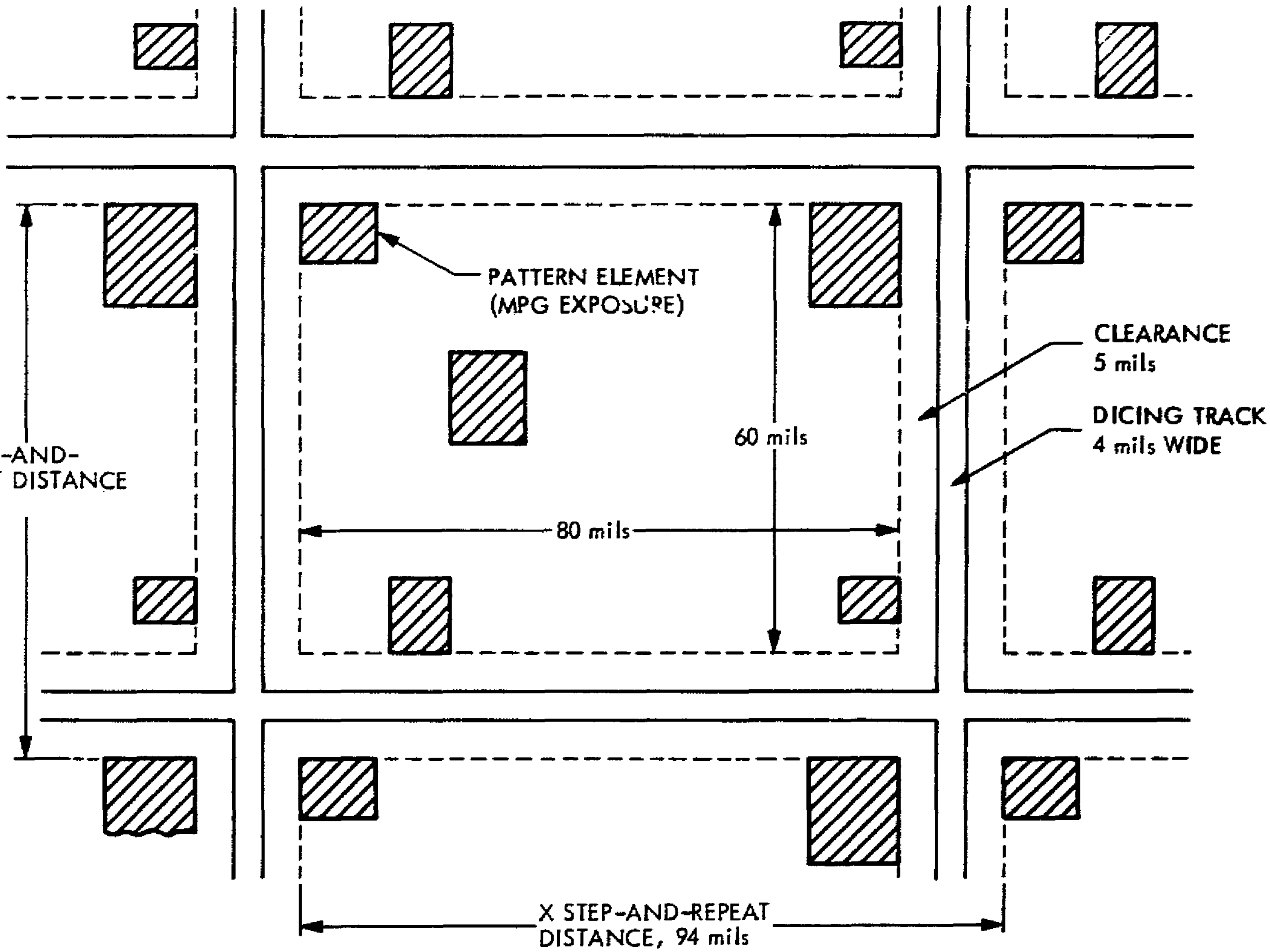

Figure 3-1. Layout for Examples

Another matter to consider is symmetry. If the device is to be right-reading, the 1X mask must be right-reading with the emulsion away from the viewer. Since step-and-repeat reverses the symmetry, the reticle must be reverse-reading with the emulsion away.

The MASK program provides for reversal of symmetry, specified by a symmetry parameter, MR (see IV-C-2, "B" Data Group). Thus, for this mask example either of two methods may be used: (1) prepare the drawing or data for a reversed symmetry (opposite of the device) and use a positive value for the symmetry parameter ($MR \geq 1$), or (2) prepare the drawing or data for normal symmetry (same as the device) and use a negative symmetry parameter ($MR \leq 1$).

The parameter MR also specifies whether or not a border is to be generated. To generate a border, $|MR| \geq 3$. Thus for this mask example, use $MR \geq 3$ for method (1) or $MR \leq 3$ for method (2) above.

C. EXAMPLE 2: POSITIVE PR, METALLIZATION MASK

The second example is a mask to be used with positive resist for a metallization pattern. Assume that the metallization pattern will be produced by the normal procedure; namely, metal will first be deposited to cover the entire surface of the device, photoresist will be applied, exposed and developed, and then the unwanted metal will be removed by etching.

In this case the 1X mask will usually have opaque rectangles on a transparent background. The reticle will be the opposite: transparent rectangles on an opaque background. Thus the reticle does not need to have a border specified; in fact, a border must <u>not</u> be specified for the reticle, or adjacent patterns would be obliterated during step-and-repeat. The reticle will require reversal processing to make the exposed areas transparent. With this arrangement the dicing track will be free of metal, which is normally the desired situation. Regarding symmetry, refer to example 1.

D. EXAMPLE 3: NEGATIVE PR, OXIDE WINDOWS

The third example is a mask to be used with negative photoresist (PR) for etching windows in an oxide. This is the same as example 1 except that in example 1 positive PR was used.

Since in this example the PR is negative, the final 1X mask will have a transparent background with opaque areas where the oxide windows will be. Consequently, the reticle will have an opaque background with transparent areas corresponding to the windows. In most cases the window areas rather than the background will be made up of the rectangular MPG exposures. Thus, reversal developing will be used on the reticle.

The reticle background will be opaque so it will not need to have a border specified: in fact, a border must <u>not</u> be specified. However, to keep the dicing track free of oxide, as is usually desired, a transparent band or "moat" must surround the pattern. This is done by specifying rectangular exposures in the proper locations, using either rectangles or right-angle strip, see IV-C-3, "C" Data Group.

Suppose the pattern occupies 80 mils by 60 mils, and allow 5 mils clearance all around the pattern as shown in Figure 3-1. The inside of the moat would be 80 + 5 + 5 = 90 mils by 60 + 5 + 5 = 70 mils. Assume a dicing track of 4 mils and 94 mils by 74 mils step-and-repeat spacing. Thus the outside edge of the moat could vary from 94 mils by 74 mils (no overlap between adjacent moats) to 98 mils by 78 mils (complete overlap). A reasonable overlap would be 1 mil, requiring outside dimensions of 95 mils by 75 mils for the moat. Regarding symmetry, refer to example 1.

E. EXAMPLE 4: NEGATIVE PR, METALLIZATION MASK

The fourth example is a mask to be used with negative photoresist (PR) for a metallization pattern. This is the same as example 2 except that in example 2 positive PR was used.

Assume that the metallization pattern will be produced by the normal sequence of steps, as given in example 2. Normally, the 1X mask will have transparent rectangles on an opaque background. The reticle will be opposite: opaque rectangles on a transparent background. Thus, normal processing will be used on the reticle and a border must be specified.

Suppose the pattern occupies a region of 80 mils by 60 mils; allow 5 mils clearance all around the pattern and a 4-mil dicing track. The step and repeat distance would be 94 mils by 74 mils. To keep the dicing track free of metal, as is normally desired, the inside opening of the border must be at least equal in size to the step-and-repeat spacing. On the other hand, the inside opening could be as large as 108 mils by 88 mils without obliterating adjacent patterns during step-and-repeat. A reasonable size might be 96 mils by 76 mils. Regarding symmetry, refer to example 1.

F. EXAMPLE 5: NEGATIVE PR, OXIDE WINDOWS, CONTACT PRINT

This example is the same as example 3 except that the working mask plates (those actually used to make the device) will be made by contact printing from the 1X mask generated by step-and-repeat (the master mask plate).

The working plate will have a transparent background and opaque pattern areas, so the 1X master will be the opposite: opaque background and transparent pattern areas. This is the same as the mask in example 1, so the procedure given there can be used. However, the reticle must have the opposite symmetry from that given in example 1, since the contact printing introduces an additional symmetry reversal.

G. SUMMARY

To summarize some of the points illustrated by the preceding examples, when designing a mask first consider:

(1) The type of photoresist to be used, positive or negative.

(2) Whether the stepped-and-repeated mask will be used directly, or whether working masks will be made from it, either directly or by means of a sub-master plate.

(3) The separation between patterns, allowance for clearance, dicing track size, etc.

The above conditions will then determine:

(4) Whether the mask and reticle will have a clear or opaque background.

(5) Whether normal or reversal processing will be used to develop the reticle.

(6) Whether a border or moat is needed, and the size of the opening inside the border or the moat size.

(7) Step-and-repeat distances.

Finally, decide on:

(8) The size of the mask plate.

(9) The number of step-and-repeat patterns desired on the 1X mask.

(10) The symmetries of the plates and drawing.

SECTION IV

PREPARING THE INPUT DATA

A. GENERAL DATA FORMAT

Photomask specifications and other data are input to the programs on punched computer data cards. The data may also be input in a form equivalent to cards, for example, using a data file; however, for the purposes of this manual the data will be treated as if it were on cards.

The data for each mask is divided into data groups, each of which may contain one or more cards. The following six data groups are available at JPL:

Data Group	Function
A	To convey a message to the operator of the Mann pattern generator, and to initiate processing of data for each mask.
B	To specify scale factor, location of pattern on the mask plate, whether or not a border is desired, and true or mirror image on the plate.
C	To specify pattern data for rectangles and strip (a continuous trace whose direction can be changed at right angles).
D	To specify pattern data for strip at angles, circles, circle sectors, annuluses, and arcs.
E	To specify data for alphanumeric characters to appear on the mask plate.
I	To specify fiducial marks and border to be put on the 10X reticle mask plate. These are needed for the step-and-repeat operation.

The following three data groups are available at MSFC, in addition to the six above:

Data Group	Function
F	To specify a standard flare-out pattern to fit semiconductor chips.
G	To extract pattern cells from a library.
J	To specify a beam-lead pattern.

Cards for each data group are placed together, and the data groups are arranged in alphabetical order to form the input deck. If a data group is not needed it may be omitted. Data groups A and B must always be present. There is no limit to the number of cards that may be in a data group, except groups B and I, which may contain only one card.

B. CARD FORMAT

Column 1 of every card except continuation cards must contain one of the six data group letters to identify to which group it belongs, or a blank indicating that it is a comment card. Any other symbol will cause the card to be ignored.

Comment cards are allowed anywhere in the input data. The information on a comment card is printed out with the data cards, but is not processed by the program in any other way. Blank cards may be inserted freely into the input deck to separate data groups, masks, etc. In addition, any data card may contain comments. If two blank columns are left after the data on a card, additional characters to the right are not processed, except for printing on the data printout (this feature is not available at MSFC). Comments are useful for identifying and organizing the data and should be used liberally, as they can save a great deal of time during corrections or alterations. Comments data does not appear anywhere except in input file 53 and the computer printout. This is different from the A group data which is put into the Plot and Mann files and can appear on the plots and the MPG teletype.

Immediately following the data group character a card identification (ID) number may be punched. This can be any integer or decimal number of ≤5 columns excluding any decimal point. Examples: 0.0, 23, 1.5, 186.42. In excess of two digits to the right of the decimal point will not be printed out. This field is only for identification and is not processed by the program in any way. A comma is punched immediately following the ID number.

The remainder of the card is used to specify various input data by means of parameter fields. Each parameter field consists of a letter identifying the parameter, followed by a number indicating the value of that parameter. Examples:

H105.0 A88 X0.113

Each parameter field is terminated by a comma, which also separates the fields from each other.

List of Parameters

Symbol	Unit	Description	Data Group
A	degrees	Angle	C,E
		Initial angle of sector	D
B	degrees	Final angle of sector	D
D	DU	Downward extension of strip	C
H	DU	Rectangle height	C
		Border window height	I
I	degrees	Angle increment	D
L	DU	Leftward extension of strip	C
M	positive integer	Repetitions in X-direction	C,D,E
N	positive integer	Repetitions in Y-direction	C,D,E
R	DU	Rightward extension of strip	C
		Radius of circle, sector, annulus	D
S	DU	Separation in X-direction for repetition	C,D,E
	mils	Outside dimension of border	I
T	DU	Separation in Y-direction for repetition	C,D,E
	mils	Separation of fiducial marks	I
U	DU	Upward extension of strip	C
W	DU	Width of rectangle	C
		Width of strip	C,D
		Width of annulus	D
		Width of alphanumeric character	E
		Border window width	I
X, Y	DU	Location of center of rectangle	C
		Location of beginning of strip or extension	C,D
MR	integer ±1, ±3	Mirror or true image and flag for border	B

List of Parameters
(Continuation 1)

Symbol	Unit	Description	Data Group
SF	positive number	Scale factor	B
XC, YC	DU	Location of center of pattern	B

Notes: DU = drawing units

Width is in X-direction; height is in Y-direction.

Angles are measured counterclockwise from positive X-direction.

Numerical parameter values are governed by the following rules:

(1) All dimensions are in drawing units (DU) as explained later, except S and T on I group cards are in mils. The program will round W and H to the nearest 0.5 mil and all rectangle locations to the nearest 0.25 mil for compatibility with the MPG.

(2) All angles are in degrees, measured counterclockwise from the positive X-direction (horizontal). Any angle - < A < may be specified; however, the program will round to the nearest degree for compatibility with the MPG.

(3) All numerical parameter values are limited to 11 card columns, excluding any decimal point.

(4) Any digits to the right of the decimal point on M and N will be ignored and M and N must be ≥ 1.

(5) Blanks in the parameter fields should be avoided. Leading and trailing zeros may be used to make subsequent changes easier.

(6) A decimal point is optional for all parameters. For some parameters (M, N, A, B, I) a decimal point is never necessary, since only whole numbers are allowed.

(7) The pattern must not exceed the maximum available area for the plate size being used in the MPG (refer to table in II-C). The program does not check for this; it checks the pattern values according to the limits given in II-C, (1) through (4).

All 80 columns of the card may be used for cards to be processed at JPL. For cards to be processed at MSFC, columns 73-80 inclusive must be left blank.

The last card in each data group must have a dollar sign ($) punched immediately after the last comma, indicating the end of that data group.

C. DATA GROUPS

1. "A" Data Group

The A data group is used to put a message onto the Mann tape. The message will be printed out for the MPG operator on the teletype connected to the MPG. All identification information and special instructions should be included here.

Following the ID field and its terminating comma, the message is punched. There are no parameters on the A card. On each card the message field is terminated by (,;), except on the last card where it is terminated with (,$). On each card a maximum of 68 columns is allowed for the message. The message may include any characters except (;) and ($), since these are used to terminate the message.

The following are suggestions of information which should be included:

(1) Name of designer or user.

(2) Date.

(3) Identification and brief description of mask.

(4) Mask plate sizes.

(5) Whether or not mask is to be stepped-and-repeated.

(6) Step and repeat separation in both X and Y directions and number of patterns, or to cover plate completely.

(7) Whether exposed areas are to be opaque or transparent on (final) mask.

(8) Number of copies of masks to be made.

Each time a group of A data cards appears in the input data, the program initiates a new mask. All data cards following the A group data cards are applied to that mask, until the next A group card or an end-of-file is encountered in the input data.

Example:

A01, CMOS INVERTER CI-05, J. JONES, 5/14/77,;

A02, MASK 1, P-DIFFUSION,;

A03, USE 3 X 3 PLATE, STEP AND REPEAT X=50 MILS, Y=65 MILS,;

A04, EXPOSED AREAS ON FINAL 1X MASK TO BE TRANSPARENT,;

A05, PLEASE PROVIDE FIVE COPIES,$

2. "B" Data Group

Only one B group card is needed. It contains, in addition to the data group character and ID field, the 4 fields given below. The parameter fields on the B card have these special features: (1) each parameter is identified by two letters; (2) the fields must be in the order given below (SF, XC, YC, MR).

SF (scale factor). This parameter scales the input data according to

$$\left(\begin{array}{c}\text{DESIRED SIZE OF}\\ \text{FEATURE AS}\\ \text{EXPOSED ON}\\ \text{PLATE,}\\ \text{mils}\end{array}\right) = SF \left(\begin{array}{c}\text{SIZE OF FEATURE}\\ \text{GIVEN AS}\\ \text{INPUT DATA TO}\\ \text{PROGRAM,}\\ \text{drawing units}\end{array}\right)$$

Example 1: Suppose a rectangle on the drawing is 100 drawing units wide. The input data would be W100. If the same rectangle is to be 50 mils wide on the MPG reticle plate (5 mils on 1X mask, if it is to be stepped-and-repeated), then SF = 50/100 = 0.5.

Example 2: Suppose a rectangle on the drawing is 100 drawing units wide. The input data would be W100. If the same rectangle is to be 100 μm wide on the reticle plate, then SF = 100 μm x (0.039370079 mils/μm)/100 = 0.039370079. See Appendix B for conversion factors.

If the reticle is to be stepped-and-repeated, all input data must be 10 X final size, or SF must be multiplied by 10.

XC and YC (center coordinates)
Used to position the pattern on the photomask plate as shown in Figure 4-1. Generally XC and YC should be the coordinates of the center of the pattern. This will center the pattern in the MPG exposure area and thus on the reticle plate (approximately).

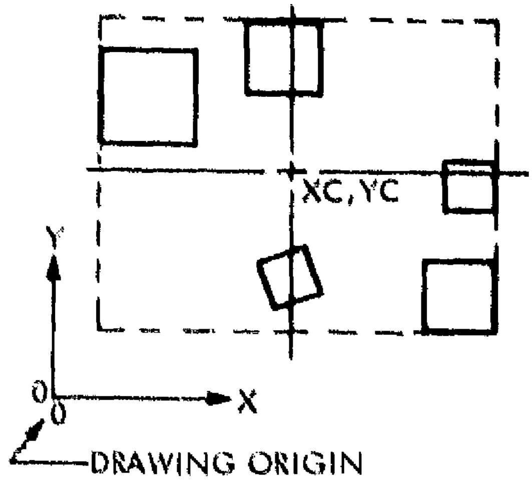

Figure 4-1. Definition of Center Coordinates XC and YC (for the situation illustrated above, XC and YC are both positive)

XC and YC are in drawing units. If the pattern is centered about the drawing origin, then XC = 0, YC = 0. Whatever point is specified by XC,YC, that point will be put at the center of the reticle plate (approximately, see VI-F).

MR (mirror and border)

If MR ≥ 1, the pattern exposed onto the reticle plate, with the emulsion away from the viewer, will read the same as the input drawing (true or right-reading image). If MR ≤ -1, the pattern exposed onto the reticle plate, with the emulsion away from the viewer, will be the mirror image of the input drawing (mirror or reverse-reading image).

Remember that symmetry is affected by step-and-repeat and copying from one plate to another (see Sections II and III).

If |MR| ≥ 3, the program will generate a border on the mask according to specifications on the I group data cards. Further information on this feature is given under "" data group.

Example:

```
B05,SF39.370079,XC12000,YC7500,MR-3,$
```

3. "C" Data Group

The C data group comprises two types of pattern data: rectangles and strip. Data must be arranged as follows: all rectangle data, sub-group separator (,;), all strip data, C-group terminator (,$).

If there is no strip data, the rectangle data may be terminated by (,$) and (;) omitted. If there is no rectangle data, (,;) must be punched after the ID number on the first C card.

a. Rectangle Data. This subgroup allows specification of rectangles and arrays of rectangles. For a single rectangle, specification is according to the following parameters and Figure 4-2:

X, Y	coordinates of center of rectangle relative to drawing origin (DU).
H	height of rectangle (DU).
W	width of rectangle (DU).
A	angle of rotation of rectangle counterclockwise from X-direction (horizontal) (degrees).

For an array of rectangles, specification is according to the following parameters and Figure 4-3.

X, Y	coordinates of center of lower left rectangle (if S, T are both positive) (DU).
W, H	same as for single rectangle.
A	rotation angle of individual rectangles. Note that array as a whole is not rotated.
M, N	number of repetitions in X-direction (integer $\geq$ 1) and Y-direction respectively.
S, T	distances between centers of adjacent rectangles (DU) in X-direction and Y-direction respectively.

Example (without strip data):

```
C06,X200,Y300,A30,W60,H100,

C07,X200.00,Y305.78,A0,W0.51,H1.10,

C08,M3,N2,S500,T300,X200,Y600,A45,W60,H100,$
```

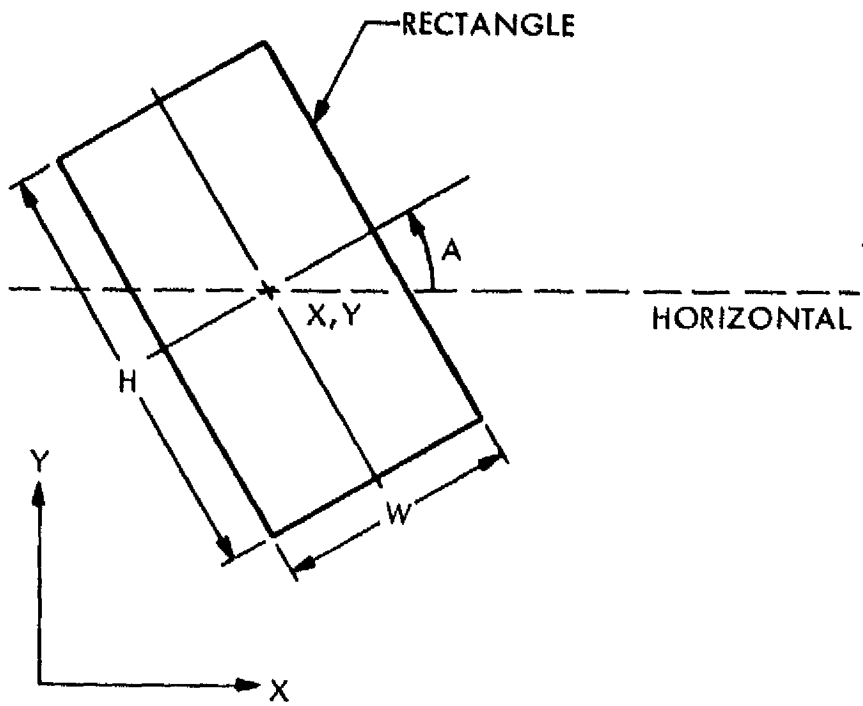

Figure 4-2. Parameter Specification for a Single Rectangle

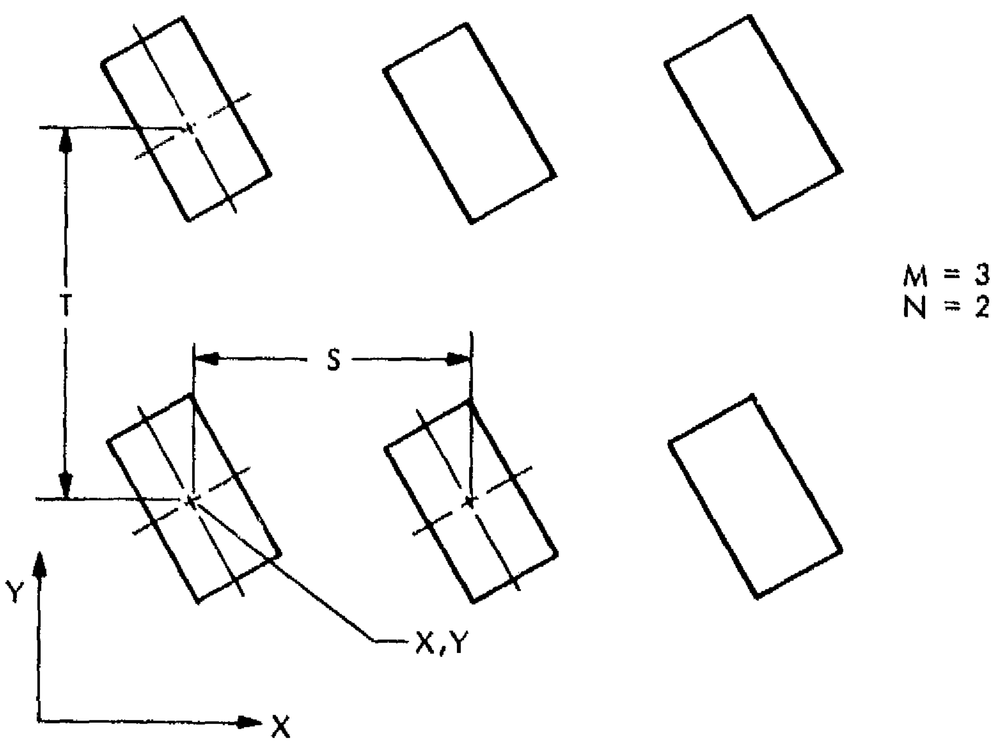

Figure 4-3. Parameter Specification for an Array of Rectangles

```
C1,;
C2,W20,X100,Y100,R300,U200,X150,Y200,R150,
```

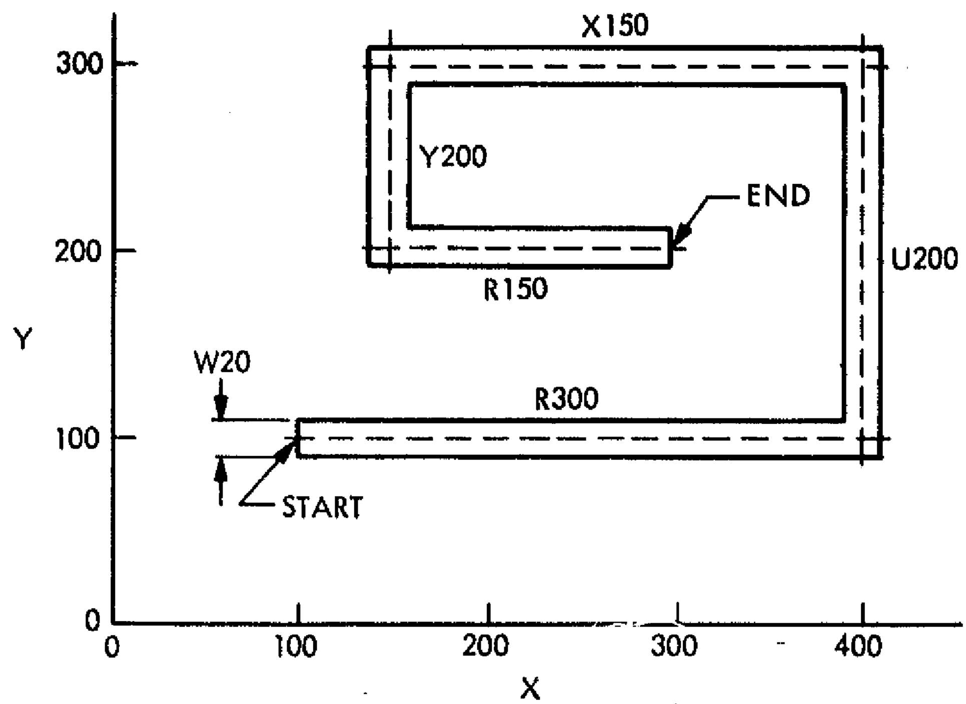

Figure 4-4. Example of Parameter Specifications for Right-Angle Strip

b. Strip Data. This subgroup allows specification of strips, usually used for interconnection. Only right angles are allowed. Specification is according to the following parameters and Figure 4-4.

X, Y — first appearance of X and Y on a card is starting point of strip. Subsequent appearance of X or Y are points to which strip will be extended horizontally or vertically, respectively (DU).

W — width of strip (DU).

U, D, L, R — distance strip will be extended upward, downward, left or right, respectively, from previous point (DU).

Note that X and Y indicate absolute locations, whereas R, L, U, D indicate relative distances: X20 means the strip will run horizontally from its last location to the point X = 20, R20 means the strip will be extended 20 DU to the right. Note that the starting and ending points are at the edges of the ends of the strip, whereas the intermediate points are at the centers of the right angle bends of the strip.

M, N, S, T same as for rectangle data.

Each appearance of "C" (C-group identifier) indicates that a new strip is to be initiated.

4. "D" Data Group

The D data group comprises two types of pattern data: (a) strip at any angle, and (b) circles, sectors, annuluses, and arcs. Unusual shapes may be built up from these elements. The data in the two subgroups must be separated by (,;) as for the C data group.

a. Strip at an Angle (see Figure 4-5).

X, Y — first appearance of X and Y on a card is starting point of strip. Subsequent appearances of X and Y are point to which strip will be extended in a straight line (DU).

W — width of strip (DU). W cannot be changed within a series of parameters.

M, N, S, T same as for rectangle data.

X and Y may be any values; however, the direction angle of the strip will be rounded to the nearest degree by the program. When strips meet at an obtuse angle they are extended by the program as shown in Figure 4-5. When strips meet at an acute angle a small rectangle is added as shown to smooth the elbow. Neither of these actions is taken for end points.

b. Circles and Arcs. This data subgroup allows circular patterns to be approximated from rectangles, as shown in Figure 4-6.

R — distance from arc center (X,Y) to centerline of annulus (DU).

W — width of annulus (DU).

A, B — angles indicating beginning and end of annular sector (degrees). Annulus goes from A to B in a counter-clockwise direction.

I — angular increment of each rectangle (at its outer edge) used to create annulus (degrees). Default 5 degrees.

X, Y — location of center of annulus (DU).

M, N, S, T same as for rectangle data.

D1,W0.2,X2.0,Y1.0,X3.0,Y1.0,X1.5,Y2.0,X0.5,
*2,Y1.5,X0.5,Y2.5,X1.5,Y3.0,

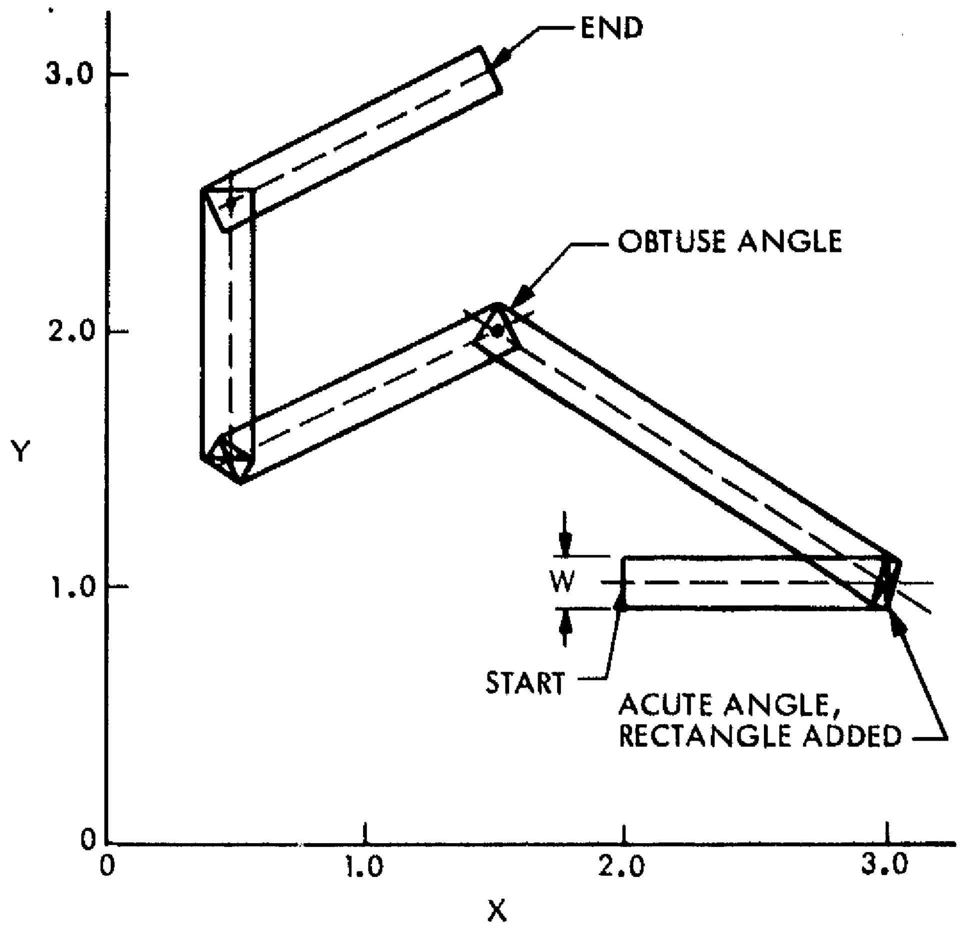

Figure 4-5. Example of Parameter Specifications for Strip (dots at elbows indicate positions specified by parameters X and Y)

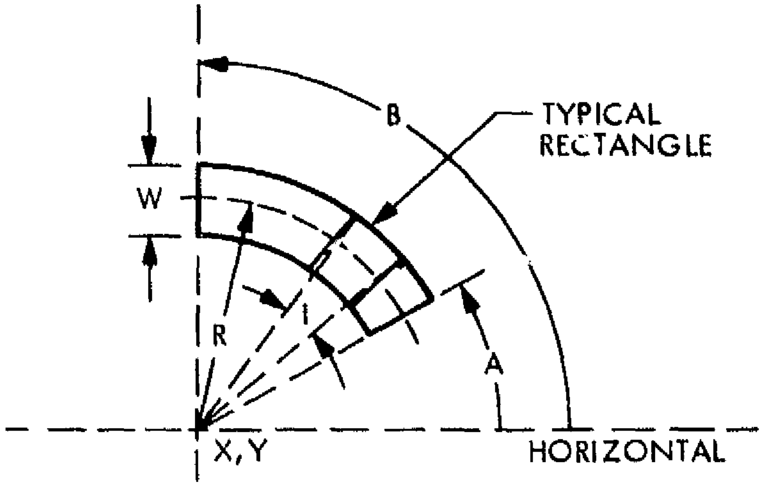

Figure 4-6. Parameter Specifications for Circles and Arcs

Note that a circle can be specified two ways: X30,Y80,R50,W100,A0,B360, or X30,Y80,R0,W200,A0,B180,. Both specify a circle at X = 30, Y = 80 with diameter 200; however, the second method requires half as many rectangles.

This subgroup should be used judiciously, since the figures require a number of exposures. For example, a circle with I=5 requires at least 36 exposures. Parameter I should not be made smaller than necessary. To see how the figures are built up from rectangles, refer to the example at the end of Section VI.

5. "E" Data Group

Following the ID field, parameters M, N, S, T, W, A, X, Y may be specified. Following these parameters a colon (:) is punched, followed by the alphanumeric characters to be placed on the mask plate. The following characters are allowed:

Ø through 9

A through Z

. , : ? ! + - * / = ( ) $ & # b̸ (blank)

Any other characters in the input data will be ignored and will result in a blank on the mask. The actual appearance of the characters is shown in Figure 4-7. Note that O (letter) and Ø (number) give the same pattern.

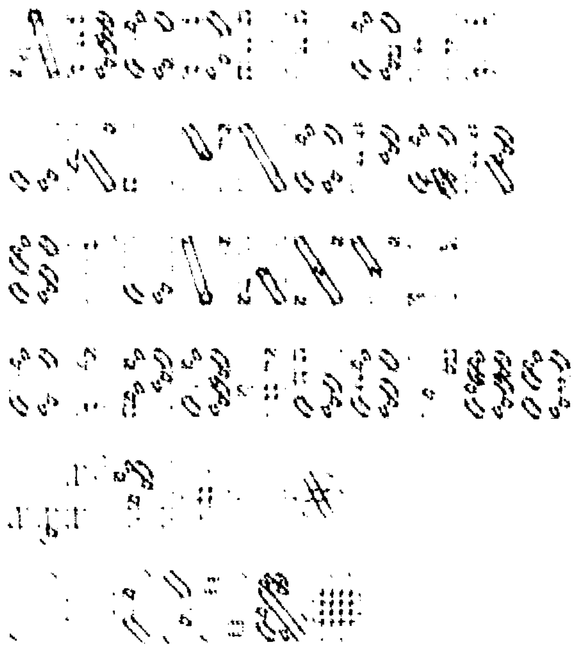

Figure 4-7. E-Group Character Set, SF1, W50.0 (approx 6X)

The alphanumeric field is terminated by (,;), except on the last data card, where it is terminated by (,$).

W — nominal width of a character, including the space between it and the following character (DU). Thus, W is approximately equal to the total message length divided by the number of characters. Some characters deviate from the nominal width as follows:

I	2/3 nominal width
. , :	1/2 nominal width
' !	1/3 nominal width
?	5/6 nominal width

Letter height:letter width:space between letters = 7:5:1

A — angle of rotation of line of characters counterclockwise from horizontal (degrees). Rotation is about lower left corner of first character. If A is zero or positive, characters will be right-reading; if A is negative, characters will be reverse reading (see Figure 4-8).

X, Y — coordinates of the lower left corner of the first character (DU).

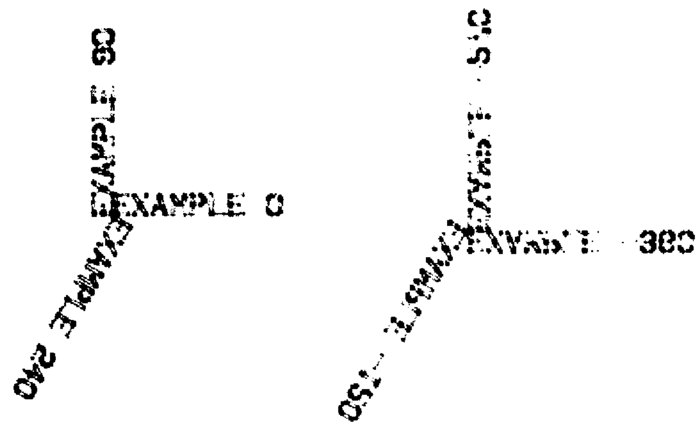

Figure 4-8. Alphanumeric Examples Showing Effect of "A" Parameter

M, N, S, T have the same meaning as for the C data group.

Examples (patterns are shown in Figure 4-8):

```
E3,M1,N1,S0,T0,A0,W50.0,X0.0,Y0.0,'EXAMPLE 0,;
E4,A090,X0.,Y0.,'EXAMPLE 90.;
E5,A240,X0.,Y0.,'EXAMPLE 240,$

E3,M1,N1,S0,T0,A-360,W50.0,X0.0,Y0.0,'EXAMPLE -360,;
E4,A-270,X0.,Y0.,'EXAMPLE -270,;
E5,A-120,X0.,Y0.,'EXAMPLE -120,$
```

6. "I" Data Group

This data group is used to specify fiducial marks and/or a border to be put on the mask plate. These are used in the step-and-repeat process. If the mask is to be stepped and repeated, fiducial marks are always necessary and a border may or may not be necessary. Refer to Sections II and III for further information. If the mask is not to be stepped-and-repeated, then no fiducial marks or border are needed; they may be put on if the designer wishes. In order for a border to be generated, the B-group card must have $|MR| \geq 3$. Only one I card is necessary per mask.

W, H (if border used) width and height of opening inside the border (DU).

S (if border used) both width and height of outside of border (mils). The outside of the border is square, with side of length S.

T vertical separation of fiducial marks (mils).

The fiducial marks are located at X=0, Y=+T/2 and X=0, Y=-T/2 relative to XC, YC. The upper one consists of two squares, the lower of three rectangles. The outside of the border is always square, and the border is centered at XC, YC. Examples of fiducial marks and borders are given in Figures 4-9, 4-10, and 4-11; all figures are approximately 2X.

The fiducial mark separation and outside dimension of the border depend on the plate size and step-and-repeat machine. For MSFC the following are standard:

2 in. x 2 in. plate	S = 1600 mils	T = 1600 mils
3 in. x 3 in. plate	S = 2600 mils	T = 2600 mils

Examples (patterns are shown in Figures 4-9, 4-10, and 4-11):

```
I201,H600,W1000,S1300,T1600,$
I98,H600,W1000,S1600,T1600,$
I12.50,H600,W1000,S1800,T1600,$
```

D. RULES GOVERNING CARD FORMAT

(1) Parameters may be punched in any order, except for strip data. The conventional order is repetition data (M, N, S, T), angle data (A, B, I), size data (W, H, R), location data (X, Y).

(2) Within a data group, a parameter retains its numerical value until changed. Thus, a parameter may be omitted if it does not change from its previous occurrence. For example:

```
C01,M1,N1,A30,X35,Y10,
C02,X50,
```

is equivalent to

```
C01,M1,N1,A30,X35,Y10,
C02,M1,N1,A30,X50,Y10,
```

Each will result in two rectangles.

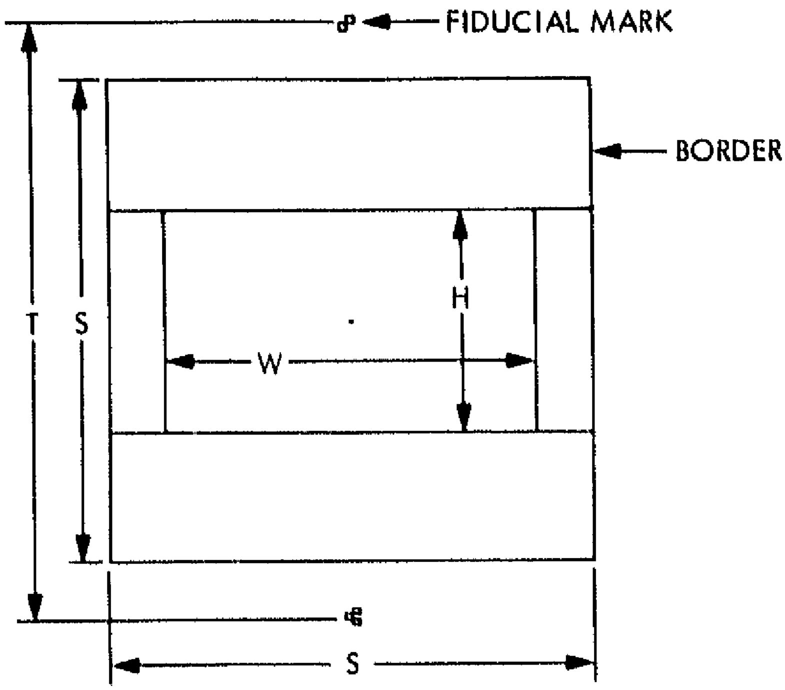

Figure 4-9. Border and Fiducial Mark Example, H600, W1000, S1300, T1600

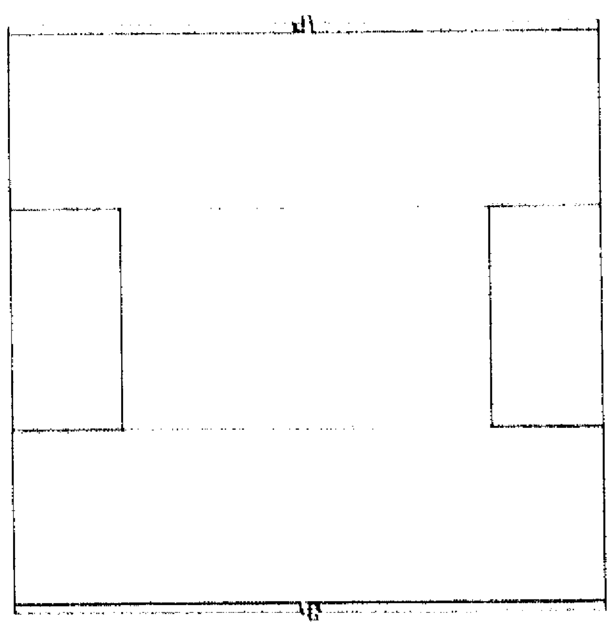

Figure 4-10. Border and Fiducial Mark Example, H600, W1000, S1600, T1600

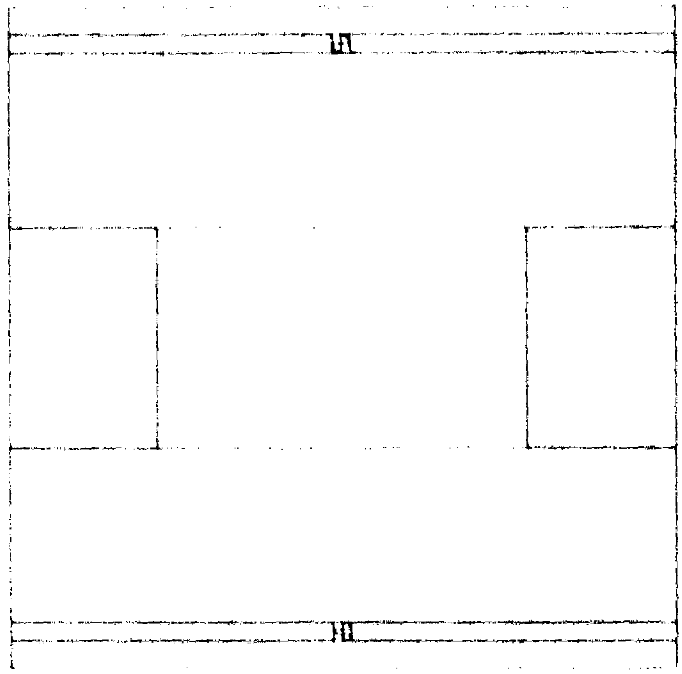

Figure 4-11. Border and Fiducial Mark Example, H600, W1000, S1800, T1600

(3) Each appearance of the data group identifier (C, D, or E) (except the initial appearance in the data group), or a terminator (;) or ($), initiates the processing to create the specified pattern. Only the most recent value assigned to a parameter is used. Thus

```
C01,M1,N1,A30,X35,Y10,X55,
C02, ---
```

is equivalent to

```
C01,M1,N1,A30,X55,Y10,
C02, --
```

and will result in one rectangle. The data group identifier (C) on the C02 card initiates processing of the preceding specifications on the C01 card. The last value of X (X55) is the one that is used.

(4) More than one set of data may be put on a single card by interposing the data group identifier. For example:

```
C01,M1,N1,A30,X35,Y10,C02,X55,
```

will result in two rectangles.

(5) A set of data may be continued from one card to another by punching the continuation character (*) in column 1,

```
C01,M1,N1
*01,A30,X35,Y10,
```

or by omitting the data group identifier.

```
C01,M1,N1,
A30,X35,Y10,
```

NOTE: Since parameters values may carry from one card to the next, it is important to remember to "reset" parameters, particularly M and N.

E. REMARKS

The pattern is generated as a set of rectangles. If the rectangles are to connect, some overlap is desirable. Overlap should be indicated on drawings to aid in subsequent translation to numerical input data.

The order in which the rectangles and other patterns appear in the input data is unimportant to the program, since they are sorted by the program. However, for ease of programming and data revision some form of organization is useful.

1. JPL/MSFC Compatibility

As stated elsewhere, the MASK program was obtained from MSFC. One of the ground rules in implementing the program at JPL was to maintain compatibility with MSFC. Thus, data cards may be used interchangeably, except for minor differences indicated in this section and summarized here (refer to MSFC manuals).

	JPL	MSFC
Card format	all 80 columns may be used	columns 0-72 only may be used
	continuation indicated by *	continuation indicated by any character except data group or parameter identifiers.
	comments may be put on data cards	comments must not be put on data cards

	JPL	MSFC
Punch codes	See following page	
Data groups	F, G, J not available	F, G, J available
A-group	message limited to 68 columns	message length limited only by space on card
E-group	quote (") not allowed	quote (") allowed
	(1) same width as other numbers	(1) narrower than other numbers
I-group	only W, H, S, T allowed	W, H, S, T and other parameters allowed

2. Punch Codes

The punch codes for data cards differ for the Univac (at JPL) and the XDS Sigma 5 (at MSFC) computer systems. This must be taken into account when sending data cards from one installation to the other, particularly for the A-group messages and the E-group alphanumeric specifications.

Fortunately, the alphabet, digits, and most of the data characters (. , ; $ * -) are the same. The plus sign (+) is different; to simplify data preparation, do not use it since an unsigned number is always assumed to be positive. For the E-group alphanumerics flag the colon (:) is used at JPL and the apostrophe (') at MSFC since this results in the same card code (5-8).

Card Punch Codes

Character	Name	Univac (JPL)	XDS Sigma 5 (MSFC) IBM 360, 370 (CIT)
A thru I	letters	same, 12-1 thru 12-9	
J thru R	letters	same, 11-1 thru 11-9	
S thru Z	letters	same, Ø-2 thru Ø-9	
Ø thru 9	digits	same, Ø thru 9	
.	period/decimal point	same, 12-3-8	
,	comma	same, Ø-3-8	
;	semicolon	same, 11-6-8	
$	dollar sign	same, 11-3-8	
*	asterisk	same, 11-4-8	
/	slash	same, Ø-1	
-	minus sign	same, 11	
+	plus sign	12	12-6-8
=	equal sign	3-8	6-8
<	less than	12-6-8	12-4-8
>	greater than	6-8	Ø-6-8
(	left parenthesis	Ø-4-8	12-5-8
)	right parenthesis	12-4-8	11-5-8
'	apostrophe	4-8	5-8
:	colon	5-8	2-8
?	question mark	12-Ø	Ø-7-8
!	exclamation point	11-Ø	11-2-8
"	quotation mark	not available	7-8
#	number sign	12-7-8	3-8
%	percent sign	Ø-5-8	Ø-4-8
@	at sign	7-8 (may be Δ)	4-8
&	ampersand	2-8	12

SECTION V

DIGITIZING PHOTOMASK DRAWINGS

The input data for the pattern can be prepared and punched onto cards by hand according to the directions given in the preceding section. A faster and less error-prone method is to use a digitizer to take the data from a drawing. Directions for this method are given in this section. Only data for the C group (rectangles) can be accommodated by this method; the data for A, B, D, E, and I groups must still be prepared wholly or partially by hand. This is not a serious limitation, since most mask patterns can be made up of rectangles and right-angle strips. Contact J. H. Hix (JPL) regarding use of the digitizer.

A. PREPARING THE DRAWING

(1) Use paper having 10 grid lines to the inch.

(2) Check that grid lines on the paper are accurately spaced to within 1/4 of a grid division over the area to be used for the drawing.

(3) Drawing should consist of rectangles whose edges lie on grid lines or half-way between grid lines (anything else, such as rectangles at an angle, curved lines, edges not on grid lines or half-way between, etc., will require additional work). Rectangles which are to be connected should have some overlap (equivalent to 1/2 mil - 1 mil at final 1X size). All lines need not be drawn in -- only two diagonally opposite corners are needed for each rectangle.

(4) Decide on an origin for the drawing (X=0, Y=0).

B. DIGITIZING THE DRAWING

(1) Load a drum card into the digitizer keypunch. Use one of the schemes shown in Figure 5-1.

(2) Place the drawing on the digitizer table and rotate it until it is aligned to the digitizer table X and Y axes within about ±10 mils over the drawing area.

(3) Place the cursor at the drawing origin (X=0, Y=0) and initialize the digitizer by pressing the extreme right (red) button on the cursor (see Figure 5-2). The X and Y indicators on the digitizer panel should then reset to 00000.

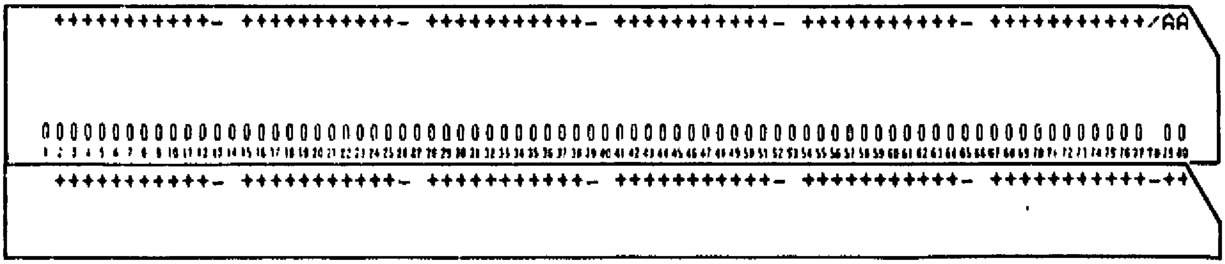

Figure 5-1. Digitizer Keypunch Drum Cards (top: to duplicate label; bottom: for no label)

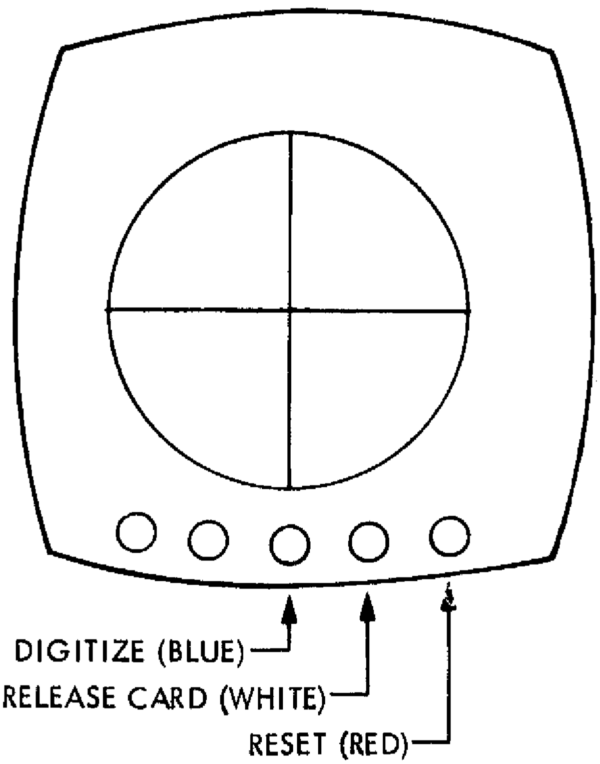

Figure 5-2. Moveable Cursor on Digitzer

(4) If the first drum card shown in Figure 5-1 is used, columns 78-80 of the data cards may contain a label (any characters) for identification. Before digitizing each set of data, disengage the drum, punch the label in columns 78-80, and re-engage the drum. The label will then be duplicated on the succeeding data cards. A label should not be used if the cards will be input to the MSFC computer.

(5) Digitize the rectangles on the drawing (one mask at a time) by doing the following: Align cursor over one corner of the rectangle, press the middle (blue) button on the cursor, then align cursor over the diagonally opposite corner of the same rectangle and press the button again. Either pair of diagonally opposite corners may be used, and in any order. However, a consistent scheme is recommended to make later editing easier. Six X-Y pairs, corresponding to three rectangles are punched onto each card.

Although rectangles at an angle, circles, etc., cannot be correctly handled by the digitizer program, they should be digitized anyway to get their X,Y location and eliminate that part of the hand work.

Lifting the cursor off the table or moving it too fast will "lock" the digitizer. Repeat step (3) and resume.

(6) After all rectangles in the group (for example, one mask) are digitized, eject the last card from the keypunch by pressing the white button on the cursor.

The last data set (2 X,Y pairs) must contain blanks or zeros. This indicates the end of a set of data. In some cases this will require a blank card as the last card.

C. CONVERTING DIGITIZER CARDS INTO C-GROUP CARDS

The cards from the digitzer are converted into C-group cards which can be input to the MASK program by assembling them into a deck as shown below. This program runs on the Univac 1108 at JPL. Be sure that the @RUN card allows sufficient cards to be punched.

```
@RUN
@XQT     FILE.DIGITTOCABS
--initialization card--
--data cards from digitizer, last card must have 4 fields blank--
--initialization card--
--data cards ...
etc.
@FIN
```

Each set of data cards (a set might correspond to an individual mask) must be preceded by an "initialization card" containing the following:

Columns 1-4: The initial value for the C group identification number. The C cards will be numbered consecutively starting with this number. It must be an integer (no decimal point).

11-16: An XSHIFT value. This number will be added by the program to all X values in the set of data cards following this card. It must be an integer and may be + or -.

21-26: A YSHIFT value, analogous to the XSHIFT value.

31-71: May contain a label. It will appear on the printed output.

All other columns may contain anything desired to identify, etc. Any or all of the columns may be left blank, in which case the numbers will be interpreted as equal to 0. In any case an initialization card must precede every set of data cards.

The data cards are used as they come from the digitizer. Four consecutively blank or zero fields terminate the data set. The label in columns 78-80 will appear in the printed output and be punched in columns 73-75 of the C-group cards generated from the digitizer card (C-group cards to be processed at MSFC must not contain a label). Each digitizer card generates three C cards (except at the end of a data set).

To delete the data for a rectangle, punch any character in the blank column between the four data fields for the rectangle.

The program first rounds the digitizer data values to the nearest 50 mils (nearest grid line or halfway point). The H, W, X, and Y values are then calculated. If H or W is zero, a WARNING is printed in the computer output. However, the corresponding C card is punched anyway.

The punched C group cards will have the following format:

```
C****,W*******,H******,X******,Y******,                    ###
```

where each * represents a digit. The digit fields will not contain any blanks; they will be zero filled on the left, since a blank following a parameter letter (W, H, X, Y, etc.) would cause the MASK program to ignore all the succeeding data on that card. ### is the three character label from columns 78-80 of the corresponding digitizer data card.

When preparing the C-group cards to be input to the MASK program, any rectangle can be repeated by preceding its C-group card with a C-group card containing the appropriate M, N, S, and T values. The card containing the W, H, X, and Y data should have the letter C in column 1 replaced with a * (continuation card indicator, see Section IV-D-5). To terminate the C-group cards, the last card may have a $ added following the last comma, or a separate C card (for example C9999,$) may be added at the end.

D. EXAMPLE OF THE PROCEDURE

Figures 5-3 through 5-6 illustrate an example of the procedure. On the drawing the solid rectangles are "P+ diffusion;" the dashed rectangles are "METAL." The second set of data (METAL) is shifted 1.0 inch to the left and 0.5 inch up. Two mistakes were made while digitizing: the first one was flagged for deletion by an X, the second was not deleted (a zero width rectangle), but was detected by the program.

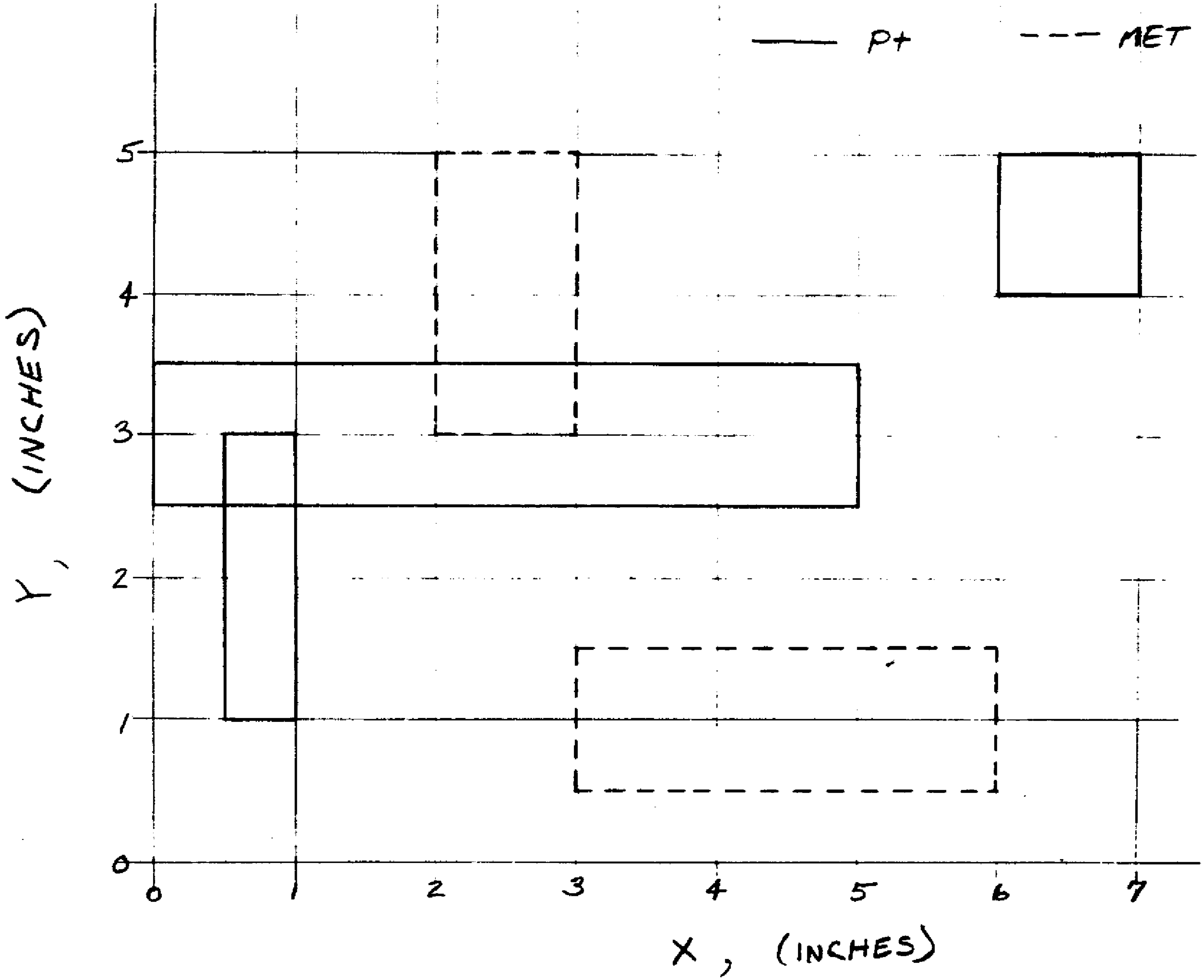

Figure 5-3. Drawing for Example

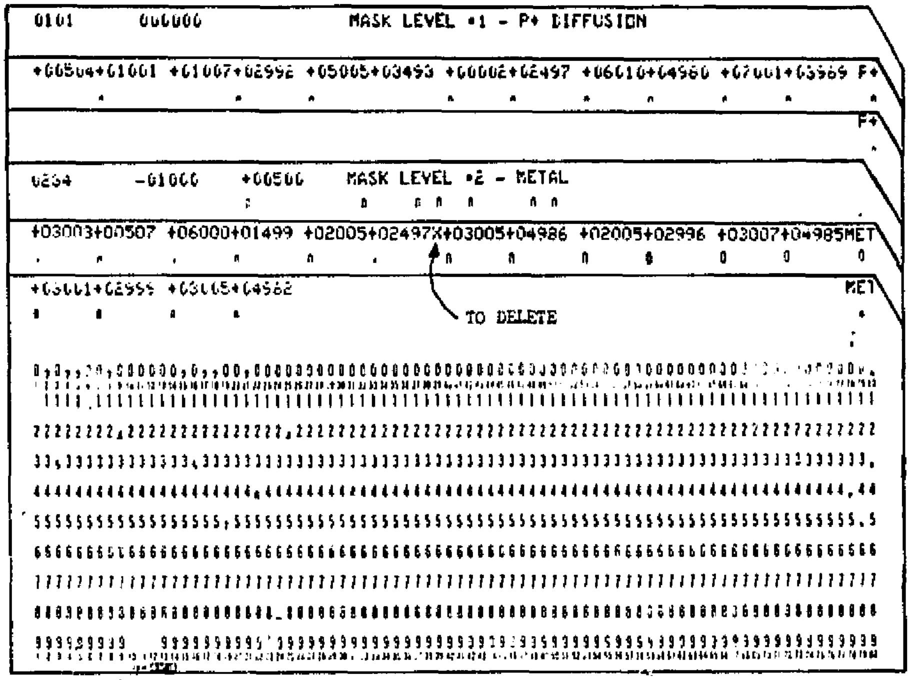

Figure 5-4. Data Cards from Digitizer and Initialization Cards

```
---------------------- DIGITIZER DATA CARDS TO MASK PROGRAM C-GROUP CARDS ----------------------


 *  XSHIFT=      0     YSHIFT=      0         MASK LEVEL #1 - P+ DIFFUSION                  *

   504,  1001.    1007.  2992. /   5005.  3493.       2.  2497. /   6010.  4980.     7001.  3989. /   P+
C0101,W00500,H02000,X000750,Y002000,                                P+
C0102,W05000,H01000,X002500,Y003000,                                P+
C0103,W01000,H01000,X006500,Y004500,                                P+
     0.     0.      0.     0. /     0.     0.       0.     0. /     0.     0.        0.     0. /

*  END OF DATA,      3 RECTANGLES,     0 WARNINGS.     MASK LEVEL #1 - P+ DIFFUSION                *


 *  XSHIFT=  -1000     YSHIFT=    500         MASK LEVEL #2 - METAL                         *

   3003.   507.    6000.  1499. /   2005.  2497. X  3005.  4986. /   2005.  2996.     3007.  4985. /  MET
C0234,W03000,H01000,X003500,Y001500,                                MET
C0235,W01000,H02000,X001500,Y004500,                                MET
   3001.  2999.    3005:  4982. /     0.     0.       0.     0. /     0.     0.        0.     0. /  MET
xxxxx WARNING: ZERO WIDTH OR HEIGHT **  C0236,W00000,H02000,X002000,Y004500,     ET xxxxx
C0236,W00000,H02000,X002000,Y004500,                                MET

*  END OF DATA,      3 RECTANGLES,     1 WARNINGS.     MASK LEVEL #2 - METAL                       *


------------------------------- END OF JOB.     6 RECTANGLES TOTAL -------------------------------
```

Figure 5-5. Printed Output from Program

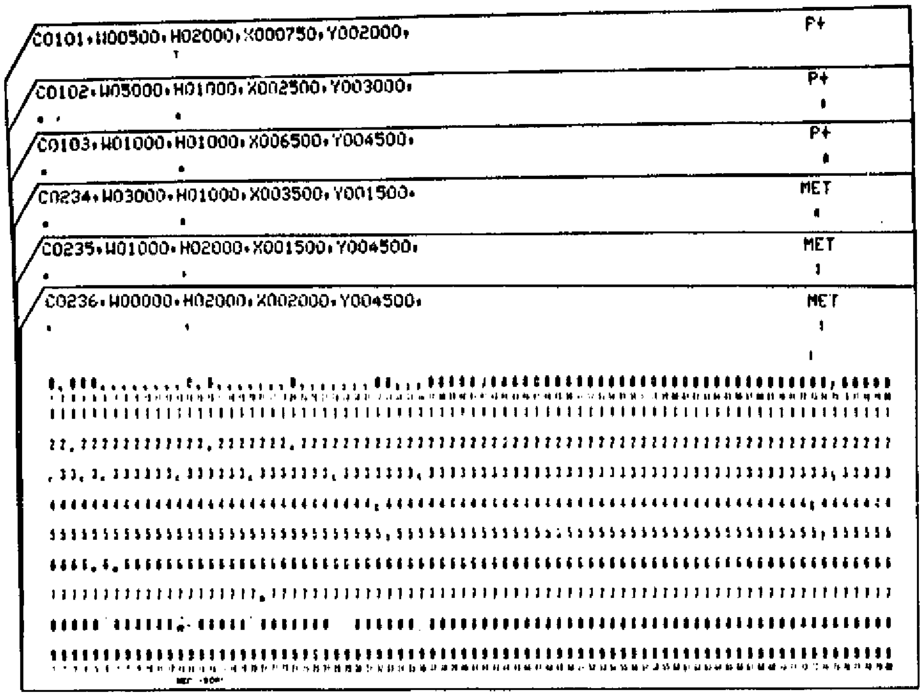

Figure 5-6. Punched C-Group Cards from Program

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SECTION VI

RUNNING THE MASK PROGRAM

A. SETUP AND INPUT

The MASK program runs on the Univac 1108 at JPL. Prior to using the program, it is necessary to establish files 53, 55, and 57 for data and to have the programs residing in a program file, called FILE in this manual. It may be desirable to permanently catalog all these files. Consult the appropriate GPCF and Univac manuals. To execute the MASK program, set up the deck as follows:

```
@RUN
@ASG,A      53.
@DATA,IL    53.
     ---Mask Specification data cards,     Omit if data is
        data groups A through I---         already in file 53.
@END
@ASG,A      55.                  If plot data will be generated
@ERS        55.
@ASG,A      57.                  If Mann data will be generated
@ERS        57.
@XQT        FILE.MASKABS
--initialization card (optional)--
@FIN
```

Data from more than one mask may be processed in one computer run by placing the sets of data cards for the masks one after the other.

The initialization card should contain the following:

Columns 1-10:	Initial photomask number to be used, right justified, default: 1
11-20:	XBIAS in mils, default: 0.0 (see B below)
21-30:	YBIAS in mils, default: 0.0 (see B below)
31-40:	If > 0, the plot data will be generated and put into file 55; if > 2, a cross (+) will be placed on the plot at the point XC,YC (see E-1 below); default 2.
41-50:	If > 0, the Mann data will be generated and put into file 57, default: 0.
51:	Flag for rectangle data printout in drawing units
52:	Flag for rectangle data printout in mils
53:	Flag for mann pattern generator printout in Mann format (0.1 mils).

For columns 51, 52, 53, if number is 1, full printout of all data will occur; if 2, abridged printout of only one page of data will occur. If neither 1 nor 2, no printout will occur. Default is 0 in all cases. Usually these printouts are used for diagnostic purposes, and are not selected for normal runs.

54-80: Not used by program, may be used for identification or comments

Defaults apply only if entire initialization card is omitted.

B. BIAS

The parameters XBIAS and YBIAS specify a shift of the entire pattern of exposures on the photoplate. They are needed when it is necessary to use the maximum possible plate area for the pattern, usually for the 2 inch X 2 inch plate. The proper values of XBIAS and YBIAS center the image in the usable exposure area, which is determined by the opening in the clamping frame that holds the photoplate. The current values are given below. Since these values change from time to time, check with Don Routh at MSFC. See F below.

Nominal Plate Size	XBIAS (mils)	YBIAS (mils)
2 in. x 2 in.	-43.5	-29.5

C. HOW THE PROGRAM WORKS

At execution, the MASK program scans each data card in turn. Processing of the card is directed to an appropriate subroutine, depending on the data group indicated (see Appendix C). The data is extracted and converted into specifications for rectangles, then stored. Repetitions (M, N, S, T) are taken care of at this time.

When the end of data for a mask is encountered (next A-group card or end-of-file), or if 1000 rectangles have been generated before the end is encountered, the accumulated rectangle data is processed. The data is converted to mils, shifted, and angles are converted to Mann-compatible angles. Some checking of sizes is done.

The data for the rectangles is sorted according to location, prepared for plotting purposes, and written into the plot file if the plot option was selected.

If the Mann option was selected, the data is further processed for the MPG. The size of the rectangles is checked and those larger than 120 mils are partitioned into smaller rectangles, referred to as exposures. The exposures are sorted for efficient MPG operation and the total MPG mask-exposing time is calculated. The exposure data is written into the Mann file in MPG format.

The program then returns to scanning the data cards. When the end of data for a mask is encountered, the mask is closed out and summary data printed. The process then repeats for any succeeding masks. At the end of all data, the last mask is closed out, the Plot and Mann files are closed and processing is terminated.

D. ERRORS

The MASK program recognizes certain types of errors and prints a message when they are encountered. These can be distinguished from the computer operating system error messages by the fact that they all begin ERROR:-- The program does not recognize all possible errors. The error messages are given below:

Message	Occurrence
ERROR: UNKNOWN DATA GROUP, CARD NOT PROCESSED	
ERROR: CANNOT INTERPRET CARD	any data group
ERROR: SEMICOLON (;) OR DOLLAR ($) MISSING	A, E Groups
ERROR: MESSAGE TOO LONG, 68 CHARACTERS MAXIMUM	A group
ERROR: DOLLAR ($) MISSING	B, I groups
ERROR: ILLEGAL PARAMETER '*'	D, C, E, I groups
ERROR: ILLEGAL CHARACTER '*'	E group
ERROR: APOSTROPHE/COLON MISSING	E group
ERROR: M=*, M=1 ASSUMED	rectangle processing
ERROR: N=*, N=1 ASSUMED	rectangle processing
ERROR: W OR H NEGATIVE, 0.5 MIL IS ASSUMED	rectangle processing
ERROR: W OR H LESS THAN 0.5 MIL, 0.5 MIL ASSUMED	rectangle processing
ERROR: EXPOSURE OUTSIDE OF LIMIT, X < 0.0 MILS	exposure processing
ERROR: EXPOSURE OUTSIDE OF LIMIT, X > 4000.0 MILS	exposure processing
ERROR: EXPOSURE OUTSIDE OF LIMIT, Y < 0.0 MILS	exposure processing
ERROR: EXPOSURE OUTSIDE OF LIMIT, Y > 4000.0 MILS	exposure processing

*indicates character or number inserted by program.

Detection of an error generally causes the parameter, card, or rectangle to be ignored. The program then proceeds to subsequent data. In some cases a default value is used, as indicated in the above list and elsewhere in this manual. Detection of an error does not cause termination of the program execution. Note: error detection and defaults differ at JPL and MSFC.

E. PROGRAM OUTPUTS

Execution of the program results in three outputs: (1) a printout, (2) a plot file, and (3) a Mann file. (1) is always produced and is described in the example at the end of this chapter. (2) and (3) are produced if selected on the initialization card, and are described below.

1. Plot Data

The plot data is written into file 55. Use of this data for plots is covered in Section VII. The file format is as follows:

Columns 1-4 : Flag indicating type of data:

- AƀƀO - First line of A-group message
- Bƀƀ1 - Last line of A-group message, rectangle data follows
- Xƀƀ3 - "+" data
- Zƀƀ4 - End of rectangle data

5-72: A-group message or rectangle data

73-80: Blank

If the A-group message is only one line, then card columns 1-4 contain Bƀƀ. The rectangle data are in 4(1X,2F8.2) format and consist of X1,Y1, X2,Y2, X3,Y3, X4,Y4, where X1,Y1 are the coordinates of the first corner of the rectangle, etc. All data are in mils. An example is shown in Figure 6-1. The rectangles are sorted (for each mask, or groups of 1000) by the program according to the location of their center, and arranged in the file so that plotting takes place along a zigzag path as shown in Figure 6-2. If more than one mask is run the data are put into file 55 end-to-end.

If columns 31-40 on the initialization card are >2, the program adds two small rectangles, one with zero height, one with zero width, to the end of the plot data. When plotted, they form a cross at the center of the mask exposure area (2000+XBIAS, 2000+YBIAS), which is also the point XC,YC, the center coordinates specified on the B-group data card (see F below).

A	0	*****	TEST AND DEMONSTRATION PATTERNS						**
B	1	R. K. KIRSCHMAN, 4-77							
		1100.00	1507.87	1409.45	1507.87	1409.45	2492.12	1100.00	2492.12
		1100.00	1175.00	1975.00	1175.00	1975.00	1225.00	1100.00	1225.00
		1100.00	2775.00	1975.00	2775.00	1975.00	2825.00	1100.00	2825.00
		1645.67	2322.83	1685.04	2322.83	1685.04	2346.46	1645.67	2346.46
		1645.67	2244.09	1685.04	2244.09	1685.04	2267.72	1645.67	2267.72
		1654.21	2117.72	1688.31	2137.41	1676.50	2157.87	1642.40	2138.18
		1654.21	2038.98	1688.31	2058.67	1676.50	2079.13	1642.40	2059.44
		1681.29	1870.08	1688.79	1870.08	1688.79	1948.82	1681.29	1948.82
		1681.30	1869.75	1688.78	1870.41	1681.91	1948.85	1674.44	1948.19
		1688.78	1869.75	1695.64	1948.19	1688.17	1948.85	1681.30	1870.41
		1681.35	1869.43	1688.73	1870.73	1675.06	1948.27	1667.67	1946.97
		1688.73	1869.[illegible]	[illegible]	[illegible]94[illegible].97	1695.02	1948.27	1681.35	1870.73
		1681.4[illegible]				[illegible]48.28	1947.11	1661.04	1945.17
		[illegible]				[illegible]	1947.11	1681.42	1871.05
				[illegible]			[illegible]5.36	1654.59	1942.79
			[illegible]5.12	2401.50	1843.10	[illegible]		1648.36	1939[illegible]
		[illegible].08	1869.86	2383.28	1909.23	2381[illegible]			
		2317.11	1867.01	2381.61	1912.17	2377.31	1[illegible]		
		2317.37	1867.21	2377.69	1917.82	2372.87	1923.[illegible]		
		2317.61	1867.43	2373.29	1923.10	2367.99	1928.41	[illegible]	[illegible]72.73
		2317.83	1867.67	2368.45	1927.99	2362.70	1932.81	2312.09	1872.49
		2381.89	1865.58	2405.51	1865.58	2405.51	1870.33	2381.89	1870.33
		2404.80	1857.95	2405.54	1866.42	2382.00	1868.48	2381.26	1860.01
		2403.40	1850.17	2404.87	1858.54	2381.61	1862.64	2380.13	1854.27
		2401.33	1842.54	2403.53	1850.75	2380.71	1856.86	2378.51	1848.65
		2381.89	1680.35	2405.51	1680.35	2405.51	1697.10	2381.89	1697.10
		2025.00	1175.00	2900.00	1175.00	2900.00	1225.00	2025.00	1225.00
		2025.00	2775.00	2900.00	2775.00	2900.00	2825.00	2025.00	2825.00
		2590.55	1507.87	2900.00	1507.87	2900.00	2492.12	2590.55	2492.12
X	3	1980.00	2000.00	2020.00	2000.00	2020.00	2000.00	1980.00	2000.00
X	3	2000.00	1980.00	2000.00	1980.00	2000.00	2020.00	2000.00	2020.00
Z	4								

Figure 6-1. Example of Data in File 55

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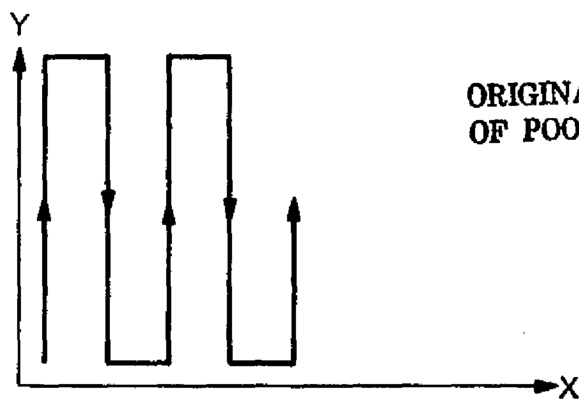

Figure 6-2. Plotting Path of Sorted Rectangles

2. Mann Data

The Mann data is written into file 57. The details of converting this data into a tape to drive the MPG are presented in Section VIII. The format is as follows:

Columns 1-4: Flag, same as for plot data, except there is no XbbЗ, and there is Zbb5 flagging the summary data at the end of each mask

5-72: A-group message

5-50: Exposure data

If there is only one A-group message then card columns 1-4 contain Bbb1. The exposure data are in 4I10,I6 format and consist of X, Y, W, H, A. X, Y are the coordinates of the center of the exposure in 0.1 mil units. The last digit may only be 0, 2, 5 or 7. A last digit of 2 indicates 0.25 mils and a last digit of 7 indicates 0.75 mils, since X and Y increments are 0.25 mils. The minimum value of X or Y is 0 and the maximum is 40000. W, H are the width and height of the exposure, also in 0.1 mil units. The last digit may only be 0 or 5. The minimum value is 0 and the maximum value is 1200. A is the angle of the exposure in degrees; possible values are integers from 0 to 89.

The end of the exposure data is indicated by 99999 in columns 7-11. The next line contains summary data as shown in the example in Figure 6-3. The exposures are sorted by the program for efficient mask generation by the MPG. If more than one mask in run, the data are put into file 57 end-to-end.

F. EXPOSURE FIELD

As indicated above, the X and Y values in file 57 for the MPG range from 0 to 40000. Accordingly, in this manual and the MASK program the exposure field is considered to occupy the region 0 to 4000 mils in X and Y. Thus, the center of the field is at 2000,2000 (mils). When a photoplate is mounted in the MPG its center is approximately at 2000,2000 (mils). The data input to the MASK program is translated (shifted) so that the point specified by XC,YC is placed at 2000+XBIAS,2000+YBIAS (mils) in the MPG exposure field. XBIAS and YBIAS allow for a slight correction in placing the pattern on the plate (see VI-B and IV-C-2 "B" Data Group).

This translation (shift) manifests itself in the data in file 57 and the printouts headed "THE MANN EXPOSURE DATA (0.1 MIL UNIT)", "RECTANGLE DATA (MIL UNIT, SHIFTED AND SCALED)" and "PATTERN LIMITS". In addition, it manifests itself in the plot data in file 55, and must be taken into account when plotting.

A	0	*****	TEST AND DEMONSTRATION PATTERNS			**
B	1	R. K. KIRSCHMAN, 4-77				
		11565	11375	1130	750	0
		12690	11375	1130	750	0
		13815	11375	1130	750	0
		14940	11375	1130	750	0
		16062	11375	1130	750	0
		17187	11375	1130	750	0
		18312	11375	1130	750	0
		19437	11375	1130	750	0
		19900	11860	200	140	0
		20562	11375	1130	750	0
		21687	11375	1130	750	0
		22812	11375	1130	750	0
		23937	[illegible]	1130	750	0
		25060		[illegible]130	750	0
		[illegible]			750	0
			[illegible]		750	0
			28625	[illegible]	[illegible]	[illegible]
		[illegible]940	28625	[illegible]		
		16062	28625	1130		
		17187	28625	1130	[illegible]	
		18312	28625	1130	750	0
		19437	28625	1130	750	0
		20562	28625	1130	750	0
		21687	28625	1130	750	0
		22812	28625	1130	750	0
		23937	28625	1130	750	0
		25060	28625	1130	750	0
		26185	28625	1130	750	0
		27310	28625	1130	750	0
		28435	28625	1130	750	0
Z	4	99999				
Z	5	687 EXP.	ON 47K OS	EXP TIME,	END MASK	1

Figure 6-3. Example of Data in File 57

G. EXAMPLE OF THE PROCEDURE

Figures 6-4 through 6-7 present examples of input data and program execution illustrating the procedure described in this section. The printout from the Univac 1108 system is shown. Various features are explained by notes on the printout.

```
@DATA,IL     53.
DATA 6-A  07/28/77  14:48:57
        A1,   +++++              TEST AND DEMONSTRATION PATTERNS               +++++,!
        A2,   R. K. KIRSCHMAN, 4-77 ,$
        K14.1,
        B3.,SF39.37,XC0,YC00.00,MR-3,$

            RECTANGLES AT VARIOUS ANGLES
        C4,M3,N2,S1.5,T2.0,A0,H.6,W1.,X-8.5,Y6.5,
        C5,A30.,X-8.5,Y1.5,
        C6,A60.,X-3.5,Q1.2,
        Y6.5,!

            RIGHT ANGLE STRIP
        C7,M1,N1,S0,T0,A0,W.5,X2.0,Y8.5,R4.5,D2.5,L2.5,U1.,R1.5,U.75,L2.75,
        *9,D2.5,R3.5,$

            STRIP AT ANGLES
        D10.1,M1,N1,S1,T1,W.4,X1.,Y01.,X2.,Y1.,X2.,Y3.,
        X1.5,Y2.5,X1.5,Y4,W.2,X8,Y4,X7,Y1,X7,Y3,W0.5,X4.,Y2.,X6.0,Y1.5,!

            CIRCLES, ARCS, RINGS
        D11.123,M1,N1.8,S5,T0,R1.,W2.,A0.,B360.,X-8.,Y-3.3,
        D12,R1.7,W0.600,X-3.,Y-3.3,Z4.0,
        D12.5,M2,N1,S5.0,T0.,
        *13.,R1.,W2.,A30.,B180,X3,Y-3.3,
        D14,R2,W00.60,A190,B360,X3.,Y-3.3,
        K14.1,
        D15.004,I20.,      CHANGE TO 20 DEGREE INCREMENT
        *16.123,M0,N-3,S5.,T0,R1.,W2.,A0.,B360.,X-8.,Y-7.7,
        D17,R1.7,W0.600,X-3.,Y-7.7,D17.5,M2,N1,S5.0,T0.,
        *18.,R1.,W2.,A30.,B180,X3,Y-7.7,
        D19,R2,W00.60,A190,B360,X3.,Y-7.7,$
        E123.45 M1,N1,S0,T0,A0,W1.,X-6.5,Y10.,:TEST PATTERNS o ,$
        I3,H25.,W0030,Q123,S1800,T1600,=456,$

@ASG,A  55.

@ERS   55.
FURPUR 27-L  07/28/77  14:50:03
END ERS.

CPU:.003   CTP:.004   SUPS:1.443

@ASG,A  57.

@ERS   57.
FURPUR 27-L  07/28/77  14:50:25
END ERS.

CPU:.004   CTP:.004   SUPS:1.444

@XQT      MASK.MASKABS

   xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx  MASK PROGRAM  xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

        1       .00       .00       4.00       2.00122        TEST PATTERN RUN

  IMASK=         1          XBIAS=       .00     YBIAS=      .00          PLOT: YES       MANN: YES
```

COMMENTS

INPUT DATA CARDS

FROM INITIALIZATION CARD

Figure 6-4(a). Example of Input Data and Program Execution

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```
                       MASK   1:    INPUT DATA PRINTOUT

    ------------------------- A GROUP ----- MESSAGE ON THE MANN TAPE -------------------------

      A1,   *****              TEST AND DEMONSTRATION PATTERNS              ******,I <—— INPUT DATA CARD
ERROR: MESSAGE TOO LONG, 68 CHARACTERS MAXIMUM
    A   1.00:   *****              TEST AND DEMONSTRATION PATTERNS            **   <—— REDUCTION OF CARD
                                                                                         BY PROGRAM
      A2,   R. K. KIRSCHMAN, 4-77 ,$
    A   2.00:   R. K. KIRSCHMAN, 4-77
      K14.1,
ERROR: UNKNOWN DATA GROUP, CARD NOT PROCESSED

    ------- B GROUP ----- SCALE FACTOR(SF), CENTER COORDINATE(XC,YC), MIRROR IMAGE(MR) -------

      B3,,SF39.37,XC0,YC00.00,MR-3,$
    B   3.00:      SF=   39.370000    XC=       .000    YC=       .000    MR=-3.0    $

          RECTANGLES AT VARIOUS ANGLES <—— COMMENT

    ------------------- C GROUP ----- RECTANGLE AND RIGHT-ANGLED STRIP --------------------

      C4,M3,N2,S1.5,T2.0,A0,H,6,W1,,X-8.5,Y6.5,
    C   4.00:  M      3.000,  N      2.000,  S      1.500,  T      2.000,  A       .000,
               H       .600,  W      1.000,  X     -8.500,  Y      6.500,

      C5,A30,,X-8.5,Y1.5,
    C   5.00:  A     30.000,  X     -8.500,  Y      1.500,

      C6,A60,,X-3.5,Q1.2,
    C   6.00:  A     60.000,  X     -3.500,  Q      1.200,
ERROR: ILLEGAL PARAMETER 'Q'

      Y6.5,I <—— PARAMETERS CONTINUED FROM PREVIOUS CARD
    Y   6.50:  I


          RIGHT ANGLE STRIP                                                   —— INPUT DATA CARD

      C7,M1,N1,S0,T0,A0,W.5,X2.0,Y8.5,R4.5,D2.5,L2.5,U1,,R1.5,U.75,L2.75,
    C   7.00:  M      1.000,  N      1.000,  S       .000,  T       .000,  A       .000, }
               W       .500,  X      2.000,  Y      8.500,  R      4.500,  D      2.500, } <—— REDUCTION OF CARD
               L      2.500,  U      1.000,  R      1.500,  U       .750,  L      2.750, }     BY PROGRAM
ERROR: ILLEGAL PARAMETER 'A'

      *9,D2.5,R3.5,$ <————————————— CONTINUATION CARD
    *   9.00:  D      2.500,  R      3.500,  $

          STRIP AT ANGLES

    --------------------------- D GROUP ----- STRIP AND CIRCULAR CURVE -------------------------

      D10.1,M1,N1,S1,T1,W,4,X1,,Y01,,X2,,Y1,,X2,,Y3,,
```

Figure 6-4(b). Example of Input Data and Program Execution

ORIGINAL PAGE IS
OF POOR QUALITY

```
D   10.10:  M      1.000,  N      1.000,  S      1.000,  T      1.000,  W       .400,
            X      1.000,  Y      1.000,  X      2.000,  Y      1.000,  X      2.000,
            Y      3.000,

    X1.5,Y2.5,X1.5,Y4,W.2,X8,Y4,X7,Y1,X7,Y3,W0.5,X4,,Y2,,X6.0,Y1.5,!
X    1.50:  Y      2.500,  X      1.500,  Y      4.000,  W       .200,  X      8.000,
            Y      4.000,  X      7.000,  Y      1.000,  X      7.000,  Y      3.000,
            W       .500,  X      4.000,  Y      2.000,  X      6.000,  Y      1.500,
            !



         CIRCLES, ARCS, RINGS  <------  N1.8 WILL BE TRUNCATED TO N = 1
    D11.123,M1,N1.8,S5,T0,R1,,W2,,A0,,B360,,X-8,,Y-3.3,
D   11.12:  M      1.000,  N      1.800,  S      5.000,  T       .000,  R      1.000,
            W      2.000,  A       .000,  B    360.000,  X     -8.000,  Y     -3.300,

    D12,R1.7,W0.600,X-3,,Y-3.3,Z4.0,
D   12.00:  R      1.700,  W       .600,  X     -3.000,  Y     -3.300,  Z      4.000,
ERROR: ILLEGAL PARAMETER 'Z'

    D12.5,M2,N1,S5.0,T0,,
D   12.50:  M      2.000,  N      1.000,  S      5.000,  T       .000,

    *13.,R1.,W2.,A30.,B180,X3,Y-3.3,
*   13.00:  R      1.000,  W      2.000,  A     30.000,  B    180.000,  X      3.000,
            Y     -3.300,

    D14,R2,W00.60,A190,B360,X3.,Y-3.3,
D   14.00:  R      2.000,  W       .600,  A    190.000,  B    360.000,  X      3.000,
            Y     -3.300,

    K14.1,
K   14.10:
ERROR: ILLEGAL PARAMETER 'K'

    D15.004,I20.,         CHANGE TO 20 DEGREE INCREMENT
D   15.00:  I     20.000,

    *16.123,M0,N-3,S5,,T0,R1,,W2,,A0,,B360,,X-8,,Y-7.7,
*   16.12:  M       .000,  N     -3.000,  S      5.000,  T       .000,  R      1.000,
            W      2.000,  A       .000,  B    360.000,  X     -8.000,  Y     -7.700,

    D17,R1.7,W0.600,X-3.,Y-7.7,D17.5,M2,N1,S5.0,T0.,
D   17.00:  R      1.700,  W       .600,  X     -3.000,  Y     -7.700,  D     17.500,
            M      2.000,  N      1.000,  S      5.000,  T       .000,
ERROR: M =    0, M=1 ASSUMED
ERROR: N =   -3, N=1 ASSUMED

    *18.,R1.,W2.,A30.,B180,X3,Y-7.7,
*   18.00:  R      1.000,  W      2.000,  A     30.000,  B    180.000,  X      3.000,
            Y     -7.700,

    D19,R2,W00.60,A190,B360,X3.,Y-7.7,$
D   19.00:  R      2.000,  W       .600,  A    190.000,  B    360.000,  X      3.000,
            Y     -7.700,  $

------------------------- E GROUP ----- ALPHANUMERICS ON THE MASK -------------------------

    E123.45,M1,N1,S0,T0,A0,W1,,X-6.5,Y10.,:TEST PATTERNS <>,$
E  123.45:  M      1.000,  N      1.000,  S       .000,  T       .000,  A       .000,
            W      1.000,  X     -6.500,  Y     10.000,  :
            TEST PATTERNS <>  $
ERROR: ILLEGAL CHARACTER '<'
ERROR: ILLEGAL CHARACTER '>'

------------------------- I GROUP ----- FIDUCIAL MARKS/BORDER ---------------------------

    I3,W25.,W0030,Q123,S1800,T1600,=456,$
I    3.00:  W     25.000,  W     30.000,  Q    123.000,  S   1800.000,  T   1600.000,
            =    456.000,  $
ERROR: ILLEGAL PARAMETER 'Q'
ERROR: ILLEGAL PARAMETER '='

         FIDUCIAL MARKS  YES             BORDER  YES
```

Figure 6-4(c). Example of Input Data and Program Execution

RECTANGLE NUMBER

FULL PRINTOUT

MASK 11 RECTANGLE DATA (DRAWING UNIT)

N	X	Y	W	H	A	N	X	Y	W	H	A
1	-8.50	6.50	1.00	.60	.0	2	-7.00	6.50	1.00	.60	.0
3	-5.50	6.50	1.00	.60	.0	4	-8.50	8.50	1.00	.60	.0
5	-7.00	8.50	1.00	.60	.0	6	-5.50	8.50	1.00	.60	.0
7	-8.50	1.50	1.00	.60	30.0	8	-7.00	1.50	1.00	.60	30.0
9	-5.50	1.50	1.00	.60	30.0	10	-8.50	3.50	1.00	.60	30.0
11	-7.00	3.50	1.00	.60	30.0	12	-5.50	3.50	1.00	.60	30.0
13	-3.50	6.50	1.00	.60	60.0	14	-2.00	6.50	1.00	.60	60.0
15	-.50	6.50	1.00	.60	60.0	16	-3.50	8.50	1.00	.60	60.0
17	-2.00	8.50	1.00	.60	60.0	18	-.50	8.50	1.00	.60	60.0
19	4.37	8.50	4.75	.50	.0	20	6.50	7.25	2.98	.50	-90.0
21	5.25	6.00	2.98	.50	-180.0	22	4.00	6.50	1.48	.50	90.0
23	4.75	7.00	1.98	.50	.0	24	5.50	7.37	1.23	.50	90.0
25	4.12	7.75	3.24	.50	180.0	26	2.75	6.50	2.98	.50	-90.0
27	4.38	5.25	3.76	.50	.0	28	1.59	1.00	1.19	.40	.0
29	1.89	1.80	2.20	.40	90.0	30	1.89	3.00	.37	.15	-22.5
31	1.74	2.75	.71	.40	-135.0	32	1.49	2.50	.37	.15	-22.5
33	1.49	3.35	1.69	.40	90.0	34	4.65	4.00	6.71	.40	.0
35	8.00	4.00	.32	.24	-54.0	36	7.51	2.49	3.16	.40	-108.0
37	7.03	.69	.39	.07	-8.5	38	7.01	1.99	2.01	.40	91.0
39	6.99	2.99	.32	.24	-35.5	40	5.49	2.51	3.15	.40	-162.0
41	4.00	2.02	.38	.11	-88.5	42	5.00	1.75	2.08	.40	-15.0
43	-7.00	-3.25	2.00	.11	.0	44	-7.00	-3.21	2.00	.19	5.0
45	-7.02	-3.13	2.00	.19	10.0	46	-7.03	-3.04	2.00	.19	15.0
47	-7.06	-2.96	2.00	.19	20.0	48	-7.09	-2.88	2.00	.19	25.0
49	-7.13	-2.80	2.00	.19	30.0	50	-7.18	-2.73	2.00	.19	35.0
51	-7.23	-2.66	2.00	.19	40.0	52	-7.29	-2.59	2.00	.19	45.0
53	-7.36	-2.53	2.00	.19	50.0	54	-7.43	-2.48	2.00	.19	55.0
55	-7.50	-2.43	2.00	.19	60.0	56	-7.58	-2.39	2.00	.19	65.0
57	-7.66	-2.36	2.00	.19	70.0	58	-7.74	-2.33	2.00	.19	75.0
59	-7.83	-2.32	2.00	.19	80.0	60	-7.91	-2.30	2.00	.19	85.0
61	-8.00	-2.30	2.00	.19	90.0	62	-8.09	-2.30	2.00	.19	95.0
63	-8.17	-2.32	2.00	.19	100.0	64	-8.26	-2.33	2.00	.19	105.0
65	-8.34	-2.36	2.00	.19	110.0	66	-8.42	-2.39	2.00	.19	115.0
67	-8.50	-2.43	2.00	.19	120.0	68	-8.57	-2.48	2.00	.19	125.0
69	-8.64	-2.53	2.00	.19	130.0	70	-8.71	-2.59	2.00	.19	135.0
71	-8.77	-2.66	2.00	.19	140.0	72	-8.82	-2.73	2.00	.19	145.0
73	-8.87	-2.80	2.00	.19	150.0	74	-8.91	-2.88	2.00	.19	155.0
75	-8.94	-2.96	2.00	.19	160.0	76	-8.97	-3.04	2.00	.19	165.0
77	-8.98	-3.13	2.00	.19	170.0	78	-9.00	-3.21	2.00	.19	175.0
79	-9.00	-3.30	2.00	.19	180.0	80	-7.00	-3.35	2.00	.11	.0
81	-7.00	-3.39	2.00	.19	-5.0	82	-7.02	-3.47	2.00	.19	-10.0
83	-7.03	-3.56	2.00	.19	-15.0	84	-7.06	-3.64	2.00	.19	-20.0
85	-7.09	-3.72	2.00	.19	-25.0	86	-7.13	-3.80	2.00	.19	-30.0
87	-7.18	-3.87	2.00	.19	-35.0	88	-7.23	-3.94	2.00	.19	-40.0
89	-7.29	-4.01	2.00	.19	-45.0	90	-7.36	-4.07	2.00	.19	-50.0
91	-7.43	-4.12	2.00	.19	-55.0	92	-7.50	-4.17	2.00	.19	-60.0
93	-7.58	-4.21	2.00	.19	-65.0	94	-7.66	-4.24	2.00	.19	-70.0
95	-7.74	-4.27	2.00	.19	-75.0	96	-7.83	-4.28	2.00	.19	-80.0
97	-7.91	-4.30	2.00	.19	-85.0	98	-8.00	-4.30	2.00	.19	-90.0
99	-8.09	-4.30	2.00	.19	-95.0	100	-8.17	-4.28	2.00	.19	-100.0
101	-8.26	-4.27	2.00	.19	-105.0	102	-8.34	-4.24	2.00	.19	-110.0
103	-8.42	-4.21	2.00	.19	-115.0	104	-8.50	-4.17	2.00	.19	-120.0
105	-8.57	-4.12	2.00	.19	-125.0	106	-8.64	-4.07	2.00	.19	-130.0

Figure 6-4(d). Example of Input Data and Program Execution

107	-8.71	-4.01	2.00	.19	-135.0	108	-8.77	-3.94	2.00	.19	-140.0
109	-8.82	-3.87	2.00	.19	-145.0	110	-8.87	-3.80	2.00	.19	-150.0
111	-8.91	-3.72	2.00	.19	-.55.0	112	-8.94	-3.64	2.00	.19	-160.0
113	-8.97	-3.56	2.00	.19	-165.0	114	-8.98	-3.47	2.00	.19	-170.0
115	-9.00	-3.39	2.00	.19	-175.0	116	-1.30	-3.25	.60	.11	.0
117	-1.31	-3.15	.60	.19	5.0	118	-1.33	-3.00	.60	.19	10.0
119	-1.36	-2.88	.60	.19	15.0	120	-1.40	-2.72	.60	.19	20.0
121	-1.46	-2.58	.60	.19	25.0	122	-1.53	-2.45	.60	.19	30.0
123	-1.61	-2.32	.60	.19	35.0	124	-1.70	-2.21	.60	.19	40.0
125	-1.80	-2.10	.60	.19	45.0	126	-1.91	-2.00	.60	.19	50.0
127	-2.02	-1.91	.60	.19	55.0	128	-2.15	-1.83	.60	.19	60.0
129	-2.28	-1.76	.60	.19	65.0	130	-2.42	-1.70	.60	.19	70.0
131	-2.56	-1.66	.60	.19	75.0	132	-2.70	-1.63	.60	.19	80.0
133	-2.85	-1.61	.60	.19	85.0	134	-3.00	-1.60	.60	.19	90.0
135	-3.'5	-1.61	.60	.19	95.0	136	-3.30	-1.63	.60	.19	100.0
137	-3.44	-1.66	.60	.19	105.0	138	-3.58	-1.70	.60	.19	110.0
139	-3.72	-1.76	.60	.19	115.0	140	-3.85	-1.83	.60	.19	120.0
141	-3.98	-1.91	.60	.19	125.0	142	-4.09	-2.00	.60	.19	130.0
143	-4.20	-2.10	.60	.19	135.0	144	-4.30	-2.21	.60	.19	140.0
145	-4.39	-2.32	.60	.19	145.0	146	-4.47	-2.45	.60	.19	150.0
147	-4.54	-2.58	.60	.19	155.0	148	-4.60	-2.72	.60	.19	160.0
149	-4.64	-2.88	.60	.19	165.0	150	-4.67	-3.00	.60	.19	170.0
151	-4.69	-3.15	.60	.19	175.0	152	-4.70	-3.30	.60	.19	180.0
153	-1.30	-3.35	.60	.11	.0	154	-1.31	-3.45	.60	.19	-5.0
155	-1.33	-3.60	.60	.19	-10.0	156	-1.36	-3.74	.60	.19	-15.0
157	-1.40	-3.88	.60	.19	-20.0	158	-1.46	-4.02	.60	.19	-25.0
159	-1.53	-4.15	.60	.19	-30.0	160	-1.61	-4.28	.60	.19	-35.0
161	-1.70	-4.39	.60	.19	-40.0	162	-1.80	-4.50	.60	.19	-45.0
163	-1.91	-4.60	.60	.19	-50.0	164	-2.02	-4.69	.60	.19	-55.0
165	-2.15	-4.77	.60	.19	-60.0	166	-2.28	-4.84	.60	.19	-65.0
167	-2.42	-4.90	.60	.19	-70.0	168	-2.56	-4.94	.60	.19	-75.0
169	-2.70	-4.97	.60	.19	-80.0	170	-2.85	-4.99	.60	.19	-85.0
171	-3.00	-5.00	.60	.19	-90.0	172	-3.15	-4.99	.60	.19	-95.0
173	-3.30	-4.97	.60	.19	-100.0	174	-3.44	-4.94	.60	.19	-105.0
175	-3.58	-4.00	.50	.19	-110.0	176	-3.72	-4.84	.60	.19	-115.0
177	-3.85	-4.77	.60	.19	-120.0	178	-3.98	-4.69	.60	.19	-125.0
179	-4.09	-4.60	.60	.19	-130.0	180	-4.20	-4.50	.60	.19	-135.0
181	-4.30	-4.39	.60	.19	-140.0	182	-4.39	-4.28	.60	.19	-145.0
183	-4.47	-4.15	.60	.19	-150.0	184	-4.54	-4.02	.60	.19	-155.0
185	-4.60	-3.88	.60	.19	-160.0	186	-4.64	-3.74	.60	.19	-165.0
187	-4.67	-3.60	.60	.19	-170.0	188	-4.69	-3.45	.60	.19	-175.0
189	3.84	-2.76	2.00	.11	30.0	190	8.84	-2.76	2.00	.11	30.0
191	3.82	-2.73	2.00	.19	35.0	192	8.82	-2.73	2.00	.19	35.0
193	3.77	-2.66	2.00	.19	40.0	194	8.77	-2.66	2.00	.19	40.0
195	3.71	-2.59	2.00	.19	45.0	196	8.71	-2.59	2.00	.19	45.0
197	3.64	-2.53	2.00	.19	50.0	198	8.64	-2.53	2.00	.19	50.0
199	3.57	-2.48	2.00	.19	55.0	200	8.57	-2.48	2.00	.19	55.0
201	3.50	-2.43	2.00	.19	60.0	202	8.50	-2.43	2.00	.19	60.0
203	3.42	-2.39	2.00	.19	65.0	204	8.42	-2.39	2.00	.19	65.0
205	3.34	-2.36	2.00	.19	70.0	206	8.34	-2.36	2.00	.19	70.0
207	3.26	-2.33	2.00	.19	75.0	208	8.26	-2.33	2.00	.19	75.0
209	3.17	-2.32	2.00	.19	80.0	210	8.17	-2.32	2.00	.19	80.0
211	3.09	-2.30	2.00	.19	85.0	212	8.09	-2.30	2.00	.19	85.0
213	3.00	-2.30	2.00	.19	90.0	214	8.00	-2.30	2.00	.19	90.0
215	2.91	-2.30	2.00	.19	95.0	216	7.91	-2.30	2.00	.19	95.0
217	2.83	-2.32	2.00	.19	100.0	218	7.83	-2.32	2.00	.19	100.0
219	2.74	-2.33	2.00	.19	105.0	220	7.74	-2.33	2.00	.19	105.0

Figure 6-4(e). Example of Input Data and Program Execution

221	2.00	-3.25	2.00	.11	180.0	222	7.00	-3.25	2.00	.11	180.0
223	2.00	-3.21	2.00	.19	175.0	224	7.00	-3.21	2.00	.19	175.0
225	2.02	-3.13	2.00	.19	170.0	226	7.02	-3.13	2.00	.19	170.0
227	2.03	-3.04	2.00	.19	165.0	228	7.03	-3.04	2.00	.19	165.0
229	2.06	-2.96	2.00	.19	160.0	230	7.06	-2.96	2.00	.19	160.0
231	2.09	-2.88	2.00	.19	155.0	232	7.09	-2.88	2.00	.19	155.0
233	2.13	-2.80	2.00	.19	150.0	234	7.13	-2.80	2.00	.19	150.0
235	2.18	-2.73	2.00	.19	145.0	236	7.18	-2.73	2.00	.19	145.0
237	2.23	-2.66	2.00	.19	140.0	238	7.23	-2.66	2.00	.19	140.0
239	2.29	-2.59	2.00	.19	135.0	240	7.29	-2.59	2.00	.19	135.0
241	2.36	-2.53	2.00	.19	130.0	242	7.36	-2.53	2.00	.19	130.0
243	2.43	-2.48	2.00	.19	125.0	244	7.43	-2.48	2.00	.19	125.0
245	2.50	-2.43	2.00	.19	120.0	246	7.50	-2.43	2.00	.19	120.0
247	2.58	-2.39	2.00	.19	115.0	248	7.58	-2.39	2.00	.19	115.0
249	2.66	-2.36	2.00	.19	110.0	250	7.66	-2.36	2.00	.19	110.0
251	1.04	-3.70	.60	.12	-170.0	252	6.04	-3.70	.60	.12	-170.0
253	1.07	-3.82	.60	.22	-165.0	254	6.07	-3.82	.60	.22	-165.0
255	1.12	-3.98	.60	.22	-160.0	256	6.12	-3.98	.60	.22	-160.0
257	1.19	-4.15	.60	.22	-155.0	258	6.19	-4.15	.60	.22	-155.0
259	1.27	-4.30	.60	.22	-150.0	260	6.27	-4.30	.60	.22	-150.0
261	1.36	-4.45	.60	.22	-145.0	262	6.36	-4.45	.60	.22	-145.0
263	1.47	-4.59	.60	.22	-140.0	264	6.47	-4.59	.60	.22	-140.0
265	1.59	-4.71	.60	.22	-135.0	266	6.59	-4.71	.60	.22	-135.0
267	1.71	-4.83	.60	.22	-130.0	268	6.71	-4.83	.60	.22	-130.0
269	1.85	-4.94	.60	.22	-125.0	270	6.85	-4.94	.60	.22	-125.0
271	2.00	-5.03	.60	.22	-120.0	272	7.00	-5.03	.60	.22	-120.0
273	2.15	-5.11	.60	.22	-115.0	274	7.15	-5.11	.60	.22	-115.0
275	2.32	-5.18	.60	.22	-110.0	276	7.32	-5.18	.60	.22	-110.0
277	2.48	-5.23	.60	.22	-105.0	278	7.48	-5.23	.60	.22	-105.0
279	2.65	-5.27	.60	.22	-100.0	280	7.65	-5.27	.60	.22	-100.0
281	2.83	-5.29	.60	.22	-95.0	282	7.83	-5.29	.60	.22	-95.0
283	3.00	-5.30	.60	.22	-90.0	284	8.00	-5.30	.60	.22	-90.0
285	3.17	-5.29	.60	.22	-85.0	286	8.17	-5.29	.60	.22	-85.0
287	5.00	-3.35	.60	.12	.0	288	10.00	-3.35	.60	.12	.0
289	4.99	-3.47	.60	.22	-5.0	290	9.99	-3.47	.60	.22	-5.0
291	4.97	-3.65	.60	.22	-10.0	292	9.97	-3.65	.60	.22	-10.0
293	4.93	-3.82	.60	.22	-15.0	294	9.93	-3.82	.60	.22	-15.0
295	4.88	-3.98	.60	.22	-20.0	296	9.88	-3.98	.60	.22	-20.0
297	4.81	-4.15	.60	.22	-25.0	298	9.81	-4.15	.60	.22	-25.0
299	4.73	-4.30	.60	.22	-30.0	300	9.73	-4.30	.60	.22	-30.0
301	4.64	-4.45	.60	.22	-35.0	302	9.64	-4.45	.60	.22	-35.0
303	4.53	-4.59	.60	.22	-40.0	304	9.53	-4.59	.60	.22	-40.0
305	4.41	-4.71	.60	.22	-45.0	306	9.41	-4.71	.60	.22	-45.0
307	4.29	-4.83	.60	.22	-50.0	308	9.29	-4.83	.60	.22	-50.0
309	4.15	-4.94	.60	.22	-55.0	310	9.15	-4.94	.60	.22	-55.0
311	4.00	-5.03	.60	.22	-60.0	312	9.00	-5.03	.60	.22	-60.0
313	3.85	-5.11	.60	.22	-65.0	314	8.85	-5.11	.60	.22	-65.0
315	3.68	-5.18	.60	.22	-70.0	316	8.68	-5.18	.60	.22	-70.0
317	3.52	-5.23	.60	.22	-75.0	318	8.52	-5.23	.60	.22	-75.0
319	3.35	-5.27	.60	.22	-80.0	320	8.35	-5.27	.60	.22	-80.0
321	-7.00	-7.52	2.00	.37	.0	322	-7.06	-7.36	2.00	.72	20.0
323	-7.23	-7.06	2.00	.72	40.0	324	-7.50	-6.83	2.00	.72	60.0
325	-7.83	-6.72	2.00	.72	80.0	326	-8.17	-6.72	2.00	.72	100.0
327	-8.50	-6.83	2.00	.72	120.0	328	-8.77	-7.06	2.00	.72	140.0
329	-8.94	-7.36	2.00	.72	160.0	330	-9.00	-7.70	2.00	.72	180.0
331	-7.00	-7.86	2.00	.37	.0	332	-7.06	-8.04	2.00	.72	-20.0
333	-7.23	-8.34	2.00	.72	-40.0	334	-7.50	-8.57	2.00	.72	-60.0

Figure 6-4(f). Example of Input Data and Program Execution

335	-7.83	-8.68	2.00	.72	-80.0	336	-8.17	-8.68	2.00	.72	-100.0
337	-8.50	-8.57	7.00	.72	-120.0	338	-8.77	8.34	2.00	.72	-140.0
339	-8.94	-8.04	2.00	.72	-160.0	340	-1.30	-7.52	.60	.37	.0
341	-1.40	-7.12	.60	.72	20.0	342	-1.70	-6.61	.60	.72	40.0
343	-2.15	-6.23	.60	.72	60.0	344	-2.70	-6.03	.60	.72	80.0
345	-3.30	-6.03	.60	.72	100.0	346	-3.85	-6.23	.60	.72	120.0
347	-4.30	-6.61	.60	.72	140.0	348	-4.60	-7.12	.6	.72	160.0
349	-4.70	-7.70	.60	.72	180.0	350	-1.30	-7.88	.60	.37	.0
351	-1.40	-8.28	.60	.72	-20.0	352	-1.70	-8.79	.60	.72	-40.0
353	-2.15	-9.17	.60	.72	-60.0	354	-2.70	-9.37	.60	.72	-80.0
355	-3.30	-9.37	.60	.72	-100.0	356	-3.85	-9.17	.60	.72	-120.0
357	-4.30	-8.79	.60	.72	-140.0	358	-4.60	-8.28	.60	.72	-160.0
359	3.78	-7.04	2.00	.37	30.0	360	8.78	-7.04	2.00	.37	30.0
361	3.64	-6.93	2.00	.72	50.0	362	8.64	-6.93	2.00	.72	50.0
363	3.34	-6.76	2.00	.72	70.0	364	8.34	-6.76	2.00	.72	70.0
365	3.00	-6.70	2.00	.72	90.0	366	8.00	-6.70	2.00	.72	90.0
367	2.66	-6.76	2.00	.72	110.0	368	7.66	-6.76	2.00	.72	110.0
369	2.00	-7.52	2.00	.37	180.0	370	7.00	-7.52	2.00	.37	180.0
371	2.06	-7.36	2.00	.72	160.0	372	7.06	-7.36	2.00	.72	160.0
373	2.23	-7.06	2.00	.72	140.0	374	7.23	-7.06	2.00	.72	140.0
375	2.50	-6.83	2.00	.72	120.0	376	7.50	-6.83	2.00	.72	120.0
377	1.07	-8.25	.60	.43	-170.0	378	6.07	-8.25	.60	.43	-170.0
379	1.27	-8.70	.60	.83	-150.0	380	6.27	-8.70	.60	.83	-150.0
381	1.71	-9.23	.60	.83	-130.0	382	6.71	-9.23	.60	.83	-130.0
383	2.32	-9.58	.60	.83	-110.0	384	7.32	-9.58	.60	.83	-110.0
385	3.00	-9.70	.60	.83	-90.0	386	8.00	-9.70	.60	.83	-90.0
387	5.00	-7.91	.60	.43	.0	388	10.00	-7.91	.60	.43	.0
389	4.88	-8.38	.60	.83	-20.0	390	9.88	-8.38	.60	.83	-20.0
391	4.53	-8.89	.60	.83	-40.0	392	9.53	-8.89	.60	.83	-40.0
393	4.00	-9.43	.60	.83	-60.0	394	9.00	-9.43	.60	.83	-60.0
395	3.35	-9.67	.60	.83	-80.0	396	8.35	-9.67	.60	.83	-80.0
397	-6.09	11.07	.84	.17	.0	398	-6.09	10.54	1.08	.17	-90.0
399	-5.10	11.07	.84	.17	.0	400	-5.18	10.58	.51	.17	.0
401	-5.10	10.08	.84	.17	.0	402	-5.43	10.58	1.17	.17	-90.0
403	-3.78	10.8[illegible]	.13	.17	90.0	404	-3.86	10.99	.32	.17	135.0
405	-4.11	11.07	.41	.17	180.0	406	-4.35	10.99	.32	.17	-135.0
407	-4.44	10.82	.24	.17	-91.0	408	-4.36	10.66	.32	.17	-45.0
409	-4.11	10.58	.41	.17	.0	410	-3.86	10.50	.32	.17	-44.0
411	-3.78	10.33	.25	.17	-89.0	412	-3.86	10.16	.32	.17	-136.0
413	-4.11	10.08	.41	.17	179.0	414	-4.36	10.17	.32	.17	135.0
415	-4.44	10.27	.13	.17	-90.0	416	-3.12	11.07	.84	.17	.0
417	-3.12	10.54	1.08	.17	-90.0	418	-1.46	10.58	1.17	.17	90.0
419	-1.20	10.58	.55	.17	.0	420	-.89	10.66	.30	.17	46.0
421	-.81	10.83	.25	.17	89.0	422	-.89	10.99	.30	.17	136.0
423	-1.20	11.07	.55	.17	.0	424	-.47	10.05	.11	.17	90.0
425	-.31	10.60	1.12	.17	72.0	426	.19	10.05	.11	.17	90.0
427	.02	10.60	1.12	.17	108.0	428	-.14	11.07	.18	.17	-90.0
429	-.15	10.41	.47	.17	.0	430	.85	11.07	.84	.17	.0
431	.85	10.54	1.08	.17	-90.0	432	1.84	11.07	.84	.17	.0
433	1.84	10.54	1.08	.17	-90.0	434	2.83	11.07	.84	.17	.0
435	2.75	10.58	.51	.17	.0	436	2.83	10.08	.84	.17	.0
437	2.50	10.58	1.17	.17	-90.0	438	3.49	10.58	1.17	.17	90.0
439	3.76	10.58	.55	.17	.0	440	4.07	10.66	.30	.17	46.0
441	4.15	10.83	.25	.17	89.0	442	4.07	10.99	.30	.17	136.0
443	3.76	11.07	.55	.17	.0	444	4.15	10.05	.11	.17	90.0
445	3.99	10.31	.64	.17	124.0	446	4.48	10.58	1.17	.17	90.0
447	5.14	10.58	1.17	.17	90.0	448	4.81	10.58	1.24	.17	-58.0
449	6.13	10.88	.13	.17	90.0	450	6.05	10.99	.32	.17	135.0
451	5.80	11.07	.41	.17	180.0	452	5.55	10.99	.32	.17	-135.0
453	5.47	10.82	.24	.17	-91.0	454	5.55	10.66	.32	.17	-45.0
455	5.80	10.58	.41	.17	.0	456	6.04	10.50	.32	.17	-44.0
457	6.13	10.33	.25	.17	-89.0	458	6.05	10.16	.32	.17	-136.0
459	5.80	10.08	.41	.17	179.0	460	5.55	10.17	.32	.17	135.0
461	5.47	10.27	.13	.17	-90.0	462	.25	20.57	.51	.51	.0
463	-.25	20.07	.51	.51	.0	464	-.25	-20.32	.51	.36	.0
465	.25	-20.68	.51	.36	.0	466	.25	- 9.96	.51	.36	.0
467	-18.93	.00	7.86	25.00	.0	468	18.93	.00	7.86	25.00	.0
469	.00	-21.91	45.72	1.91	.0	470	.00	21.91	45.72	1.91	.0
471	-11.75	-20.32	22.23	1.27	.0	472	.1.75	-20.32	22.23	1.27	.0
473	-11.75	20.32	22.23	1.27	.0	474	11.75	20.32	22.23	1.27	.0
475	.00	-16.09	45.72	7.19	.0	476	.00	16.09	45.72	7.19	.0

Figure 6-4(g). Example of Input Data and Program Execution

ORIGINAL PAGE IS
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ABRIDGED ONE-PAGE PRINTOUT

MASK 1: RECTANGLE DATA (MIL UNIT, SCALED AND SHIFTED)

N	X	Y	W	H	A	N	X	Y	W	H	A
1	1665.35	2255.90	38.37	23.62	.0	7	1665.35	2058.05	38.37	23.62	30.0
13	1862.20	2255.90	38.37	23.62	60.0	19	2171.90	2334.64	187.00	19.68	.0
25	2162.24	2304.96	127.50	19.68	.0	31	2088.60	2108.35	28.00	15.75	45.0
37	2276.60	2038.82	2.60	15.53	82.0	43	1724.41	1871.95	78.74	4.25	.0
49	1719.14	1889.76	78.74	7.50	30.0	55	1704.72	1904.17	78.74	7.50	60.0
61	1685.04	1909.45	7.50	78.74	.0	67	1665.35	1904.17	7.50	78.74	30.0
73	1650.94	1889.76	7.50	78.74	60.0	79	1645.67	1870.08	78.74	7.50	.0
85	1720.72	1853.44	7.30	78.74	65.0	91	1707.62	1837.83	7.50	78.74	35.0
97	1688.47	1830.86	7.50	78.74	5.0	103	1668.40	1834.40	78.74	7.50	65.0
109	1652.79	1847.50	78.74	7.50	35.0	115	1645.82	1866.65	78.74	7.50	5.0
121	1942.55	1888.36	23.62	7.50	25.0	127	1920.28	1924.90	23.62	7.50	55.0
133	1887.72	1936.75	23.62	7.50	85.0	139	1853.60	1930.74	7.50	23.62	25.0
145	1827.06	1908.47	7.50	23.62	55.0	151	1815.22	1875.91	7.50	23.62	85.0
157	1844.78	1847.19	7.50	23.62	70.0	163	1824.91	1818.81	7.50	23.62	40.0
169	1883.51	1804.17	7.50	23.62	10.0	175	1859.00	1807.19	23.62	7.50	70.0
181	1830.62	1827.06	23.62	7.50	40.0	187	1815.98	1858.46	23.62	7.50	10.0
193	2148.27	1885.39	78.74	7.50	40.0	199	2140.69	1902.33	78.74	7.50	55.0
205	2131.58	1907.07	78.74	7.50	70.0	211	2121.54	1909.30	78.74	7.50	85.0
217	2111.27	1908.85	7.50	78.74	10.0	223	2078.89	1873.51	7.50	78.74	85.0
229	2081.11	1883.54	7.50	78.74	70.0	235	2085.86	1892.66	7.50	78.74	55.0
241	2092.80	1900.24	7.50	78.74	40.0	247	2101.47	1905.76	7.50	78.74	25.0
253	2042.05	1849.70	23.62	8.50	15.0	259	2049.92	1830.71	23.62	8.50	30.0
265	2062.43	1814.40	23.62	8.50	45.0	271	2078.74	1801.89	23.62	8.50	60.0
277	2097.73	1794.02	23.62	8.50	75.0	283	2118.11	1791.34	8.50	23.62	.0
289	2196.55	1863.22	8.50	23.62	85.0	295	2192.10	1843.15	8.50	23.62	70.0
301	2182.61	1824.92	8.50	23.62	55.0	307	2168.72	1809.76	8.50	23.62	40.0
313	2151.39	1798.72	8.50	23.62	25.0	319	2131.78	1792.54	8.50	23.62	10.0
325	1681.88	1735.62	78.74	28.50	80.0	331	1724.41	1689.73	78.74	14.75	.0
337	1665.35	1662.76	78.74	28.50	60.0	343	1915.35	1754.81	23.62	28.50	60.0
349	1814.96	1686.85	23.62	28.50	.0	355	1870.27	1630.94	23.62	28.50	80.0
361	2143.42	1727.01	78.74	28.50	50.0	367	2104.64	1733.85	28.50	78.74	20.0
373	2087.95	1722.16	28.50	78.74	50.0	379	2049.92	1657.48	23.62	32.50	30.0
385	2118.11	1618.11	32.50	23.62	.0	391	2178.43	1646.24	32.50	23.62	50.0
397	1760.34	2435.95	33.00	6.50	.0	403	1851.34	2428.45	6.50	5.00	.0
409	1838.20	2416.47	16.00	6.50	.0	415	1825.34	2404.45	6.50	5.00	.0
421	1988.20	2426.25	10.00	6.50	89.0	427	2000.78	2417.38	6.50	44.00	18.0
433	2072.34	2414.95	6.50	42.50	.0	439	2147.84	2416.45	21.50	6.50	.0
445	2157.05	2406.04	6.50	25.00	34.0	451	2228.36	2435.94	16.00	6.50	.0
457	2241.34	2406.65	6.50	10.00	1.0	463	1990.00	2790.00	20.00	20.00	.0
469	2000.00	1137.50	1800.00	75.00	.0	475	2000.00	1366.44	1800.00	282.88	.0

** END OF BLOCK ** 476 RECTANGLES ** PATTERN LIMITS (MILS)

	X	Y
MAX	2900.00	2900.00
MIN	1100.00	1100.00
MAX-MIN	1800.00	1800.00
CENTER	2000.00	2000.00

Figure 6-4(h). Example of Input Data and Program Execution

ORIGINAL PAGE IS
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MASK 1: THE MANN EXPOSURE DATA (0.1 MIL UNIT)

ABRIDGED ONE-PAGE PRINTOUT

N	X	Y	W	H	A
1	11565	11375	1130	750	0
19	27357	12000	1100	500	0
37	12680	12725	1130	950	0
55	25060	13665	1130	950	0
73	17187	14605	1130	950	0
91	12547	16720	1035	1100	0
109	21065	16310	235	285	80
127	22755	16887	785	150	0
145	18212	17040	785	150	0
163	20667	17387	285	235	50
181	16517	17987	235	85	65
199	18425	18020	235	85	60
217	21410	18072	75	235	20
235	16282	18145	235	85	45
253	23015	18330	785	75	70
271	16137	18367	235	85	25
289	23507	18535	75	785	65
307	18032	18680	235	50	0
325	23520	18835	785	75	20
343	17237	18770	785	75	10
361	18540	18880	75	785	45
379	23480	18897	785	75	30
397	23047	19080	75	785	15
415	18885	19057	785	75	65
433	16685	19057	75	785	25
451	21287	19360	235	75	80
469	11517	20000	1035	1100	0
487	19215	21182	145	60	22
505	13577	22187	1035	1100	0
523	22755	23347	385	235	0
541	17717	24165	160	65	0
559	20187	23857	65	45	0
577	21747	24262	65	95	1
595	19667	24360	330	65	0
613	19437	25305	1130	950	0
631	18312	26335	1130	950	0
649	23837	27275	1130	950	0
667	15822	28000	1100	500	0
685	26185	28625	1130	750	0

N	X	Y	W	H	A
7	18312	11375	1130	750	0
25	20800	12000	1100	500	0
43	19437	12725	1130	950	0
61	18312	13665	1130	950	0
79	23837	14605	1130	950	0
97	16712	16182	235	325	80
115	23080	16580	785	285	80
133	17612	16752	170	235	80
151	22755	17040	785	150	0
169	16885	17337	785	285	70
187	17120	17880	85	235	20
205	19152	17887	85	235	25
223	21515	18120	75	235	30
241	20707	18227	235	75	45
259	22825	18377	785	75	55
277	20552	18472	235	75	20
295	20535	18527	235	75	15
313	21850	18700	235	75	0
331	21847	18760	235	75	5
349	16520	18915	45	785	60
367	20535	18875	75	235	75
385	28482	18807	1035	1100	0
403	21760	19035	235	75	30
421	18887	19087	785	75	80
439	16782	19087	75	785	10
457	21565	19250	235	75	55
475	19215	20750	155	865	0
493	12547	21082	1035	1100	0
511	18130	22757	780	195	0
529	18745	23347	940	195	0
547	18367	23857	65	45	0
565	20577	24165	65	460	0
583	28482	24372	1035	1100	0
601	17620	24327	125	65	45
619	26185	25305	1130	950	0
637	11565	26335	1130	950	0
655	27357	28000	1100	500	0
673	12680	28625	1130	750	0

N	X	Y	W	H	A
13	23837	11375	1130	750	0
31	15822	12000	[illegible]	500	0
49	26185	12725	1130	950	0
67	11565	13665	1130	950	0
85	27452	15627	1035	1100	0
103	18080	16700	235	325	20
121	26422	16720	1035	1100	0
139	17245	17040	785	150	0
157	23450	17222	785	285	40
175	18850	17812	85	235	0
193	18750	17817	235	85	85
211	21240	18035	75	235	5
229	18375	18145	85	235	45
247	23115	18307	785	75	85
265	18532	18367	85	235	65
283	23427	18422	75	785	45
301	18042	18565	235	85	10
319	23537	18632	75	785	80
337	18210	18735	785	75	5
355	17172	18827	785	75	35
373	22782	18867	75	785	65
391	22852	19042	75	785	30
409	18072	19002	785	75	50
427	18587	19002	75	785	40
445	20787	19250	75	235	35
463	27452	20000	1035	1100	0
481	27452	21082	1035	1100	0
499	28482	22187	1035	1100	0
517	22755	22560	385	235	0
535	17717	23870	160	65	1
553	18387	24262	65	100	1
571	21747	24045	65	50	0
589	21520	24327	125	65	45
607	12680	25305	1130	950	0
625	25080	26335	1130	950	0
643	17187	27275	1130	950	0
661	20800	28000	1100	500	0
679	19437	28625	1130	750	0

TOTAL NUMBER OF EXPOSURES = 687 TOTAL EXPOSURE TIME = 0 HR 47 MIN 0 SEC

xxx END OF MASK 1 xx 12 ERRORS xxx

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx END OF JOB xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Figure 6-4(i). Example of Input Data and Program Execution

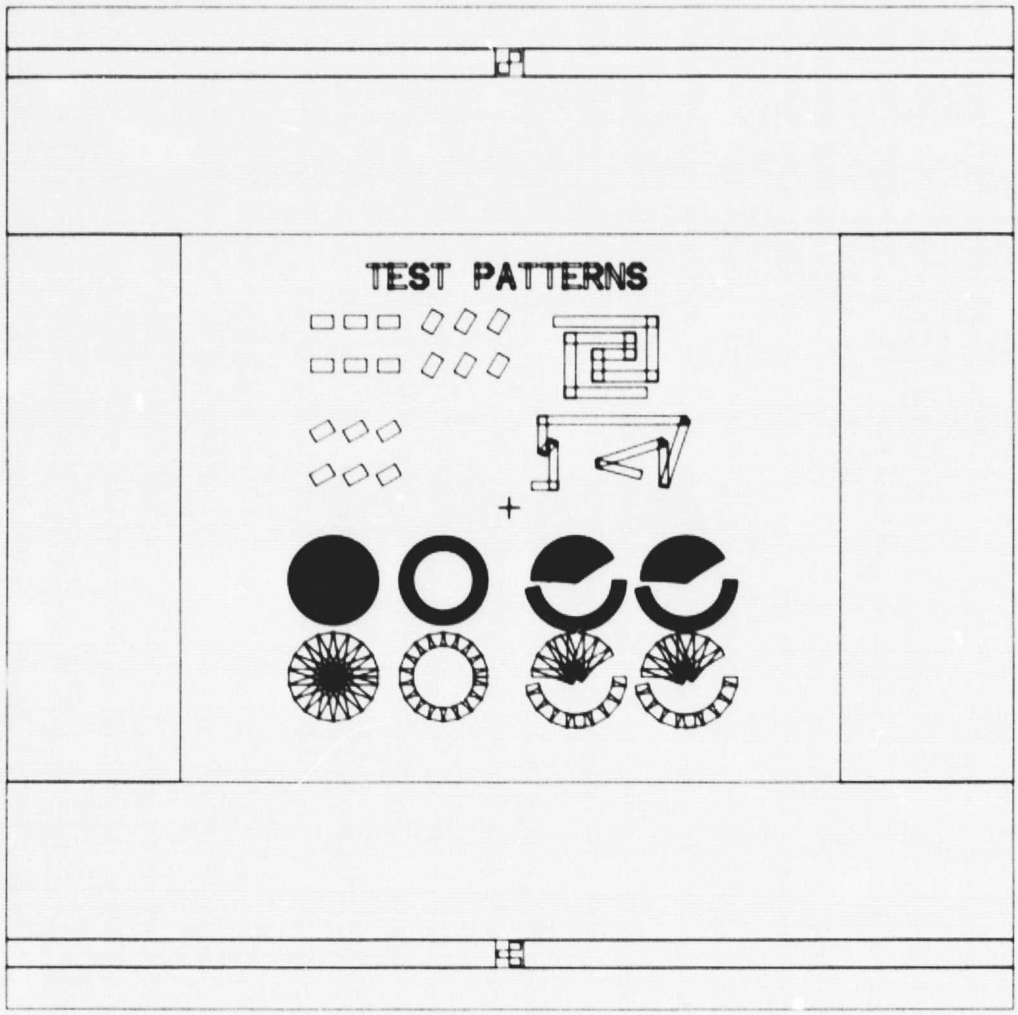

Figure 6-5. Plot of Rectangle Data (File 55)
for Mask Example

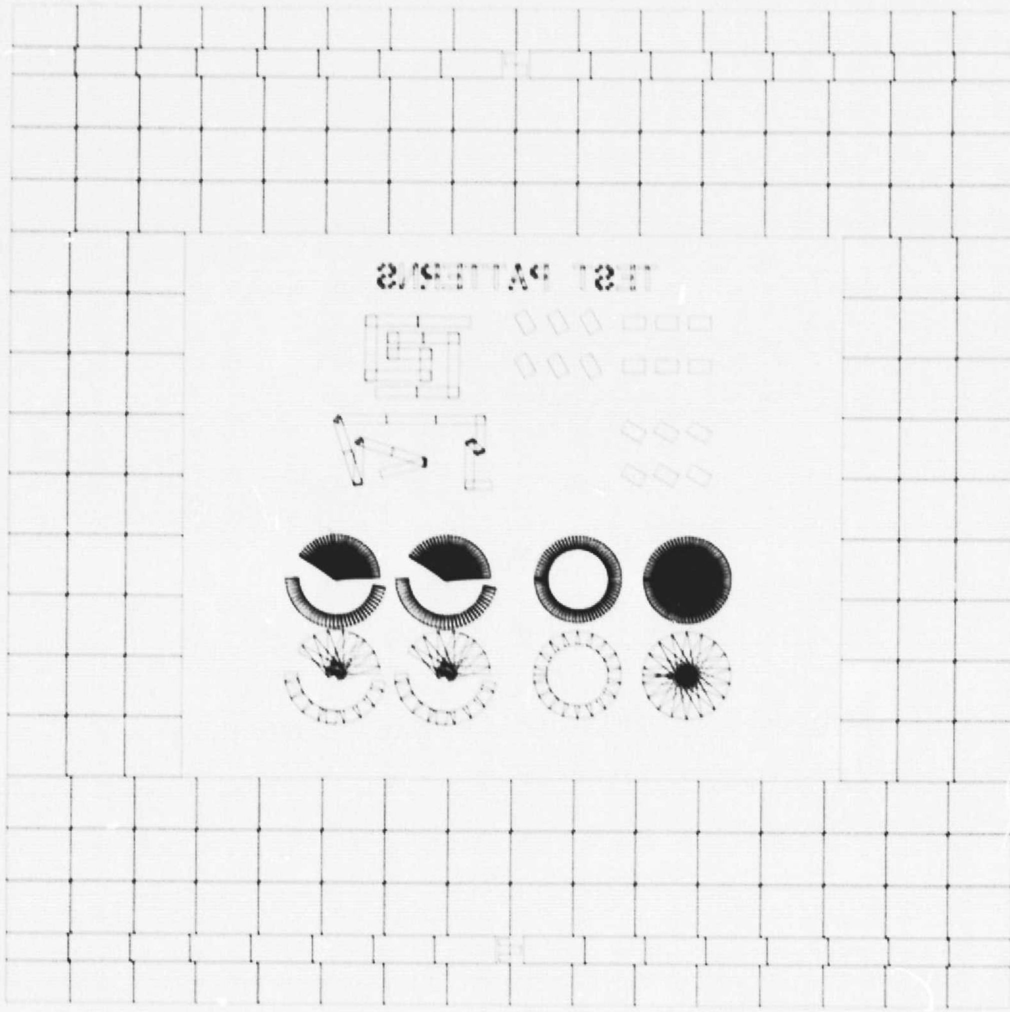

Figure 6-6. Plot of Exposure Data (File 57) for Mask Example (note partitioning of large rectangles; also symmetry reversed from MR-3)

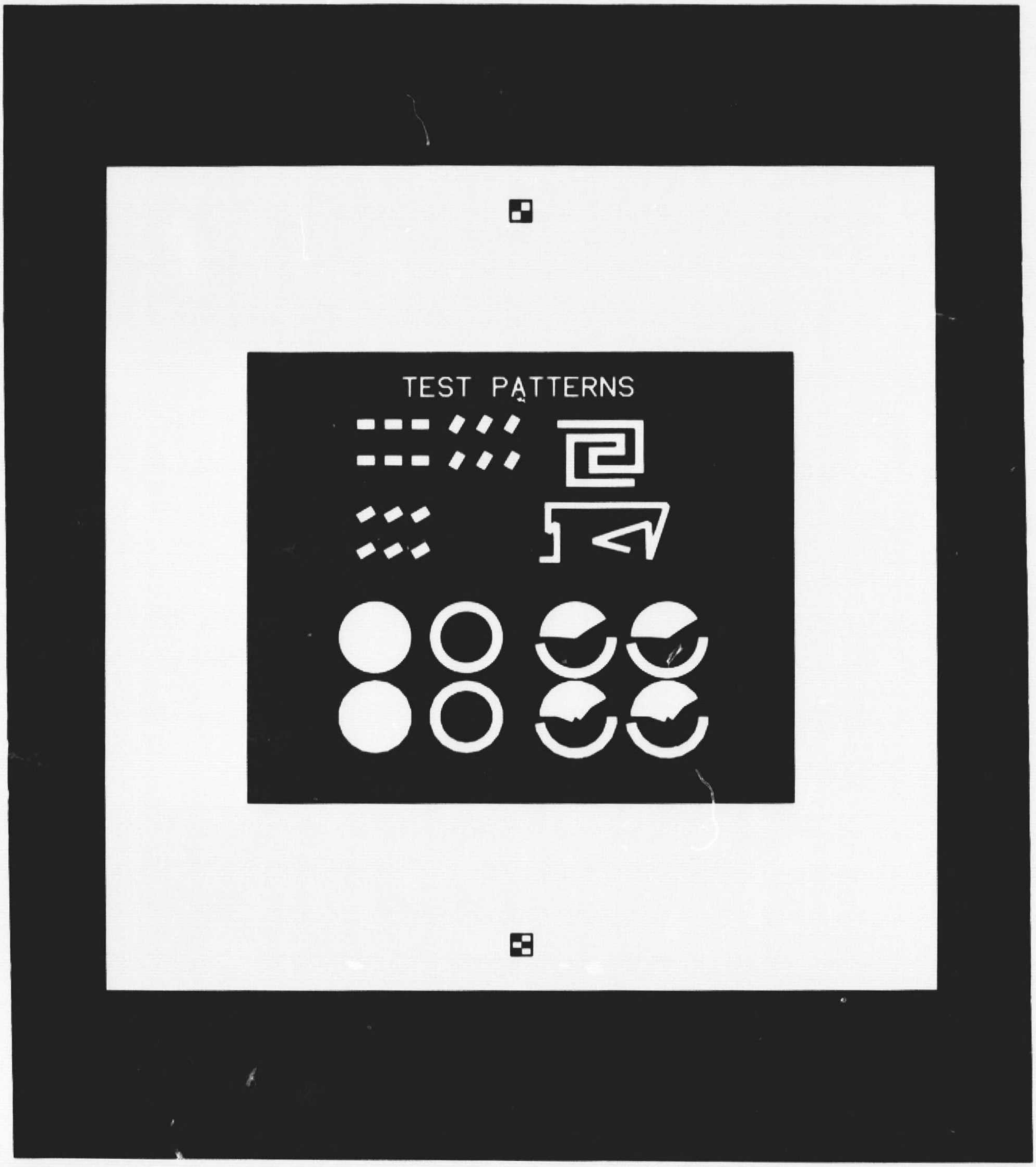

Figure 6-7. Photographic Print or "Blowback" from Completed Mask Plate (approx 3X; image tone is reversed from plate: patterns are opaque on the mask plate; image symmetry is the same as that of the plate if the emulsion on the plate is toward the viewer; MR is -3 for this mask)

SECTION VII

PLOTTING PHOTOMASKS

A. INTRODUCTION

As discussed in the preceding section, executing the MASK program with the PLOT option generates plot data in file 55. This data can then be used to create various plots on paper, plastic, film, or cathode ray tube screen as explained in this section.

Except for plots on the Tektronix graphics display terminal, all plot programs are set up such that the allowed plotting area is larger in the X direction than it is in the Y direction. Thus, if the mask pattern is not square, it should be oriented so that the larger dimension is along the X axis, to allow for maximum enlargement. Plots made on drum plotters are plotted with the Y axis parallel to the drum axis. All plots are right-reading regardless of the value of the mirror parameter, MR, in the MASK program.

Remember that the pattern has been translated: the point XC,YC has been translated to 2000+XBIAS,2000+YBIAS in the plot data (see VI-F).

B. CALCOMP 11-in. DRUM PLOTTER

Figure 7-1 shows a sample plot made on an 11-in. Calcomp drum plotter.

ACCESS		Plotter is on line to the 1108 computer, so the plot can be obtained more quickly than by other methods. Plot is generated directly by executing the proper program (CC11ABS).
MAXIMUM SIZE -	X	Essentially unlimited
	Y	10.5-in. allowed (paper is 11 in. wide between tear strips)
MEDIUM		Ballpoint pen on paper, pen color usually black, other colors sometimes available.
RESOLUTION		10 mils - does not produce as nice a plot as larger plotters.
COMMENTS		This method is good for rough checks or simple patterns; it does not produce as large or smooth a plot as other plotters. Overlay of one plot on another is possible, but not very effective. On complex patterns registration may be a problem due to enlargement of sprocket holes in paper as paper rolls back and forth.

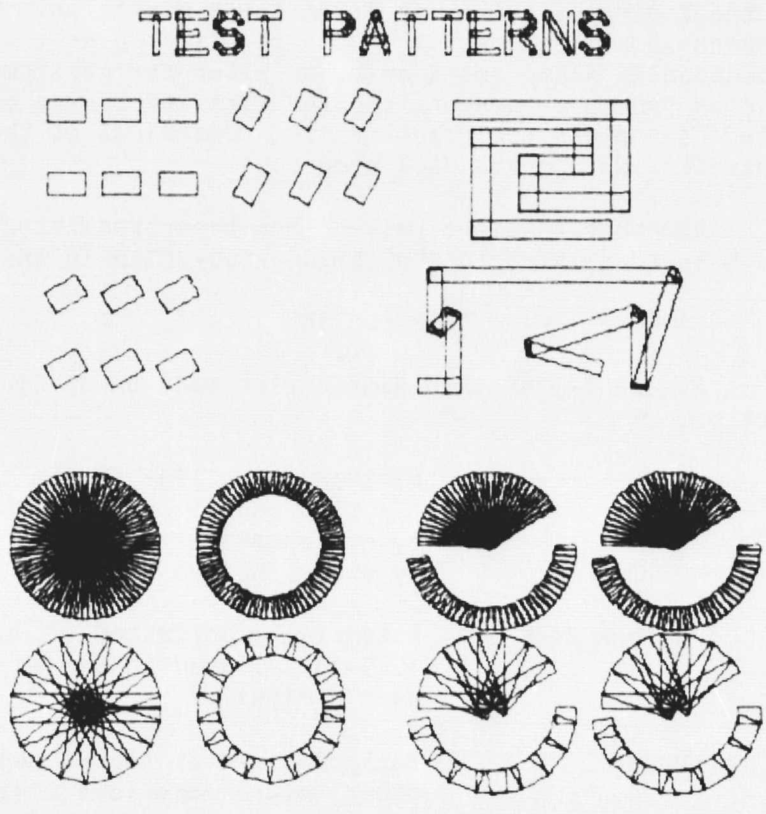

Figure 7-1. Example of Plot Made on 11-in. Calcomp Drum Plotter

USE — Enter the following runstream:

```
@RUN - - - -     be sure to allow for sufficient
                 card punching-typically 10000.
@SYM,C PUNCH$,bldg/box,G9300x  x is site at which
                               plot is to be
                               generated
@ASG,A     55.
@XQT       FILE.C11ABS
----initialization card---- (optional)
@FIN
```

The initialization card must contain the following:

Columns 1-10:	XCEN	the X coordinate of the center of the area to be plotted (mils), default: 2000.
11-10:	YCEN	analogous to XCEN, default: 2000.
21-30:	XSIZE	the size in the X direction of the area to be plotted (mils), default: 2000.
31-40:	YSIZE	analogous to XSIZE, default: 2000.
41-50:	FACTOR	the factor by which the plot data is to be multiplied to produce the plot, default: 5.0

All the above parameter values (except FACTOR) are in mils and refer to the mask dimensions, rather than plotted sizes. All parameter values must contain a decimal point. Defaults apply only if entire initialization card is omitted.

If the values on the initialization card are incompatible because YSIZE and FACTOR would require more than 10.5 inches, YSIZE is reduced accordingly and a warning message printed. For example if the values were

XCEN=2000. YCEN=2000. XSIZE=1000. YSIZE=1000. FACTOR=20.

the plot area on the paper would have to be 20 in. in the X direction, which is allowed, and 20 in. in the Y direction, which is too large. Consequently, YSIZE would be reduced by the program to 525. mils, and WARNING: PLOT TOO LARGE IN Y DIRECTION would be printed.

If any part of a rectangle lies outside the plot area defined by XSIZE and YSIZE, no part of the rectangle is plotted, even though part of the rectangle might lie inside the plot area. If rectangles lie outside the plot area and are rejected by the program, this warning is printed:

```
WARNING: RECTANGLES OUTSIDE PLOT AREA, *X<, *X>, *Y<, *Y>
```

Where each * is the number of rectangles to the left of the allowed plot area, to the right of the allowed plot area, etc.

Any messages from A-group data cards are plotted to the left of each pattern. The paper advances for each new pattern (mask). Targets are plotted near the four corners of the plot area as shown in Figure 7-1. Their Y separation is 10.5 in. and their X separation is XSIZE x FACTOR. Their location is identical for all plots generated with one program execution.

C. CALCOMP 34-in. DRUM PLOTTER

Figure 7-2 shows an example of a printout for drum plotter programs.

ACCESS	Executing the program CC34ABS writes a magnetic tape which may be taken to the plotter, which is off line. Contact J. H. Hix (JPL) regarding this equipment.
MAXIMUM SIZE - X	Essentially unlimited.
Y	32.5 in. allowed (paper is 34 in. wide between tear strips).
MEDIUM	Ballpoint pen (6 colors available: black, blue, red, green, orange, brown) or liquid ink, on paper (translucent bond, rag, vellum). Plastic (mylar) may also be used. The plotter can accommodate three pens which are selected as explained below.
RESOLUTION	2.5 mils
COMMENTS	This method has been the most useful since the plot can be made large enough for accurate checking and masks may be overlaid in different colors. Typical use has been ballpoint on paper. One problem is loss of close registration due to enlargement of sprocket holes in the paper as paper rolls back and forth.
USE	Enter the following runstream:

```
@RUN    - - -
@ASG      55.
@ASG,T    20,T,*****
@MSG      PLEASE MOUNT TAPE **** TO WRITE FOR RKK
          (for batch), or-
@MSG,W    PLEASE MOUNT TAPE **** TO WRITE FOR RKK
          (for demand), where **** is the identi-
          fication of the tape to be used
@XQT      FILE.CC34ABS
----   data card (optional)  --
@FIN
```

NOTE: Only one set of plot data (from one @XQT) may be written on a single tape.

```
********************  CALCOMP 34 INCH DRUM PLOT PROGRAM  ********************

XCEN= 2000.00 MIL,   XSIZE= 1500.00 MIL  45.0 IN,    FACTOR=  30.00
YCEN= 2000.00 MIL,   YSIZE= 3000.00 MIL  90.0 IN

WARNING: PLOT TOO LARGE IN Y DIRECTION


- PLOT NUMBER   1 - PEN NUMBER 1 SELECTED -

     *** FIDUCIAL MARKS AND BORDER TEST ***
WARNING: RECTANGLES OUTSIDE PLOT AREA,     3 X<,     0 X>,     3 Y<,     2 Y>

- PLOT NUMBER   2 - PEN NUMBER 1 SELECTED -

     *** FIDUCIAL MARKS AND BORDER TEST ***
WARNING: RECTANGLES OUTSIDE PLOT AREA,     C X<,     0 X>,     4 Y<,     3 Y>

- PLOT NUMBER   3 - PEN NUMBER 1 SELECTED -

     *** FIDUCIAL MARKS AND BORDER TEST ***
WARNING: RECTANGLES OUTSIDE PLOT AREA,     5 X<,     3 X>,     3 Y<,     2 Y>

- PLOT NUMBER   4 - PEN NUMBER 1 SELECTED -

     *** FIDUCIAL MARKS AND BORDER TEST ***
WARNING: RECTANGLES OUTSIDE PLOT AREA,     7 X<,     3 X>,     3 Y<,     2 Y>

- PLOT NUMBER   5 - PEN NUMBER 1 SELECTED -

      *** MASK CHARACTER SET ***

- PLOT NUMBER   6 - PEN NUMBER 1 SELECTED -

       *****  TEST AND DEMONSTRATION PATTERNS  *****
       R. K. KIRSCHMAN, 1-76


**  END OF JOB --  6 PLOTS,   609 RECTANGLES INPUT,   769 RECTANGLES PLOTTED **
```

Figure 7-2. Example of Printout for 34-in. Drum Plotter Programs (other programs give a similar printout)

The initialization card is identical to that for the Calcomp 11-in. drum plotter, except that (1) the maximum plot size is 32.5 in. in the Y direction, and (2) an additional field is available:

Columns 51-60: Pen selection: a sequence of digits indicating the order of the pens to be used for the masks. Three pen locations are available. For example, if pens 1, 2, and 3 are to be used for masks 1, 2, and 3, the data field would read 123, beginning in column 51.

If any column is left blank, or contains any digit other than 1, 2, or 3, the corresponding plot will default to pen 1.
Since there are only 3 pen locations, if more than 3 colors are to be used, the pens must be changed by the plotter operator between masks.

Two targets at X=0,Y=0 and X=0,Y=32.5 in. are plotted prior to plotting of each mask. A search address is generated prior to and after plotting these targets. Thus if the plotter controller is in "single plot" mode, corrections for paper movement or pen changes can be made.

The masks are plotted directly over one another, in register. If this is not desired, the paper should be advanced between plots.

D. CALCOMP FLAT BED PLOTTER

ACCESS	Executing the program CCFBABS writes a magnetic tape which may be taken to the plotter, which is off line.
MAXIMUM SIZE - X Y	81 in. allowed 47 in. allowed Roll of paper is approximately 51-in. wide (Y direction).
MEDIUM	Same as Calcomp 34-in. plotter. Refer to previous subsection.
RESOLUTION	0.2 mils
COMMENTS	This method avoids the registration problem of the drum plotters. Plots can be made on mylar plastic (when plotting on mylar, a mirror image is recommended -- this allows the plot to be mounted with the inked side in to protect it). In most cases this plotter allows the largest size plot.
USE	Not implemented at this time, contact author.

E. CALCOMP COM SYSTEM

ACCESS	The plotter is "on line" to the 1108 computer as far as the user is concerned. Executing the program COMABS generates a plot file which is transferred to the plotting system at intervals by computer personnel.
MAXIMUM SIZE	On the film - X - 1.00 in. Y - 0.75 in. (reduced by 15X from 15 in. by 11.25 in. image area on cathode ray tube)
MEDIUM	35 mm film roll. Plotted lines which outline rectangles are transparent on an opaque field (negative). The film image may be enlarged and printed by Xerox or photography (see Figures 7-3 and 7-4), or a microfilm reader may be used.

RESOLUTION — Practical resolution is approximately 2 mils on the film.

COMMENTS — Overlays are difficult. The actual plotting is very fast, but turnaround time is slower than other methods. The actual plot film and/or copies are sent to the user in one-two days.

USE — Enter the following runstream:

```
@RUN - - -
@COM      CAMERA/35MM, FRAMES/**,BLDG/bldg,BOX/box
          where ** is the maximum number of
          frames expected. The plot program
          used two frames per plot, plus 2
          extra frames at beginning and end.
@XQT      FILE.COMABS
- - - data card (optional) - - -
@FIN
```

The data card is the same as for the Calcomp 11-in. drum plotter, except that FACTOR will generally be smaller. Default values for XCEN, YCEN, XSIZE, YSIZE are the same as for the 11-in. plotter; default value for FACTOR is 0.333. Targets are plotted at the four corners: X separation is 1.0 in., Y separation is 0.75 in.

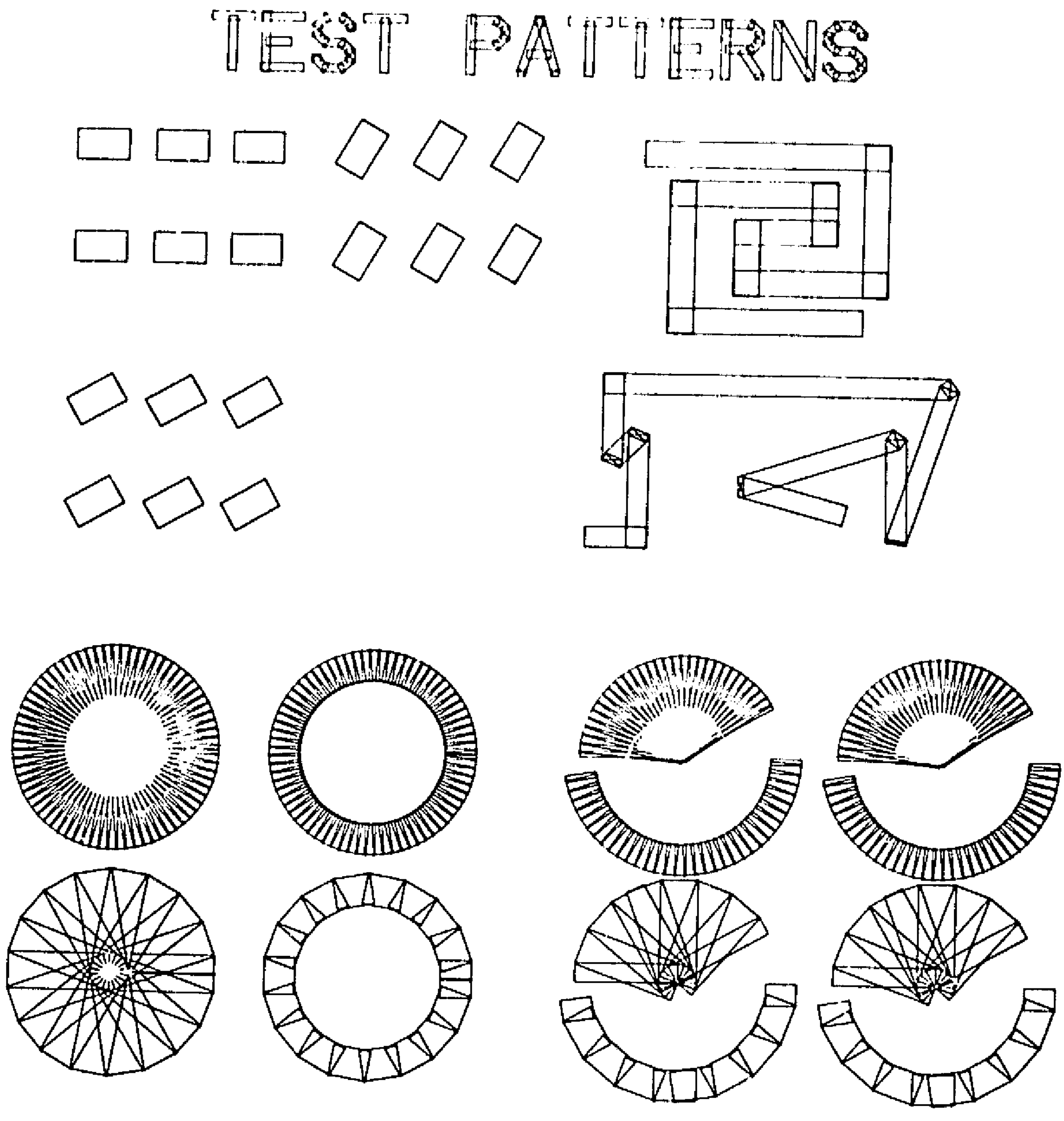

Figure 7-3. Example of Xerox Print Made from Film Plotted by COM System (approx 11X)

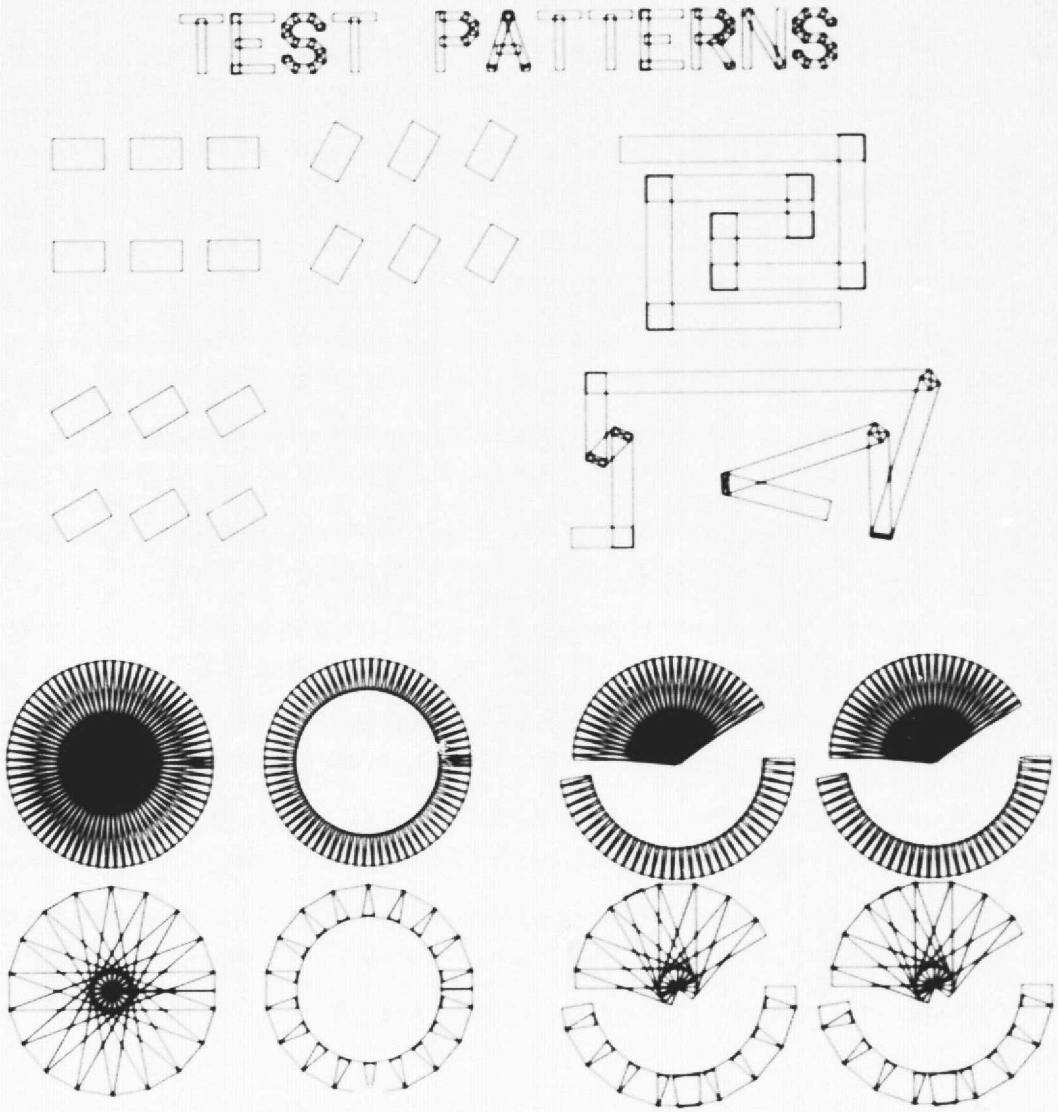

Figure 7-4. Example of Photographic Enlargement Made from Film Plotted on COM System (approx 10X)

F. TEKTRONIX GRAPHICS TERMINAL

ACCESS	Program is executed from terminal and plotting is immediate.
MAX SIZE	Depends on model, for 4002 or 4012: X - approx 5-1/2 in. allowed Y - approx 5-1/2 in. allowed
MEDIUM	Image is plotted on a memory cathode-ray tube screen. A paper copy may be made if a hard-copy unit is connected to the terminal (see Figure 7-5).
RESOLUTION	Approximately 0.1%, or approximately 10 mils on the screen.
COMMENTS	This method gives a rapid means of performing an overall check of the pattern. Overlays are possible, but not too effective. Small size of plot makes details and close registration difficult to observe. The user can plot any desired area of the pattern, enlarging or reducing the size of the pattern.
USE	Refer to Univac, GPCF, and Tektronix manuals regarding basic use of Tektronix terminals. The following runstream should be entered:

```
@RUN - - - -
@ASG,A    55.
@XQT      E.TEKABS
```

The program will respond with *** MASK PLOTTING PROGRAM *** and will wait for a command to be entered on the keyboard. The commands are:

XCEN****.**	Specifies the center of the square area to be plotted, where ****.** is the X coordinate of the center (mils), default: 2000.
YCEN****.**	Analogous to XCEN, default: 2000.
SIZE****.**	Specifies the size of the square area to be plotted, where ****.** is the size of the area for both X and Y directions (mils), default: 2000. Refer to Figure 7-6. The values used by the program for XCEN, YCEN, and SIZE are always the most recent ones entered by the user. The numerical values must contain a decimal point and must be contained in the 10 spaces following the command name.

PAR	Directs the program to print the current values of the parameters XCEN, YCEN, SIZE on the screen.
PLOT	Directs the program to read the plot data file (55) and either to print the messages, if they are the next data records in the file, or to plot the rectangles for the pattern if they are the next data records in the file. The process will continue until the end of the messages is reached, or until the end of the rectangle data is reached. In the latter case the program will respond with ** END OF MASK ** indicating that the plotting is completed. To stop plotting during a plot enter @@X c/r. The terminal will respond with * EXECUTION TERMINATED *. To resume, the plotting program must be re-executed by @XQT FILE.TEKABS. The plotting process must then be started at the beginning, since the plot file will have been rewound and all commands will have been forgotten.
SKIP	Directs the program to skip to the end of the current mask. When the end is reached, the program responds with ** END OF MASK **.
REW	Directs the program to rewind the plot file to the beginning, so that the program is ready to read the first mask.
TERM	Terminates the program. The program responds with ***** PROGRAM TERMINATED *****.

The above commands may be entered at any point that the terminal responds with >. If anything else is entered, the program responds with * UNRECOGNIZABLE COMMAND '####' *, where #### is the command; the unrecognizable command is ignored, and nothing is altered.

If the end of the plot file (55) is reached by use of the PLOT or SKIP commands, the program will respond with *** END OF FILE ENCOUNTERED IN MASK DATA ***. The file may be rewound (REW) or the program terminated (TERM). Entering PLOT or SKIP at this point will cause the program to terminate in error.

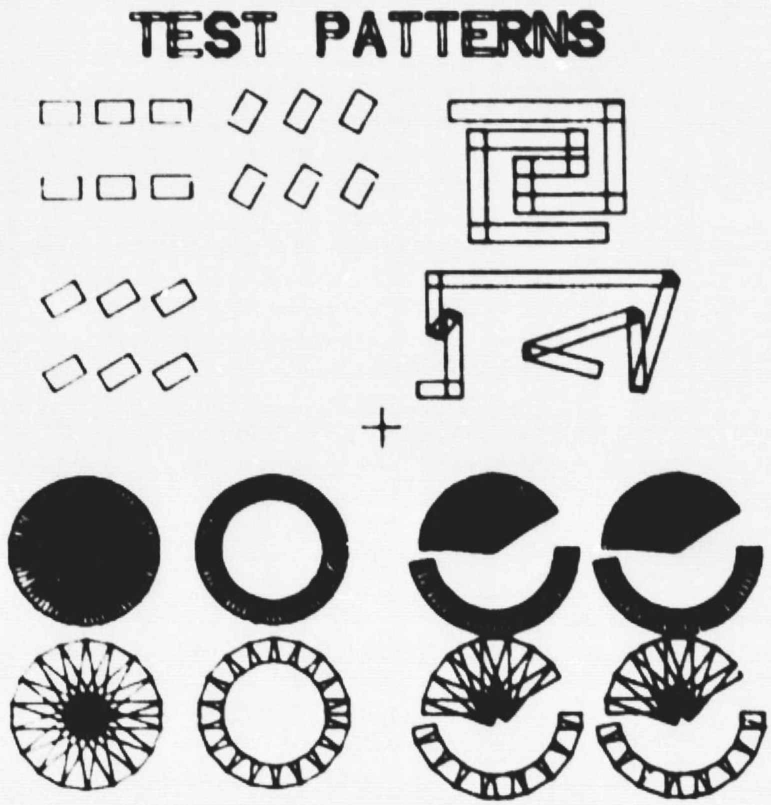

Figure 7-5. Example of Plot from Tektronix Hard Copy Unit

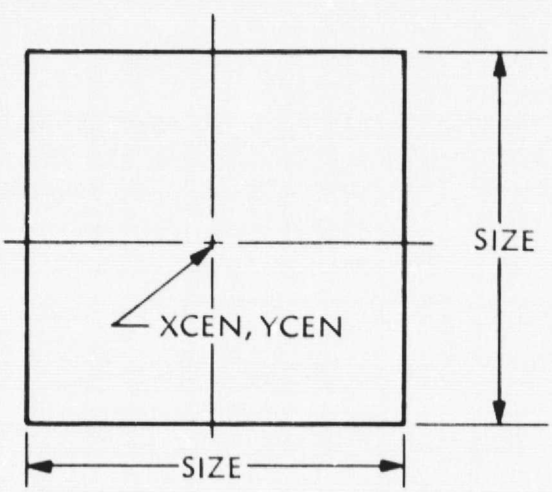

Figure 7-6. Definitions of Parameters for Tektronix Plots

SECTION VIII

PREPARING DATA FOR THE MPG

As mentioned previously, the Mann exposure data in file 57 may be converted into data on a magnetic tape to control the MPG. Unfortunately, the Univac 1108 system at JPL cannot conveniently write a tape in the required format. Consequently, another computer is used to convert the data, as explained in this section. Contact the author regarding these procedures.

A. TAPE FORMAT

The MPG at MSFC uses a 9 track tape written at 800 bpi. The tape must be in standard IBM format, unlabelled. The data must be in 512 character (byte) records. This is a special record length for MSFC; the standard is 1040 as stated in the MPG manual. The data code is EBCDIC. A maximum reel size of 8 1/2 in. (approximately 600 feet of tape) can be accommodated. This is adequate for most sets of masks since 10,000 exposures requires about 70 feet of tape.

Each exposure must be written on the tape in the following format:

X*****Y*****W****H****A**;

where each * represents a digit. As explained in VI-E-2, the last digit for X and Y is 0, 2, 5 or 7 and for W and H is 0 or 5. The semicolon (;) indicates that an exposure is to be made, using the preceding data values for X, Y, W, H, A. The data for each exposure is thus 26 characters (bytes) long. Each tape record can contain data for 19 exposures, with 18 bytes left over which are blank-filled.

The MPG data input format allows for simplification and has greater flexibility than indicated above. However, these features are not used for this scheme. For further information refer to the MPG manual.

Messages to be typed out on the MPG teletype are preceded by a quotation mark (") and terminated by a carriage return (c/r). The following is an example:

"MESSAGE TEXTc/r.

This feature is used for A-group messages and additional data. For simplicity, each A-group message is limited to 68 characters in the JPL programs. If a message is shorter than 68 characters the remainder is blank filled. A tape record thus accommodates 6 A-group messages.

EBCDIC Codes

Character	Name	Code (hexadecimal)
A thru Z	letters	C1 thru C9
J thru R	letters	D1 thru D9
S thru Z	letters	E2 thru E9
Ø thru 9	digits	EØ thru 9
.	period/decimal point	4B
,	comma	6B
;	semicolon	5E
$	dollar sign	5B
*	asterisk	5A
/	slash	61
-	minus sign	6Ø
+	plus sign	4E
=	equal sign	7E
<	less than	4C
>	greater than	6E
(	left parenthesis	4D
)	right parenthesis	5D
'	apostrophe	7D
:	colon	7A
?	question mark	6F
!	exclamation point	5A
"	quotation mark	7F
#	number sign	7B
%	percent sign	6C
@	at sign	7C
&	ampersand	5Ø
	blank	4Ø
c/r	carriage return (non-printing)	15

B. GENERATING THE MPG TAPE

The procedure is as follows:

(1) The data in file 57 are punched onto data cards by executing the program FILETOCARD. Any characters in the A-group messages which have different punch codes for Univac and IBM must be changed by hand.

(2) The cards are taken to CIT, the data reformatted and written onto tape by the program MASKTRAN, running on the IBM 370/158.

(3) The tape is now ready to be used on the MPG at MSFC.

To check the tape the procedure is reversed:

(4) The tape is read and the data reformatted and punched onto cards by the program TAPETRAN, running on the IBM 370/158 at CIT.

(5) The cards are read and the data translated and put into the plot file 55 by the program CARDTOPLOT running on the Univac 1108 at JPL.

The pattern may then be plotted by the procedures given in Section VII. However, in this case the plot is of the actual exposures, so the partitioning of large rectangles will be plotted; also the plot will be "right reading" or "reverse reading" according to whether MR is positive or negative (see Fig. 6-6).

It would be preferable to eliminate the punch cards and to transfer the data between the computers by tape; however, this has not been implemented. The procedures outlined above should be considered provisional.

C. COMPATIBILITY WITH OTHER MASK-GENERATING MACHINES

The programs described in this manual could be used with pattern generators other than the MSFC Mann 1600. There are a number of pattern generators which operate on the principles presented in this manual. Generating a data tape for one of these machines could be done with a minimum of modification to the programs. In many instances modification of the file 57 to MPG tape translation program (MASKTRAN) is all that would be required.

If it were desired to take advantage of the increased capabilities of some of the newer machines, some modification of the MASK program would also be necessary. The following characteristics of the machine in question should be considered:

1) Tape format for exposure data and messages.

2) Maximum available area for pattern.

3) Smallest increment in X, Y, W, M, A.

4) Maximum size for W and H.

Photoplotters such as the Gerber or similar machines have different operating principles from those for which the programs described in this manual were designed. However, the programs can be used with such machines. Regarding such use, contact D. E. Routh at MSFC, W. H. Causey at Mississippi State University, or the author.

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APPENDIX A

TERMS AND ABBREVIATIONS

b̸	blank
BORDER	an opaque area on the reticle photoplate surrounding the pattern, used to block off unwanted light during step-and-repeat
c/r	carriage return
CIT	California Institute of Technology, Pasadena, California
COMMENT	alphanumerics inserted into the input data, but which are not processed by the program. For user reference
DATA GROUP	one of the groups of data input to the MASK program, identified by one of the letters A, B, C, D, E or I. Each group is used to specify a certain type of data
DIGITIZER	a device resembling a drafting board, used to convert information on a drawing into computer data
DRAWING UNIT (DU)	the units in which drawing dimensions and input parameter data are expressed
DU	drawing unit
EXPOSURE	a single exposed rectangular area on a mask plate created by the Mann pattern generator
FIDUCIAL MARK	a pattern of two or three small rectangles near the edges of the reticle mask, used for alignment of the reticle mask for the step-and-repeat process
GPCF	General Purpose Computing Facility (JPL)
ID NUMBER	a number placed after the data group letter on an input card for identification purposes. Not processed by the program
IMAGE	the pattern of transparent and opaque areas on a photoplate
JPL	Jet Propulsion Laboratory
MANN PATTERN GENERATOR (MPG)	an optical/mechanical machine used to generate a photomask from computer data

MESSAGE	alphanumerics which are part of the A group data and are placed into the Plot and Mann files and may appear on plots and the Mann pattern generator teletype
MIL	0.001 inch
MPG	Mann pattern generator
MSFC	NASA Marshall Space Flight Center, Huntsville, Alabama
O	letter O
Ø	number Ø
PATTERN	a set of rectangles or exposures
PARAMETER	one of the items of input data identified by one of the letters M, N, S, T, A, B, W, H, X, Y, I, U, D, R, L
PARAMETER VALUE	a numerical value associated with a parameter
PLOT	refers to data or procedures related to plotting a mask layout
PR	photoresist
RECTANGLE	a rectangle forming part of the input pattern. A single rectangle may have to be partitioned (broken down) into several exposures on the plate
RETICLE	10X photoplate created on the Mann pattern generator which may be stepped-and-repeated to make the final 1X mask
SCALE FACTOR (SF)	a number relating size of a feature in the input data to size of the feature on the mask plate
STEP-AND-REPEAT	the process of reproducing a single pattern onto a photoplate repeatedly in a regular rectangular array
STRAP/STRIP	a rectangle or trace in the pattern which is specified by its endpoints rather than by its center. Generally narrow and used as an interconnection
TAPE BLOCK/ TAPE RECORD	a unit of data written (recorded) onto a magnetic tape. For the MSFC MPG each record is 512 bytes long

APPENDIX B

CONVERSION FACTORS

1 mil = 25.4 μm

1 mil = 0.0254 mm

1 microinch = 0.0254 μm

1 mm = 39.370079 mils

1 mm = 39370.079 microinches

1 μm = 0.039370079 mils

1 μm = 39.370079 microinches

APPENDIX C

DESCRIPTION OF PROGRAMS AND SUBROUTINES

MASK PROGRAMS (see Figure C-1)

MAINPROG (MP)	the master program which is called by the @XQT control statement. It initializes the data processing, calls appropriate subroutines to process data groups, and closes out processing
AGROUP	processes A group cards and writes the messages to Plot (55) and Mann (57) files
ALPHA1	generates data for alphanumeric characters and punctuation marks according to specifications on E group cards, as translated by subroutine E
B	processes B group data cards
C	processes C group data cards
D	processes D group data cards
DATUM	used by subroutines C and D to interpret C and D data cards and extract parameters and parameter values
DISPLA	translates pattern data from COW(I,J) array into data for plotting; sorts data according to location for more efficient plotting. Translated data is written into file 55
E	processes E group data cards, specifications are passed to subroutine ALPHA1
EXTR	extracts fixed or floating point field, containing a parameter value, from data cards
I	generates data for fiducial marks and border for reticle mask according to data on I group cards
MAGTPE	takes data from COW(I,J) array and translates it into Mann data which is stored in MAN(I,J) array and written into file 57. Breaks large rectangles into smaller ones that can be accommodated by Mann pattern generator
SEGMNT	generates data for a strip connecting two points at arbitrary locations
STORE	inserts rectangle data into COW(I,J) array; generates data for repetitions (M,N > 1)

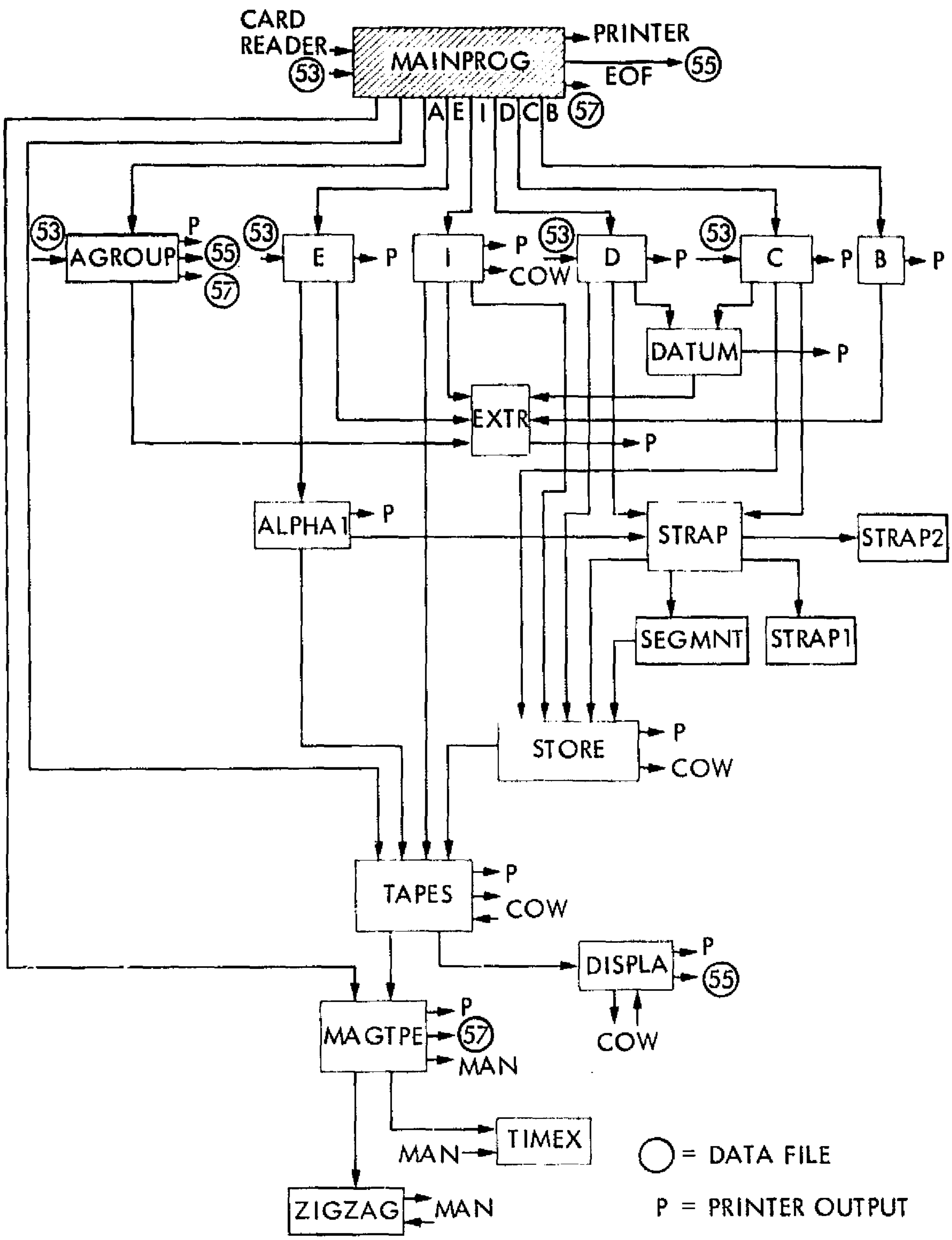

Figure C-1. Mask Program Subroutine Linkages

STRAP	processes strip data
STRAP1	rounds angle to nearest degree for strip at an angle
STRAP2	similar to STRAP1
TAPES	takes data from COW(I,J) array, applies shift, scaling, angle manipulation for compatibility with Mann pattern generator, and puts manipulated data back into COW
TIMEX	calculates Mann pattern generator exposure time from data in MAN array, according to formulas given in Mann 1600 manual
ZIGZAG	sorts data in MAN array according to location for more efficient exposure

NOTES: All above programs except EXTR require an extended FORTRAN compiler.

MP indicates main program, all others are subroutines.

AUXILIARY PROGRAMS

CC11 (MP)	used with Calcomp 11-in. drum plotter to plot data in file 55
CC34 (MP)	used with Calcomp 34-in. drum plotter (off line). Translates data from file 55 to tape for plotter
CCPLOT	calculates plotting points and detects out-of-range values for CC11 and CC34 programs
COM (MP)	used with Calcomp COM plotter to plot data in file 55
COMTGT	generates targets for COM plotter. Used by COM program
DIGITTOC (MP)	converts data on cards from digitizer into C-group data
TARGET	generates targets for plotters. Used by CC11 and CC34
TEKPLOT (MP)	used with Tektronix graphics terminal to plot data in file 55

NOTE: MP indicates main programs, others are subroutines.