INTERACTIVE GRAPHICS PLOTTING SYSTEM (IGPS)

BRADLEY M. LUFKIN

SEPTEMBER 1982

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED
DISPOSITION

Destroy this report when no longer needed. Do not return it to the originator.

DISCLAIMER

The findings in this report are not to be construed as an official Department of the Army position unless so specified by other official documentation.

WARNING

Information and data contained in this document are based on the input available at the time of preparation. The results may be subject to change and should not be construed as representing the DARCOM position unless so specified.

TRADE NAMES

The use of trade names in this report does not constitute an official endorsement or approval of the use of such commercial hardware or software. The report may not be cited for purposes of advertisement.
IGPS is a computer-graphics program which produces high-quality plots of two-dimensional data; it is written in BASIC for the Tektronix 4051 desktop computer. IGPS features: a large variety of axis systems, including probability paper for several distributions, logarithmic paper, and user-definable paper; neat tick mark and axis labeling with automatic or user-controlled decimal-point selection; several curve marker and dashed line types; legends; curve fitting; plotting of user-defined functions; data storage and retrieval on all Tektronix 4051 peripherals; and storage and retrieval of entire plots.
## CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. INTRODUCTION</td>
<td>5</td>
</tr>
<tr>
<td>2. USING IGPS</td>
<td>9</td>
</tr>
<tr>
<td>2.1 User Key Number 1: Limits</td>
<td>10</td>
</tr>
<tr>
<td>2.2 User Key Number 2: Labels</td>
<td>13</td>
</tr>
<tr>
<td>2.3 User Key Number 3: Format</td>
<td>13</td>
</tr>
<tr>
<td>2.3a Linear Paper</td>
<td>17</td>
</tr>
<tr>
<td>2.3b Xlog Paper</td>
<td>17</td>
</tr>
<tr>
<td>2.3c Ylog Paper</td>
<td>18</td>
</tr>
<tr>
<td>2.3d Loglog Paper</td>
<td>20</td>
</tr>
<tr>
<td>2.3e User-Definable Paper</td>
<td>20</td>
</tr>
<tr>
<td>2.3f Uniform Probability Paper</td>
<td>25</td>
</tr>
<tr>
<td>2.3g Normal Probability Paper</td>
<td>27</td>
</tr>
<tr>
<td>2.3h Lognormal Probability Paper</td>
<td>29</td>
</tr>
<tr>
<td>2.3i Rayleigh Probability Paper</td>
<td>29</td>
</tr>
<tr>
<td>2.3j Weibull Probability Paper</td>
<td>31</td>
</tr>
<tr>
<td>2.4 User Key Number 4: Input and Output</td>
<td>32</td>
</tr>
<tr>
<td>2.4a Input</td>
<td>32</td>
</tr>
<tr>
<td>2.4b Output</td>
<td>34</td>
</tr>
<tr>
<td>2.4c File Structure</td>
<td>35</td>
</tr>
<tr>
<td>2.4d Address Number of the 4924</td>
<td>35</td>
</tr>
<tr>
<td>2.5 User Key Number 5: Curve Fits</td>
<td>35</td>
</tr>
<tr>
<td>2.6 User Key Number 6: 4051</td>
<td>37</td>
</tr>
<tr>
<td>2.7 User Key Number 7: 4662</td>
<td>27</td>
</tr>
<tr>
<td>2.8 User Key Number 8: Storage and Retrieval</td>
<td>38</td>
</tr>
<tr>
<td>2.9 User Key Number 9: Data Generation</td>
<td>38</td>
</tr>
<tr>
<td>2.10 User Key Number 10: Menu</td>
<td>41</td>
</tr>
<tr>
<td>3. SHORTCUTS</td>
<td>43</td>
</tr>
<tr>
<td>4. POSTSCRIPT</td>
<td>47</td>
</tr>
<tr>
<td>REFERENCE</td>
<td>49</td>
</tr>
<tr>
<td>APPENDIX A - PROGRAM LISTING</td>
<td>51</td>
</tr>
<tr>
<td>DISTRIBUTION LIST</td>
<td>77</td>
</tr>
</tbody>
</table>

Next page is blank
INTERACTIVE GRAPHICS PLOTTING SYSTEM (IGPS)

1. INTRODUCTION

IGPS (Interactive Graphics Plotting System) is a computer-graphics program, written in BASIC for the Tektronix 4051 desktop computer, which generates high-quality plots of two-dimensional data; the plots can be used for slide presentations or can be inserted into reports.

The program is interactive and prompts the user for all the information required to construct a plot; furthermore, the program is structured to permit rapid changes to an existing plot. Therefore, the user can keep modifying the plot he is drawing and can preview it on the screen of the Tektronix 4051 until he is satisfied with its appearance. Then, simply by depressing one key on the keyboard, the user can exactly reproduce his plot on a Tektronix 4662 x-y plotter.

Figure 1.1 is a sample plot produced in this fashion by IGPS on a 4662. The plot was drawn directly onto a piece of report paper 8-1/2 inches high by 11 inches long placed in the lower left-hand corner of the 4662. The figure number, title, and page number were then added with a conventional typewriter.

The sample, which could have been used directly to make a slide, displays some of the features of IGPS: an unusual axis system (in fact, Rayleigh Paper), neat tick mark and axis labeling, multiple curve marker types, legends, and curve fitting. Table 1-1 is a summary of the features currently available with IGPS.
Figure 1.1 Sample Plot Produced by IGPS
# TABLE 1-1 SUMMARY OF IGPS

<table>
<thead>
<tr>
<th>Tick Mark Spacing:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• uniform</td>
<td></td>
</tr>
<tr>
<td>• user-controlled</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tick Mark Labeling:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• uniform with automatic</td>
<td></td>
</tr>
<tr>
<td>decimal-point selection</td>
<td></td>
</tr>
<tr>
<td>• user-controlled</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Frame Types:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• axis</td>
<td></td>
</tr>
<tr>
<td>• grid</td>
<td></td>
</tr>
<tr>
<td>• border</td>
<td></td>
</tr>
<tr>
<td>• suppressed</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Standard Paper Types:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• linear in x and y</td>
<td></td>
</tr>
<tr>
<td>• linear in x, logarithmic in y</td>
<td></td>
</tr>
<tr>
<td>• logarithmic in x, linear in y</td>
<td></td>
</tr>
<tr>
<td>• logarithmic in x, logarithmic</td>
<td></td>
</tr>
<tr>
<td>in y</td>
<td></td>
</tr>
<tr>
<td>• user-definable</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Probability Paper Types:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• uniform distribution</td>
<td></td>
</tr>
<tr>
<td>• normal distribution</td>
<td></td>
</tr>
<tr>
<td>• lognormal distribution</td>
<td></td>
</tr>
<tr>
<td>• Rayleigh distribution</td>
<td></td>
</tr>
<tr>
<td>• Weibull distribution</td>
<td></td>
</tr>
<tr>
<td>• user-defined distribution</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Input/Output Devices:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Tektronix 4051 Internal Tape</td>
<td></td>
</tr>
<tr>
<td>Drive</td>
<td></td>
</tr>
<tr>
<td>• Tektronix 4924 Auxiliary Tape</td>
<td></td>
</tr>
<tr>
<td>Drive</td>
<td></td>
</tr>
<tr>
<td>• Tektronix 4907 File Manager</td>
<td></td>
</tr>
<tr>
<td>(Disc)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Line Types:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• solid</td>
<td></td>
</tr>
<tr>
<td>• dashed</td>
<td></td>
</tr>
<tr>
<td>• dashed-dotted</td>
<td></td>
</tr>
<tr>
<td>• dotted</td>
<td></td>
</tr>
<tr>
<td>Curve Markers:</td>
<td></td>
</tr>
<tr>
<td>-------------------------------</td>
<td></td>
</tr>
<tr>
<td>• crosses</td>
<td></td>
</tr>
<tr>
<td>• x-shaped</td>
<td></td>
</tr>
<tr>
<td>• squares</td>
<td></td>
</tr>
<tr>
<td>• triangles</td>
<td></td>
</tr>
<tr>
<td>• upside-down triangles</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Curve Fits (Linear, Least-Squares):</th>
</tr>
</thead>
<tbody>
<tr>
<td>• estimate slope and intercept</td>
</tr>
<tr>
<td>• estimate slope, intercept fixed</td>
</tr>
<tr>
<td>• estimate intercept, slope fixed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Plotting Devices:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Tektronix 4051 Screen</td>
</tr>
<tr>
<td>• Tektronix 4662</td>
</tr>
<tr>
<td>• Tektronix 4662, Option 31</td>
</tr>
</tbody>
</table>
2. USING IGPS

Once IGPS has been loaded into the memory of the Tektronix 4051, it needs to be initialized. This can be done by typing in RUN followed by a carriage return. IGPS will initialize itself and will display the following menu on the screen of the 4051.

```
LIMITS   LABELS   FORMAT   IO   FITS

1   2   3   4   5

USER DEFINABLE

4051   4662   S&R   FUNCTION   MENU

6   7   8   9   10
```

Figure 2.1 Menu for IGPS

The 10 rectangles in the menu correspond to the 10 user-definable keys located in the upper left-hand corner of the keyboard of the 4051. These 10 keys are used to control IGPS.

If, at any time during a plotting session with IGPS, the user wishes to examine the menu, he can either type in RUN followed by a carriage return or he can depress user key number 10.

Table 2-1 summarizes the action of the 10 user-definable keys.
<table>
<thead>
<tr>
<th>User Key Number</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Establish limits over which plotting is done.</td>
</tr>
<tr>
<td>2</td>
<td>Inputs axis labels and title.</td>
</tr>
<tr>
<td>3</td>
<td>Defines axis system.</td>
</tr>
<tr>
<td>4</td>
<td>Inputs data curves from peripheral or keyboard; saves data curves on peripheral.</td>
</tr>
<tr>
<td>5</td>
<td>Does least-squares, linear fits on data curves.</td>
</tr>
<tr>
<td>6</td>
<td>Plots graph on screen of 4051.</td>
</tr>
<tr>
<td>7</td>
<td>Plots graph on 4662 x-y plotter.</td>
</tr>
<tr>
<td>8</td>
<td>Stores graph on peripheral; retrieves previously saved graph from peripheral.</td>
</tr>
<tr>
<td>9</td>
<td>Generates x-y data from user-defined parametric functions.</td>
</tr>
<tr>
<td>10</td>
<td>Displays menu on the screen.</td>
</tr>
</tbody>
</table>

2.1 User Key Number 1: Limits.

This key is used to establish the limits between which data plotting is to take place (in other words, data outside the limits will not be plotted); the key is also used to define the distance between tick marks and between tick mark labels.

After the user depresses key number 1, IGPS will prompt him with

UNIFORM TICKS ON THE X AXIS (1=YES, 2=NO):

If the user responds with a 1, meaning that he wants uniformly spaced tick marks and labels, IGPS will prompt with
The user should respond to each prompt with a suitable number. The response to XMIN establishes the smallest value on the x axis and that to XMAX the largest. The response to MAJOR TICKS establishes the distance between adjacent tick mark labels and the response to MINOR TICKS the distance between adjacent tick marks. The sequence to generate the x axis of Figure 1.1, for instance, is

XMIN: 0
XMAX: 96
MAJOR TICKS: 12
MINOR TICKS: 4

In no case should XMIN ever be the same as XMAX and, for best results, MAJOR TICKS and MINOR TICKS should be multiples of the difference between XMAX and XMIN; furthermore, MAJOR TICKS should be a multiple of MINOR TICKS. Results are unpredictable if these conditions are not met. In fact, IGPS will create n tick marks, where

\[ n = 1 + \left\lceil \frac{(XMAX - XMIN)}{MINOR TICKS} \right\rceil, \]

and the quantity in brackets denotes "the largest integer not to exceed," and the tick marks will appear at points \( x_i \) such that

\[ x_i = XMIN + MINOR TICKS \cdot (i-1), \quad i=1,...,n. \]

Similarly, IGPS will create m tick mark labels, where

\[ m = 1 + \left\lceil \frac{(XMAX - XMIN)}{MAJOR TICKS} \right\rceil, \]

and the labels will appear at points \( l_i \) such that

\[ l_i = XMIN + MAJOR TICKS \cdot (i-1), \quad i=1,...,m. \]

Clearly, if MAJOR TICKS is the same as MINOR TICKS, then all tick marks will be labeled.

Consider the sequence

XMIN: 0
XMAX: 1
MAJOR TICKS: 0.25
MINOR TICKS: 0.25
This produces the following x axis

0.00  0.25  0.50  0.75  1.00

Figure 2.2  Sample Axis with Uniform Tick Marks and Labels

Note that the labels are drawn centered under the appropriate tick mark, and that all labels have the same number of digits (two) to the right of the decimal point. Note also that two digits beyond the decimal point is the ideal number in this situation, in the sense that using any fewer would have caused a loss of accuracy while using any more would have caused unnecessary trailing zeroes. IGPS calculates and uses this ideal number automatically.

If the user does not like uniformly spaced tick marks and tick mark labels with automatic decimal-point selection on the x axis, then he should respond with a 2 to the prompt

UNIFORM TICKS ON THE X AXIS (1=YES, 2=NO):

By doing so, he assumes total control over the placement and appearance of tick marks and labels; after such a response, IGPS prompts with

NUMBER OF TICK MARKS (AT LEAST 2):
LOCATION OF TICK MARKS:
NUMBER OF TICK MARK LABELS:
LOCATION OF TICK MARK LABELS:

The meaning of these prompts is obvious.

At least two tick marks are required since the first one entered is assumed to be the minimum value along the x axis while the last one is assumed to be the maximum value. The number of tick mark labels, however, is unrestricted and may even be zero; if it is zero, the fourth prompt is not displayed since it is not needed.

The locations of tick mark labels must all be entered on one line and must be separated by a single blank or by a comma. The labels will be plotted by IGPS exactly as they were entered (in other words, IGPS will not calculate the number of places beyond the decimal point for the labels but will use as many as the user himself typed in).
For example, the sequence

NUMBER OF TICK MARKS (AT LEAST 2): 19
LOCATION OF TICK MARKS: .1 .2 .3 .4 .5 .6 .7 .8 .9
1 2 3 4 5 6 7 8 9
10
NUMBER OF TICK MARK LABELS: 3
LOCATION OF TICK MARK LABELS: .1 1 10

if used in conjunction with a logarithmic x axis, will produce

![Figure 2.3 Sample Axis with User-Controlled Tick Marks and Labels](image)

Once the user has supplied the specifications for the x axis, IGPS will prompt for the y axis in exactly the same way as it did for the x axis.

2.2 User Key Number 2: Labels.

This key is used to establish the axis labels and the title of the plot. If the user does not want these items, he should respond with a carriage return when prompted for them.

The x-axis label is plotted below the plotting area and is centered between the x-axis limits. The title of the plot is similarly centered but is plotted above the plotting area and is underlined twice (if the plot has no title, no underlining takes place). The y-axis label is plotted to the left of the plotting area and is centered between the y-axis limits. When plotted on the 4662 x-y plotter, the y-axis label will be written along a baseline rotated 90 degrees from the horizontal (see Figure 1.1); on the screen of the 4051, however, the individual characters are plotted on the horizontal, with the first character above the second, the second above the third, and so on (as in Chinese or Japanese)—this is done because the character-generator of the 4051 cannot produce rotated characters. Close examination of Figure 1.1 will reveal that different character sizes are used in various parts of the plot; this feature is also only available on the 4662 because the character-generator of the 4662 can produce characters of arbitrary size, unlike the generator of the 4051.

2.3 User Key Number 3: Format.

This key is used to control the basic appearance of the graph: it determines the type of frame which will be used, the speed at which the graph will be drawn, the color of the frame
and labels and, more importantly, the type of paper which will be used.

After the user depresses user key number 3, IGPS will ask for the type of frame the user wants. There are four possible answers: zero, meaning no frame or labels are to be drawn; one, meaning draw an axis system; two, meaning draw a grid; and three, meaning draw borders.

The first option is useful when a set of curves is to be added to a graph because it avoids re-plotting most of the graph.

The second option produces axes running along the left-hand side and the bottom of the plotting area.

Figure 2.4  Sample Axis System
The third option produces a grid over the plotting area; each tick mark is indicated with a solid line.

![Sample Grid](image)

**Figure 2.5 Sample Grid**

The fourth option produces axes and tick marks along the edges of the plotting area.

![Sample Borders](image)

**Figure 2.5 Sample Borders**
After he selects a frame type, the user will be prompted for the color of the frame and labels. He must reply with an integer between one and eight, corresponding to the eight pens in the turret of the 4662 x-y plotter equipped with Option 31. The choice of color is ignored if plotting is either on the screen of the 4051 or on a standard 4662.

The user is then asked for a pen speed, to which he must respond with an integer between 10 and 570. The answer is interpreted in millimeters per second and is the maximum speed at which the 4662, Option 31, plotter will draw (the response is ignored on the 4051 or the standard 4662). For previewing, the user should select 570 mm/s. However, for best results, he should select 10 mm/s since the lower speed leads to much sharper definition of vectors.

The final prompt associated with user key number 3 is for the type of paper the user wants. IGPS will display

<table>
<thead>
<tr>
<th>PAPER TYPES:</th>
<th>X-AXIS</th>
<th>Y-AXIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. LINEAR:</td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>2. XLOG:</td>
<td>LOG(X)</td>
<td>Y</td>
</tr>
<tr>
<td>3. YLOG:</td>
<td>X</td>
<td>LOG(Y)</td>
</tr>
<tr>
<td>4. LOGLOG:</td>
<td>LOG(X)</td>
<td>LOG(Y)</td>
</tr>
<tr>
<td>5. USER:</td>
<td>?</td>
<td>?</td>
</tr>
<tr>
<td>6. UNIFORM:</td>
<td>X/100</td>
<td>Y</td>
</tr>
<tr>
<td>7. NORMAL:</td>
<td>N(X/100)</td>
<td>Y</td>
</tr>
<tr>
<td>8. LOGNORMAL:</td>
<td>N(X/100)</td>
<td>LOG(Y)</td>
</tr>
<tr>
<td>9. RAYLEIGH:</td>
<td>SQR(-2*LOG(1-X/100))</td>
<td>Y</td>
</tr>
<tr>
<td>10. WEIBULL:</td>
<td>LOG(-LOG(1-X/100))</td>
<td>LOG(Y)</td>
</tr>
</tbody>
</table>

PAPER TYPE:

to which the user should respond with an integer between one and 10, corresponding to his choice of paper. As indicated by the prompt, the user's choice is in fact a selection of two transformations, or functions, one function for the x axis and one for the y axis. All data, including tick mark locations (but not tick mark labels) related to the x coordinate are transformed via the x-axis function before being plotted, as are all data related to the y coordinate via the y-axis function. Since the reader may not be familiar with all available paper types, we will describe each one, with its associated functions, separately.
2.3a Linear Paper. This is the most commonly used type of paper and is in fact plain graph paper. The two functions associated with this paper are the identity functions and therefore have no effect.

![Figure 2.6 Example of the use of Linear Paper](image)

2.3b Xlog Paper. This paper has a logarithmic x axis and a linear y axis; therefore, all x-axis data are transformed via the function

\[ F_a(x) = \ln x \]

before being plotted. Because of this transformation, there are implications for the meaning of the slope and intercept of any straight line which the user might choose to fit to his data while using xlog paper (Section 2.5, User Key Number 5). In particular, if we let \( a \) be the slope of such a line and if we let \( b \) be its intercept, and if the line appears to fit the user's data plotted on xlog paper, then an appropriate model of the user's data is:

\[ y = a \ln x + b . \]

Though this may be perfectly obvious in this case, we have chosen to emphasize the point here because the situation becomes much more complex with other types of paper (transformations). In general, if we denote the two axis transformations by \( F_a(x) \) and \( F_b(y) \), then any straight line used with those transformations is in fact a model of the form:

\[ F_b(y) = a F_a(x) + b . \]
If the user wants the model in simpler form, with only the $y$ term appearing to the left of the equal sign, he will have to apply the inverse of $F_b$ to both sides of the equation; this point is illustrated explicitly in the next section.

2.3c Ylog Paper. This paper has a linear $x$ axis and a logarithmic $y$ axis. To illustrate the use of this paper, consider the data in Table 2-2.

<table>
<thead>
<tr>
<th>TABLE 2-2 VALUES OF AIR DENSITY AS A FUNCTION OF ALTITUDE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Altitude (km)</td>
</tr>
<tr>
<td>Air Density (kg/m$^3$)</td>
</tr>
<tr>
<td>Altitude (km)</td>
</tr>
<tr>
<td>Air Density (kg/m$^3$)</td>
</tr>
<tr>
<td>Altitude (km)</td>
</tr>
<tr>
<td>Air Density (kg/m$^3$)</td>
</tr>
</tbody>
</table>

From physical reasoning, or for some other reason, we decide that air density is an exponential function of altitude (in other words, that the logarithm of air density is a linear function of altitude). To test this hypothesis, we plot the data on ylog paper and fit a straight line with user key number 5.
The plot confirms our hypothesis. The slope and intercept of the line calculated by IGPS are:

\[ a = -0.13, \]

\[ b = 0.34. \]

Therefore, our model of air density \( p \) versus altitude \( h \) is:

\[ \ln p = -0.13 h + 0.34, \]

or

\[ p = 1.40 e^{-0.13h}. \]

Note that this model does not go through the data point at zero altitude. Suppose we should want it to, in other words, suppose we should like a model of the form:

\[ p = 1.22 e^{-kh}. \]

what is the best value of \( k \) (in the least-squares sense)? Taking logarithms produces:

\[ \ln p = -kh + 0.20. \]
To determine $k$, we depress user key number 5 and request a straight-line fit with a forced intercept of

$$b = 0.20.$$  

IGPS will calculate the slope of that line as:

$$a = -0.12$$

It is clear, therefore, that the value of $k$ we are looking for is:

$$k = 0.12,$$

and that the best model which goes through the value of air density at zero altitude is:

$$p = 1.22 e^{-0.12h}.$$  

2.3d Loglog Paper. This paper has a logarithmic x axis and a logarithmic y axis. Therefore, straight-line fits to data plotted on this paper are models of the form:

$$\ln y = a \ln x + b.$$  

The user is cautioned that whenever he is using a logarithmic axis, be it horizontal or vertical, he must avoid zero or negative values along that axis, both in the data being plotted and in the choice of tick marks. This is because the logarithm of a non-positive number is undefined.

2.3e User-Definable Paper. This is one of the most powerful features of IGPS because it allows the user to define his own transformations for the axes and therefore provides an unlimited supply of paper types. If you want to use this feature, you must define your transformations before you depress user key number 3 and you must then select user-definable paper.

To define your transformations, you must replace lines 4590 and 4600 in the program with your own functions. The transformation for the x axis must appear on line 4590 and must be of the form

4590 DEF FNA(X)=

where you supply the information to the right of the equal sign. Line 4600 is for the y axis and must be of a similar form

4600 DEF FNB(Y)=

To illustrate the power of this feature, consider the data appearing in Table 2.3.
TABLE 2-3 SAMPLE DATA

<table>
<thead>
<tr>
<th>x</th>
<th>3.00</th>
<th>2.70</th>
<th>2.30</th>
<th>1.80</th>
<th>1.60</th>
<th>1.27</th>
<th>1.10</th>
</tr>
</thead>
<tbody>
<tr>
<td>y</td>
<td>.225</td>
<td>.241</td>
<td>.267</td>
<td>.304</td>
<td>.321</td>
<td>.351</td>
<td>.365</td>
</tr>
</tbody>
</table>

Plotting the data on ordinary, linear, graph paper reveals nothing unusual about them.

![Graph](image)

Figure 2.8 Sample Data Plotted on Linear Paper

Incidentally, the source of the data and the units associated with them do not concern us here. What does concern us is that a model of the form

\[
y = \frac{k}{\sqrt{x}}
\]

has been suggested for the data. To test this model, we type in

4590 DEF FNA(X)=-1/SQR(X)
4600 DEF FNB(Y)=Y

we select user-definable paper and we ask for a curve fit with a forced intercept of \( b=0 \).
IGPS calculates the slope of the line as $a = -0.40$. This means that one possible model of the data is:

$$y = \frac{0.40}{\sqrt{x}}.$$ 

Note that the x axis on user-definable paper starts at 1, whereas the x axis on ordinary paper starts at zero. This difference is necessary because the transformation of zero on user-definable paper would lead to an undefined number (in other words, $\frac{-1}{\sqrt{0}} = -\infty$). Note also that we defined the x-axis transformation as

$$F_a(x) = -\frac{1}{\sqrt{x}},$$

rather than as

$$F_a(x) = \frac{1}{\sqrt{x}}.$$ 

The minus sign is required to make the transformed value of the minimum along the x axis smaller than the transformed value of the maximum (in other words, if the minus sign had not been included, we would have had $F_a(1) > F_a(4)$, which is not allowed.
on the Tektronix). The minus sign has to be taken into account when interpreting the results of the curve fitting (which was done in constructing the final model above).

The final point to make about this example is that the value of the free parameter in our model could have been read directly off the graph at the point where the fitted line intersects the vertical line x=1. One way to see this is to note that, in our model, y=k when x=1.

What this example has illustrated is that user-definable paper, in conjunction with curve-fitting, can be used to test the adequacy of a large class of models in representing given data (though no mention of this has yet been made, it will be shown in Section 2.5 that IGPS, when curve-fitting, generates a quantitative estimate of the goodness-of-fit of the model; this estimate is known as R^2). As another example, consider the data in Table 2-4.

### TABLE 2-4 MORE SAMPLE DATA

<table>
<thead>
<tr>
<th>x</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>y</td>
<td>1.01</td>
<td>2.28</td>
<td>3.92</td>
<td>6.13</td>
</tr>
</tbody>
</table>

One proposed model for these data is:

\[ y = \frac{x}{1.1 - kx} \]

By inverting both sides of the equation and multiplying by -1, this model can be transformed into:

\[ -\frac{1}{y} = -\frac{1.1}{x} + k \]

Therefore, we can check the adequacy of the original model by typing

```
4590 DEF FNA(X)=-1/X
4600 DEF FNB(Y)=-1/Y
```

and then selecting user-defined paper and doing a curve fit with a forced slope of \( a = 1.1 \).
The plot shows that the model is a good one and as IGPS calculates the intercept of the line as $b = 0.11$, we know the value of the free parameter $k$. Therefore our model becomes:

$$Y = \frac{x}{1.1 - 0.11x}$$

This example illustrates that a particular model may need to be manipulated before it can be used to define a paper type. In general, to define a paper type, a model will have to be put into the form:

$$F_b(y) = a F_a(x) + b$$

where $F_a$ and $F_b$ are functions of $x$ and $y$ and where $a$ and $b$ are functions of the free parameters of the original model.

The paper types described so far have been suitable for sets of two-dimensional, $x$-versus-$y$, data. We now describe several types of paper suitable for testing whether a set of data is from a particular probability distribution.
2.3f Uniform Probability Paper. Let us imagine that we have a sample of \( n \) points, \( d_i, i=1,\ldots,n \), from a uniform distribution on the interval \((A, B)\). Suppose further that the cumulative fraction of the data associated with the \( i \)th point is \( q_i \), \( i=1,\ldots,n \). The \( q_i \)'s can be determined in two steps: (1) sort the \( d_i \)'s into increasing order and (2) calculate \( q_i \) as:

\[
q_i = \frac{i}{1 + n}, \quad i=1,\ldots,n.
\]

Since the \( d_i \)'s are uniformly distributed, it must be the case that

\[
q_i = F(d_i), \quad i=1,\ldots,n,
\]

where \( F \) is the cumulative distribution function (c.d.f.) of the uniform distribution on \((A, B)\):

\[
q = F(x) = \begin{cases} 
0, & x < A, \\
\frac{x - A}{B - A}, & A \leq x \leq B, \text{ and} \\
1, & x > B.
\end{cases}
\]

It follows, therefore, that

\[
d_i = F^{-1}(q_i), \quad i=1,\ldots,n,
\]

where \( F^{-1} \) represents the inverse of \( F \) (the existence of \( F^{-1} \) can be guaranteed by restricting the domain of \( F \) to the interval \( A \leq x \leq B \)). In other words,

\[
d_i = (B-A)q_i + A, \quad i=1,\ldots,n,
\]

so that if we plot the \( d_i \)'s against the \( q_i \)'s, we should be able to fit a straight line to the plotted points; what is more, if the slope of the line is \( a \) and its intercept is \( b \), we can calculate the parameters of the distribution from \( a = B - A \) and \( b = A \); these two equations in fact imply \( A = b \) and \( B = a + b \).

Consider the data in Table 2-5.
To check the uniformity of the data, we sort them in increasing order, generate the associated cumulative fractions, and plot them after asking for a curve fit (IGPS will, if requested, do the sorting and the generating of cumulative fractions; note that the fractions are expressed as percentages, however). The plot provides convincing evidence of the uniformity of the numbers; furthermore, the curve fit produces a slope $a = 2.24$ and an intercept $b = 4.87$. We conclude that the numbers are from a uniform distribution on $(4.87, 7.11)$. 

![Cumulative Frequency (%)](image)

Figure 2.11 Example of the Use of Uniform Probability Paper
Normal Probability Paper. This paper can be used to check if a given sample of data is from a normal, or gaussian, distribution.

Imagine that we have a sample of \( n \) points \( d_i \), \( i=1,\ldots,n \), from a normal distribution with unknown parameters \( m \) and \( s \). We can transform the \( d_i \)'s to standard form by setting

\[
    z_i = \frac{d_i - m}{s}, \quad i=1,\ldots,n.
\]

Furthermore, since the \( d_i \)'s are normally distributed, then the \( z_i \)'s are distributed according to the standard normal distribution, and it must therefore be the case that

\[
    q_i = F(z_i), \quad i=1,\ldots,n,
\]

where the \( q_i \)'s are the cumulative fractions of the data and \( F \) is the c.d.f. of the standard normal distribution:

\[
    F(x) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{x} e^{-\frac{1}{2} t^2} \, dt.
\]

It follows that

\[
    z_i = F^{-1}(q_i), \quad i=1,\ldots,n,
\]

and from the definition of \( z_i \) we have

\[
    \frac{d_i - m}{s} = F^{-1}(q_i), \quad i=1,\ldots,n
\]

or

\[
    d_i = s F^{-1}(q_i) + m, \quad i=1,\ldots,n.
\]

Therefore, if we plot \( d_i \) against \( F^{-1}(q_i), \quad i=1,\ldots,n \), the result will approximate a straight line whose slope and intercept can be used directly to estimate \( m \) and \( s \). Consider the data in Table 2-6.

<table>
<thead>
<tr>
<th>TABLE 2-6 NORMALLY DISTRIBUTED DATA (FREQUENCY)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
</tr>
<tr>
<td>Value</td>
</tr>
</tbody>
</table>
The same data, in cumulative form, appears in Table 2-7.

<table>
<thead>
<tr>
<th>Cumulative Frequency (%)</th>
<th>12</th>
<th>34</th>
<th>63</th>
<th>81</th>
<th>96</th>
<th>98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>3.0</td>
<td>3.5</td>
<td>4.0</td>
<td>4.5</td>
<td>5.0</td>
<td>5.5</td>
</tr>
</tbody>
</table>

We enter the data in Table 2-7 into IGPS after selecting normal paper and we do a curve fit.

Estimates of the mean and standard deviation provided by the curve fitting are \( m = 3.82 \) and \( s = 0.75 \). These two quantities can also be estimated from the graph: the mean is the point at which the line intersects the 50th percentile while the standard deviation is the difference between this value and the value
corresponding to a cumulative fraction of 0.8413. These assertions can be verified as follows: our model is of the form
\[ d = sF^{-1}(q) + m, \]
and therefore \( d = m \) where \( F^{-1}(q) = 0 \) and \( F^{-1}(q) = 0 \) when \( q = 0.50 \). To find \( s \), note that \( s = d - m \) when \( F^{-1}(q) = 1 \) and this is true when \( q = 0.8413 \). Another way to see this is to note that the mean and median of the standard normal distribution are equal while one standard deviation about the mean spans 68.26 percent of the distribution (and 50 percent plus one-half of 68.26 percent equals 84.13 percent).

Note that the x-axis tick mark labels on the graph avoid the values zero and 100. This should always be done when using normal paper because \( F^{-1}(0) = -\infty \) and \( F^{-1}(1) = +\infty \).

Finally, a remark about \( F^{-1} \) itself: since \( F^{-1} \) cannot be expressed in closed form (that is to say in terms of sums and products of functions available on the Tektronix 4051), IGPS uses an approximation of \( F^{-1} \) due to Hastings (reference 1, page 192).

The approximation is:
\[ F^{-1}(q) = \begin{cases} G(1-q), & q > 0.5, \\ -G(q), & q \leq 0.5, \end{cases} \]
where
\[ G(q) = z - \frac{h(z)}{s(z)}, \]
\[ z = \ln \frac{1}{q^2}, \]
\[ h(z) = 2.515517 + 0.802853 z + 0.010328 z^2, \] and
\[ s(z) = 1 + 1.432788 z + 0.189269 z^2 + 0.001308 z^3. \]

It is claimed that the error made in using the approximation is never greater than 0.0004 standard deviations.

2.3h Lognormal Probability Paper. Lognormal paper is similar to normal paper in all respects save one: the y axis of lognormal paper is logarithmic whereas the y axis of normal paper is linear. Therefore, lognormal paper can be used to test whether a sample of data is from a lognormal distribution, that is to say, that the logarithm of the sample is normally distributed.

2.3i Rayleigh Probability Paper. The Rayleigh distribution has c.d.f.
\[ q = F(d) = 1 - e^{-\frac{1}{2} \left( \frac{d}{s} \right)^2}. \]

This can be readily transformed into
\[ d = s \sqrt{-2 \ln (1 - q)}. \]

Therefore, given a sample of \( n \) points \( d_i, i=1,\ldots,n \), with cumulative fractions \( q_i, i=1,\ldots,n \) we can test whether the sample is from a Rayleigh distribution by plotting \( d_i \) against \( \sqrt{-2 \ln (1 - q_i)} \), \( i=1,\ldots,n \). Furthermore, we can estimate \( s \) by fitting a line with intercept \( b = 0 \) and slope \( a \) to the transformed data and setting \( s = a \). The data in Table 2-8 will illustrate the procedure.

**TABLE 2-8 NUMBERS FROM A RAYLEIGH DISTRIBUTION**

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>320</td>
<td>470</td>
<td>16</td>
<td>619</td>
<td></td>
</tr>
<tr>
<td>356</td>
<td>547</td>
<td>264</td>
<td>204</td>
<td></td>
</tr>
<tr>
<td>429</td>
<td>703</td>
<td>265</td>
<td>305</td>
<td></td>
</tr>
<tr>
<td>501</td>
<td>128</td>
<td>468</td>
<td>662</td>
<td></td>
</tr>
<tr>
<td>608</td>
<td>143</td>
<td>121</td>
<td>524</td>
<td></td>
</tr>
</tbody>
</table>

We input the data to IGPS, ask IGPS to sort it and generate the cumulative fractions, ask IGPS for a curve fit with a forced intercept of \( b=0 \), and plot the results on Rayleigh paper.

**Figure 2.13 Example of the use of Raleigh Probability Paper**
One estimate of the parameter $s$ is provided by the curve fit as $s = 314$. Another is provided directly from the graph at the point where the line intersects the 39th percentile. This is the case because our model is:

$$d = s \sqrt{-2 \ln(1-q)},$$

and therefore $d = s$ when $\sqrt{-2 \ln (1-q)} = 1$, which is the case when $q = 39\%$.

Note that the value 100 is not used as an x-axis tick mark label; this is because when $q = 1$, $\sqrt{-2 \ln (1-q)} = +\infty$.

2.3j Weibull Probability Paper. The Weibull distribution has c.d.f.

$$q = F(d) = 1 - e^{-kd^c}, \quad d > 0, \quad k > 0.$$

This can be transformed, by taking logarithms twice, into

$$\ln d = \frac{1}{c} \ln [-\ln (1 - q)] - \frac{1}{c} \ln k.$$

Weibull paper is ruled according to the function

$$F_a(x) = \ln [-\ln (1 - x)]$$

along the x axis and according to the function

$$F_b(y) = \ln y$$

along the y axis. Therefore, given a set of data $d_i$, $i=1,...,n$, from a Weibull distribution with parameters $c$ and $k$, with associated cumulative fractions $q_i$, $i=1,...,n$, then, if we plot $d_i$ against $q_i$, $i=1,...,n$, on Weibull paper, the result should approximate a straight line. Furthermore, if the slope of the line is $a$ and its intercept is $b$, then estimates of $c$ and $k$ are given by

$$c = \frac{1}{a}, \quad \text{and} \quad k = e^{-b/a}$$

Note that, because of the definition of $F_a$, values of zero and 100 should be avoided on the x-axis (in fact, $F_a(0) = -\infty$ and $F_a(1) = +\infty$); similarly, non-positive values should not be used along the y axis.

Before leaving this section, we should point out that the user can define his own probability paper by using the ideas developed in Section 2.3e. For instance, suppose the user is interested in constructing paper for the exponential distribution. Now the exponential distribution has c.d.f.
\[ q = F(d) = 1 - e^{-cd}, \quad c > 0. \]

By rearranging and taking logarithms, this can be converted to
\[ d = \frac{1}{c} \ln (1 - q). \]

Therefore, to construct exponential paper, the user would type in:
\[
4590 \text{ DEF FNA}(X) = -\text{LOG}(1-X/100) \\
4600 \text{ DEF FNB}(Y) = Y
\]

and would then select user-definable paper. Note that the argument of the function FNA is divided by 100; this is done to allow the x-axis tick marks and labels to be expressed as percentages.

We leave to the reader the problem of determining what kind of curve fit to use with exponential paper and how to estimate the parameter \( c \) from the results of the curve fit.

The overall strategy for creating distribution paper, however, is clear: the c.d.f. of the distribution of interest is manipulated into the form
\[ F_b(d) = a F_a(q) + b, \]
where \( F_a \) and \( F_b \) are functions of the cumulative frequency of the data and of the data itself and \( a \) and \( b \) are functions of the free parameters of the distribution.

2.4 User Key Number 4: Input and Output.

This key is used either to input data curves into IGPS or to save previously entered curves from IGPS onto a Tektronix peripheral.

2.4a Input. After the user chooses to input data into IGPS, he will be prompted with

\[ \text{DATA TYPE (1 = Y ONLY, 2 = X & Y)} : \]

A response of 1 indicates that the user is only going to input y-coordinate data whereas a response of 2 indicates that he is going to input both x-axis and y-axis data. A response of 1 is also a request to IGPS to do two things: (1) sort the y-axis data in increasing order and (2) generate x-axis data as:
\[ x_{i,j} = 100 \frac{j}{1 + m_i}, \quad j = 1, \ldots, m_i, \quad i = 1, \ldots, n, \]

where \( n \) is the number of curves in the data set and \( m_i \) is the number of points in the \( i \)th curve. This feature is useful with probability paper; see sections 2.3f through 2.3j.

The user is then prompted for the device he wants to read the data curves from. There are four possible responses: one, meaning the Tektronix 4907 File Manager, a disc system; two, the Tektronix 4924 Auxiliary Tape Drive; three, the Tektronix 4051 Internal Tape Drive; and four, meaning the user wants to input data into IGPS by typing it on the keyboard of the 4051.

The user is then prompted for the number of curves he wants to input and for the number of points in the curve having the largest number of points (in other words, for the number \( m_0 \) where \( m_0 = \max \{ m_i, \quad i = 1, \ldots, n \} \), where \( n \) is the number of curves being input and \( m_i \) is the number of points in the \( i \)th curve).

If the user selected the 4907 as the device to use, he is then prompted for the names of the files on which his data reside; if he selected either the 4924 or the internal tape drive, he is then prompted for the numbers of the files; and if he selected the keyboard, he is prompted for the number of points and for the values of the data points in each curve (furthermore, if the user selected y-only data, he is only prompted for the y-axis values, whereas, if he selected x & y data, he is prompted for both x-axis and y-axis values).

When IGPS has read in all the data, it asks for the type of curve marker to be used with each curve. These are nine different curve markers available:

\begin{align*}
\text{Available Curve Markers} \\
\begin{array}{l}
\text{Figure 2.14} \\
\text{Available Curve Markers}
\end{array}
\end{align*}
Interesting effects can be achieved by plotting the same curve more than once, with a different curve marker each time.

IGPS next prompts for the legend the user wants for each curve; if the user does not want a legend, he should respond with a carriage return. The legend for a particular curve is plotted slightly to the right of the last data point in the curve. This feature was used to create the symbols one through nine in the plot above.

Finally, IGPS prompts for the color the user wants for each curve. Allowable responses are integers between one and eight; these refer to the eight pens in the turret of the Tektronix 4662 x-y plotter equipped with Option 31. The responses are ignored if plotting is either on the screen of the 4051 or on the standard 4662.

If the user selected y-only data, there may now be a slight pause as IGPS sorts the y-axis data and generates the x-axis data. The y-axis data are sorted in place and the original order of the data is therefore lost.

2.4b Output. After the user chooses to output data from IGPS onto a peripheral device, he is prompted for the type of data he wants to save, either y-only or x & y. In the first case, only the y-axis values will be output, whereas in the second, both x-axis and y-axis data are transmitted.

IGPS then prompts for the device the user wishes to output the data to. Possible responses are: one, the 4907; two the 4924; and three, the 4051 Internal Tape. If the user chooses the 4907, IGPS will then ask for the file names on which to write the data; if he chooses the 4924 or the internal tape, it asks for the file numbers.

When writing to the 4907, IGPS will create files of the appropriate size for the data to be written; for tape devices, however, the user must use the MARK command to create the files on his tape before saving data. The tape files must be \( s \) bytes long, where

\[
s = \begin{cases} 
19 + 19 \cdot m, & \text{for y-only data} \\
19 + 37 \cdot m, & \text{for x & y data}
\end{cases}
\]

and \( m \) is the number of points in the curve to be written to the file. In practice, the default minimum file size of 768 bytes is adequate for most curves.

If the user attempts to output data without ever having input data during the session, an error message is printed.
2.4c File Structure. Data files to be read by IGPS or written by IGPS are in ASCII format. The structure of an IGPS-compatible file is as follows: (1) the first record in the file contains the number of points in the file; (2) each subsequent record consists of either a single number or of a data pair, depending on whether the file is a y-only or an x & y data file.

2.4d Address Number of the 4924. IGPS assumes that the 4924 Auxiliary Tape Drive is at address 2 of the General Purpose Interface Bus (GPIB). If the user's 4924 is at a different address, he will need to change IGPS. An example will illustrate the required change: if the address wanted is, say, 4 then the user should type in

9350 DO = 4 .

This must be done before initialization of IGPS.

2.5 User Key Number 5: Curve Fits.

This key is used to do least-squares, linear fits to the user's data. There are several types of fit available: (1) unconstrained, where IGPS calculates both the slope and intercept of the line which best fits the user's data; (2) fixed-slope, where IGPS calculates the intercept of the best line with user-defined slope; and (3) fixed-intercept, where IGPS calculates the slope of the best line with user-defined intercept. A fourth option allows the user to check the goodness of fit of any line he wishes. In all cases, IGPS operates not on the data the user inputs into IGPS but on the data after it has been transformed via the two functions which define the type of paper the user has asked for (see section .3). For instance, if the user asked for xlog paper, the curve fit is to the logarithm of the x-axis data values.

The following equations are used by IGPS for the different curve fits. Assume we are given a set of transformed data \((x_i, y_i)\), \(i = 1, \ldots, n\), where \(n\) is the number of points in the set, to which we wish to fit a line of the form \(y = ax + b\). The sum of the squares of the vertical deviations between the line and the data points is

\[
D = \sum_{i=1}^{n} [y_i - (ax_i + b)]^2 .
\]

In order to do an unconstrained curve fit, in other words, to calculate both \(a\) and \(b\), we differentiate \(D\) with respect to \(a\) and \(b\) and set the results to zero:
\[ \frac{dP}{da} = \sum_{i=1}^{n} (2) \left[ y_i - (a x_i + b) \right] (-x_i) = 0 \]

\[ \frac{dP}{db} = \sum_{i=1}^{n} (2) \left[ y_i - (a x_i + b) \right] (-1) = 0 \]

A little algebra reduces these equations to:

\[ a = \frac{n \sum_{i=1}^{n} x_i y_i - \sum_{i=1}^{n} x_i \sum_{i=1}^{n} y_i}{n \sum_{i=1}^{n} x_i^2 - \left( \sum_{i=1}^{n} x_i \right)^2} \]

\[ b = \frac{1}{n} \left( \sum_{i=1}^{n} y_i - a \sum_{i=1}^{n} x_i \right) \]

In order to do a fixed-slope curve fit, in other words, in order to calculate \( b \) given \( a \), we differentiate \( D \) with respect to \( b \) and set the result to zero, which yields the equation for \( b \) given above. In order to do a fixed-intercept fit, in other words, in order to calculate \( a \) given \( b \), we differentiate \( D \) with respect to \( a \) and set the result to zero, which produces:

\[ a = \frac{\sum_{i=1}^{n} x_i y_i - b \sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} x_i^2} \]

In all cases, IGPS calculates and displays a measure of the goodness of fit of the particular line through the data points. The measure is known as \( R^2 \) and is defined as:
\[ R^2 = 100 \left( 1 - \frac{D}{\sum_{i=1}^{n} (y_i - \bar{y})^2} \right), \]

where \( D \) is as before and \( \bar{y} \) is the average of \( y_i \), \( i=1,\ldots,n \):

\[ \bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i. \]

From the definition of \( R^2 \), it is apparent that the closer \( R^2 \) is to 100, the better the fit.

The prompts associated with user key number 5 are straightforward and require no discussion.

2.6 User Key Number 6: 4051.

This key is used to plot the current graph on the screen of the Tektronix 4051. If the graph is not complete, in other words, if some item of information needed to construct the graph has not been supplied to IGPS, the program will prompt the user for the missing item.

This key is particularly useful in previewing a plot: the user can look at the plot on the screen by depressing this key; if he doesn't like what he sees, he can use the other keys (or the shortcuts described in section 3) to alter the parameters of the plot; finally, he can depress key number 6 again to quickly see the results of any changes he may have made. Of course, if the user takes no action between depressions of the key, then the plot will be re-drawn on the screen without changes.

Once the user is satisfied with the plot, he can get a copy of it on the Tektronix 4662 x-y plotter by depressing user key number 7.

2.7 User Key Number 7: 4662.

This key is used to obtain a hard copy of the current graph on Tektronix 4662 x-y plotter. Before using this key, the user should prepare the 4662 for plotting by placing a piece of paper in the lower left-hand corner of the plotting area of the 4662. If the piece of paper is 11 inches long and eight and one-half inches high, and if the hardware limits of the 4662 are left at their default values, the plot produced by IGPS will be centered on the piece of paper (see Figure 1.1). To produce plots of different sizes, the user can either change the hardware limits of the 4662 or he can modify the definition of the viewport in IGPS (see the listing of IGPS in Appendix A at lines 6620 through 6660).
IGPS assumes that the 4662 plotter is at address 1 of the GPIB. If the user's 4662 is at a different address, he will need to change line 28 of the program to read

28 \text{D}=

where the new address goes to the right of the equal sign.

2.8 User Key Number 8: Storage and Retrieval.

This key is used to store onto a peripheral or retrieve from a peripheral all the information required to construct a particular plot. This feature is useful in that it allows a complex plot to be saved during one session with IGPS and then quickly reconstructed at a later session without the user having to re-input all the parameters which make up the plot; instead, the entire plot can be recreated by just depressing this one key and responding to a few prompts.

After the user depresses key number 8, IGPS will prompt him for the type of operation to carry out (either storage or retrieval). The user is then prompted for the device he wishes to use. There are three possible responses: one, meaning the 4907 file manager; two, meaning the 4924 Tape Drive; and three, meaning the internal drive. If the user selected the 4907, he is then prompted for the name of the file to use; if he selected the 4924 or the interval tape drive, he is prompted for the number of the file.

If the user attempts to store an incomplete plot, an error message is printed and no further action is taken.

When storing a plot on the 4907, IGPS will create a binary file of the appropriate size for the data to be written; for tape devices, the user must use the MARK command to create the file on his tape. The tape file must be $S$ bytes long, where $S$ is approximately given by the expression

\[ S = 1000 + 16 \cdot n \cdot m_0, \]

where $n$ is the number of data curves in the plot and $m_0$ is the number of points in the curve having the greatest number of points; for instance, storing Figure 1.1 requires approximately 2000 bytes.

The remarks in 2.4d about the address of the 4924 apply here as well.

2.9 User Key Number 9: Data Generation.

This key can be used to generate x axis and y axis data from user-defined parametric functions rather than inputting them from a peripheral or the keyboard.
After the user depresses this key, IGPS will prompt with:

DATA TYPE (1=Y ONLY, 2=X&Y):
NUMBER OF CURVES:
NUMBER OF POINTS PER CURVE (AT LEAST 2):
MIN AND MAX OF PARAMETRIC VARIABLE:

The meaning of the DATA TYPE prompt is as before: a response of 1 is a request to IGPS to sort the y axis data in increasing order and to generate x axis data as cumulative fractions.

IGPS will, after the user responds to the prompts, create the data as

\[ X_{i,j} = F_x[t_0 + S \cdot (j - 1)] \quad \text{and} \quad Y_{i,j} = F_y[t_0 + S \cdot (j - 1)], \]

where \( j = 1, \ldots, m_0 \), \( i = 1, \ldots, n \), \( n \) and \( m_0 \) are the responses to the second and third prompts,

\[ S = \frac{t_1 - t_0}{m_0 - 1}, \]

\( t_0 \) and \( t_1 \) are the minimum and maximum of the parametric variable, and \( F_x \) and \( F_y \) are the user-definable functions. These two functions must be defined by the user before he depresses user key number 9; he must do so by replacing lines 3420 and 3430 in the program with his own functions: line 3420 is for \( F_x \) and must be of the form

3420 DEF FNX(T)=

while line 3430 is for \( F_y \) and must be of the form

3430 DEF FNY(T)=

By default, the definitions are

3420 DEF FNX(T)=RO(I)*SIN(T)
3430 DEF FNY(T)=RO(I)*SIN(T)*COS(T)

where \( RO \) is an array with five entries such that

\[ RO_i = i, \quad i = 1, \ldots, 5. \]
Therefore, if the user does not alter the definitions, and if he uses the following sequence

DATA TYPE (1=Y ONLY, 2=X&Y): 2
NUMBER OF CURVES: 5
NUMBER OF POINTS PER CURVE: 21
MIN AND MAX OF INDEPENDENT VARIABLE: 0, 6.28

then, with appropriate choices of limits, labels, curve types and so on, he should be able to reproduce Figure 2.15.

Figure 2.15 Sample Plot Using Parametric Functions
2.10 User Key Number 10: Menu.

Whenever this key is depressed, IGPS will plot the menu on the screen of the 4051; see Figure 2.1.
3. SHORTCUTS

Suppose you are previewing a plot on the screen of the Tektronix 4051 and you decide to change the type of curve marker being used with one of the curves. One way to do this is to depress user key number 4 and to go through the input procedure; this, however, is clumsy and can be avoided since the variable controlling the type of curve marker is directly available to the user: it is in fact the array LO, with as many entries as there are curves, and with the \( i^{th} \) entry of LO being an integer between one and nine (see Figure 2.14) corresponding to the type of curve marker to be used with the \( i^{th} \) curve. Therefore, to change the type of curve marker for a given curve, the user need only change the entry in LO corresponding to that curve. For instance, to draw the third curve as a solid line, the user should type in LO(3)=4.

The same procedure can be used with any of the features of the plot being previewed. To find out the name of the variable which controls the feature of the plot which you want to change, consult Table 3-4.

**TABLE 3-1 DICTIONARY OF VARIABLES**

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>N1</td>
<td>Simple</td>
<td>Number of entries in X1</td>
</tr>
<tr>
<td>X1(N1)</td>
<td>Array</td>
<td>Locations of x axis tick marks</td>
</tr>
<tr>
<td>N3</td>
<td>Simple</td>
<td>Number of entries in Y1</td>
</tr>
<tr>
<td>Y1(N3)</td>
<td>Array</td>
<td>Locations of y axis tick marks</td>
</tr>
<tr>
<td>N2</td>
<td>Simple</td>
<td>Number of entries in A$</td>
</tr>
<tr>
<td>A$</td>
<td>String</td>
<td>X axis tick mark labels</td>
</tr>
<tr>
<td>N4</td>
<td>Simple</td>
<td>Number of entries in B$</td>
</tr>
<tr>
<td>B$</td>
<td>String</td>
<td>Y axis tick mark labels</td>
</tr>
<tr>
<td>X$</td>
<td>String</td>
<td>X axis label</td>
</tr>
<tr>
<td>Y$</td>
<td>String</td>
<td>Y axis label</td>
</tr>
<tr>
<td>Z$</td>
<td>String</td>
<td>Title of plot</td>
</tr>
</tbody>
</table>

\(^a\) see remarks
<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A0</td>
<td>Simple</td>
<td>Frame type:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 - None</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 - Axes</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 - Grid</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 - Border</td>
</tr>
<tr>
<td>FO</td>
<td>Simple</td>
<td>Color for frame and labels</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(must be integer between one and eight)</td>
</tr>
<tr>
<td>SO</td>
<td>Simple</td>
<td>Pen speed (must be number between 10 and 570)</td>
</tr>
<tr>
<td>pa</td>
<td>Simple</td>
<td>Paper type:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 - linear</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 - Xlog</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 - Ylog</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 - Loglog</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 - User-defined</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 - Uniform probability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 - Normal probability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 - Lognormal probability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 - Rayleigh probability</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10 - Weibull probability</td>
</tr>
<tr>
<td>N</td>
<td>Simple</td>
<td>Number of curves</td>
</tr>
<tr>
<td>MO</td>
<td>Simple</td>
<td>Number of points in the curve with the greatest number</td>
</tr>
<tr>
<td>M(N)</td>
<td>Array</td>
<td>M(I) contains the number of points in the i^th curve</td>
</tr>
<tr>
<td>X(N,MO)</td>
<td>Array</td>
<td>X(I,J) contains the j^th data point in the i^th curve</td>
</tr>
<tr>
<td>Y(N,MO)</td>
<td>Array</td>
<td>Y(I,J) contains the j^th data point in the i^th curve</td>
</tr>
</tbody>
</table>

^a see remarks
### TABLE 3-1  DICTIONARY OF VARIABLES (CONTINUED)

<table>
<thead>
<tr>
<th>Name</th>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO(N)</td>
<td>Array</td>
<td>LO(I) contains the curve type for the $i^{th}$ curve:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1 - Dashed line</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 - Dashed-dotted line</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 - Dotted line</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4 - Solid line</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5 - Crosses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>6 - X-shaped markers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 - Squares</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8 - Triangles</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 - Upside-down triangles</td>
</tr>
<tr>
<td>F$^a$</td>
<td>String</td>
<td>Legends for the $N$ curves</td>
</tr>
<tr>
<td>CO(N)</td>
<td>Array</td>
<td>CO(I) contains the color of the $i^{th}$ curve and legend (must be integer between one and eight)</td>
</tr>
<tr>
<td>C</td>
<td>Simple</td>
<td>Curve fit:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0 - No</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$\neq$0 - Yes</td>
</tr>
<tr>
<td>A(N)$^a$</td>
<td>Array</td>
<td>A(I) contains the slope of the line fit to the $i^{th}$ set of data</td>
</tr>
<tr>
<td>B(N)$^a$</td>
<td>Array</td>
<td>B(I) contains the intercept of the line fit to the $i^{th}$ set of data</td>
</tr>
<tr>
<td>R(N)$^a$</td>
<td>Array</td>
<td>R(I) contains the $R^2$ value associated with the fit to the $i^{th}$ set of data</td>
</tr>
</tbody>
</table>

$^a$ see remarks

### REMARKS:
1. The strings A$ and B$ contain the tick mark labels in compact form, which is to say, A$ consists of N2 labels juxtaposed and separated by pound signs (#). Therefore, the tick mark labels associated with Figure 2.2 could have been created by typing in
N2=5

A$="0.00#0.25#0.05#0.75#1.00#"

2. Changes to the variable P must be followed by the statement
   RUN 4410.

3. Unused entries of the arrays X and Y are zero-filled.

4. F$ contains the N legends in compact form (see remark 1 for a
   definition of compact). The legends in Figure 1.1 could have
   been created by the statement

   F$="MARK I# MARK II#"

5. The contents of the arrays A, B, and R are only meaningful
   if a curve-fit has been performed. Otherwise, they are zero-
   filled.
4. POSTSCRIPT

The author has attempted to make IGPS as useful and versatile as possible and he welcomes recommendations for improving it.
REFERENCE

APPENDIX A
PROGRAM LISTING

SET UP USER-DEFINABLE KEYS AND PROGRAM INITIALIZATION
(NOTE: 4662 ASSUMED AT ADDRESS 1 OF GPIB; SEE LINE 28)

1 GOSUB 9330
2 GO TO 3640
4 GO TO 100
8 GO TO 1310
12 GO TO 4150
16 GO TO 1410
20 GO TO 5560
24 D=32
25 GO TO 6390
28 D=1
29 GO TO 6390
32 GO TO 4920
36 GO TO 3370
40 GO TO 3640

USER KEY 1: SET UP AXIS LIMITS AND LABELS

100 PAGE
110 DELETE X1,Y1
120 AS=""
130 PRINT "UNIFORM TICKS ON THE X-AXIS (1=YES, 2=NO):";
140 INPUT L

SELECT TYPE OF X-AXIS LABELING

150 GO TO L OF 160,400

1.AUTOMATIC X AXIS

160 REM
170 M1=0
180 PRINT "XMIN:";
190 GOSUB 1010
200 D1=VAL(W$)
210 PRINT "XMAX:";
220 GOSUB 1010
230 D2=VAL(W$)
240 PRINT "MAJOR TICKS:";
250 GOSUB 1010
260 D4=VAL(W$)
270 PRINT "MINOR TICKS:";
280 INPUT D3
290 N1=1+INT((D2-D1)/D3)
300 DIM X1(N1)
310 FOR I=1 TO N1
320 X1(I)=D1+(I-1)*D3
330 NEXT I
340 N2=1+INT((D2-D1)/D4)
350 FOR I=D1 TO D2 STEP D4
360 GOSUB 1060
370 A$=A$&W$
380 NEXT I
390 GO TO 540

2. USER-CONTROLLED X AXIS

400 REM
410 PRINT "NUMBER OF TICK MARKS (AT LEAST 2):";
420 INPUT N1
430 DIM X1(N1)
440 PRINT "LOCATION OF TICK MARKS:";
450 INPUT X1
460 PRINT "NUMBER OF TICK MARK LABELS:";
470 INPUT N2
480 IF N2=0 THEN 530
490 PRINT "LOCATION OF TICK MARK LABELS:";
500 INPUT W$
510 GOSUB 1230
520 A$=W$
530 REM
540 REM
550 B$=""
560 PRINT "UNIFORM TICKS ON THE Y-AXIS (1=YES,2=NO):";
570 INPUT L

SELECT TYPE OF Y-AXIS LABELING

580 GO TO L OF 590,830

1. AUTOMATIC Y AXIS

590 REM
600 M1=0
610 PRINT "YMIN:";
620 GOSUB 1010
630 D1=VAL(W$)
640 PRINT "YMAX:";
650 GOSUB 1010
660 D2=VAL(W$)
670 PRINT "MAJOR TICKS:";
680 GOSUB 1010
690 D4=VAL(W$)
700 PRINT "MINOR TICKS:";
710 INPUT D3
720 N3=1+INT((D2-D1)/D3)
730 DIM Y1(N3)
740 FOR I=1 TO N3
750 Y1(I)=D1+(I-1)*D3
760 NEXT I
770 N4=1+INT((D2-D1)/D4)
780 FOR I=D1 TO D2 STEP D4
2. USER-CONTROLLED Y AXIS

ROUTINE TO CALCULATE THE NUMBER OF DIGITS TO THE RIGHT OF DECIMAL POINT

1010 INPUT W$
1020 IF POSCW$","",1)=0 THEN 1040
1030 M1=M1 MAX LEN(W$)-POS(W$","",1)
1040 REM
1050 RETURN

ROUTINE TO CONSTRUCT TICK MARK LABEL WITH A GIVEN NUMBER PLACES, M1, TO THE RIGHT OF THE DECIMAL POINT

1060 W$=STR(ABS(I)*10^-M1)
1070 W$=SEG(W$,2,LEN(W$)-1)
1080 IF M1=0 THEN 1170
1090 IF M1<=LEN(W$) THEN 1120
1100 U$=SEG("0000000000",1,M1-LEN(W$))
1110 W$=U$&W$
1120 REM
1130 W$=REP(".",LEN(W$)-M1+1,0)
1140 IF ABS(I)>1 THEN 1160
1150 W$=REP("0",1,0)
1160 REM
1170 REM
1180 IF I=>0 THEN 1200
1190 W$=REP("-",1,0)
1200 REM
1210 W$=W$&"#"
1220 RETURN

ROUTINE TO REPLACE BLANKS OR COMMAS WITH POUND SIGNS (#)

1230 FOR I=1 TO LEN(W$)
1240   U$=SEG(W$,I,1)
1250   IF U$<>" " AND U$<>"" THEN 1270
1260       W$=REP(" ",I,1)
1270   REM
1280 NEXT I
1290 W$=W$&"
1300 RETURN

USER KEY 2: INPUT TITLES

1310 PAGE
1320 PRINT "X-AXIS LABEL: ";
1330 INPUT XS
1340 PRINT "Y-AXIS LABEL: ";
1350 INPUT YS
1360 PRINT "PLOT TITLE: ";
1370 INPUT ZS
1380 K(2)=1
1390 PAGE
1400 RETURN

USER KEY 4: INPUT AND OUTPUT OF DATA

1410 PAGE
1420 PRINT "INPUT (1) OR SAVE (2): ";
1430 INPUT L
1440 PRINT "DATA TYPE (1=Y ONLY, 2=X&Y): ";
1450 INPUT NO

BRANCH ON WHETHER INPUT OR OUTPUT

1460 GO TO L OF 1470, 2110
1470 REM
1480 PRINT "UNIT NUMBER (1=4907, 2=4924, 3=INTERNAL TAPE, 4=KEYBOARD): ";
1490 INPUT L
1500 PRINT "NUMBER OF CURVES: ";
1510 INPUT N
1520 PRINT "MAXIMUM NUMBER OF POINTS PER CURVE: ";
1530 INPUT M0
1540 DELETE X, Y, M
1550 DIM X(N,M0), Y(N,M0), M(N)
1560 X=0
1570 Y=0
1580 FOR I=1 TO N

56
BRANCH ON DEVICE TYPE

1590 GO TO 1*(L=1)+2*(L=2 OR L=3)+3*(L=4) OF 1600,1760,1920

1. INPUT FROM 4907 FILE MANAGER

1600 REM
1610 PRINT "FILE NAME FOR CURVE NUMBER ";I;" : ";
1620 INPUT W$
1630 OPEN W$;1,"R",U$
1640 INPUT #1:M(I)
1650 FOR J=1 TO M(I)
1660 GO TO NO OF 1670,1700
1670 REM
1680 INPUT #1:Y(I,J)
1690 GO TO 1720
1700 REM
1710 INPUT #1:X(I,J),Y(I,J)
1720 REM
1730 NEXT J
1740 CLOSE 1
1750 GO TO 2070

2. INPUT FROM 4924 TAPE DRIVE OR INTERNAL DRIVE
(NOTE: 4924 ASSUMED AT ADDRESS 2 OF GPIB; SEE LINE 9350)

1760 REM
1770 PRINT "FILE NUMBER FOR CURVE NUMBER ";I;" : ";
1780 INPUT D1
1790 D=D0*(L=2)+33*(L=3)
1800 FIND @D:D1
1810 INPUT @D:M(I)
1820 FOR J=1 TO M(I)
1830 GO TO NO OF 1840,1870
1840 REM
1850 INPUT @D:Y(I,J)
1860 GO TO 1890
1870 REM
1880 INPUT @D:X(I,J),Y(I,J)
1890 REM
1900 NEXT J
1910 GO TO 2070

3. INPUT FROM KEYBOARD

1920 REM
1930 PAGE
1940 PRINT "NUMBER OF POINTS IN CURVE NUMBER ";I;" : ";
1950 INPUT M(I)
1960 FOR J=1 TO M(I)
1970 GO TO NO OF 1980,2020
1980 REM
1990 PRINT "Y(";I;",";J;") : ";
2000 INPUT Y(I,J)

57
2010     GO TO 2050
2020     REM
2030     PRINT "X(";I",";J");Y(";I",";J");"
2040     INPUT X(I,J),Y(I,J)
2050     REM
2060     NEXT J
2070     REM
2080     NEXT I
2090     GOSUB 2650
2100     GO TO 2630
2110     REM
2120     IF K(4)=0 THEN 2570
2130     PRINT "UNIT NUMBER (1=4907, 2=4924, 3=INTERNAL TAPE):"
2140     INPUT L
2150     FOR I=1 TO N
2160     GO TO 1*(L=1)+2*(L=2 OR L=3) OF 2170, 2350

1. OUTPUT TO 4907 FILE MANAGER

2170     REM
2180     PRINT "FILE NAME FOR CURVE NUMBER ";I;":"
2190     INPUT WS
2200     KILL WS
2210     CREATE WS,"A";19+(19*(N0=1)+37*(N0=2))*M(I),0
2220     OPEN WS;1,"F",US
2230     PRINT #1:M(I)
2240     FOR J=1 TO M(I)
2250     GO TO NO OF 2260, 2290
2260     REM
2270     PRINT #1:Y(I,J)
2280     GO TO 2310
2290     REM
2300     PRINT #1:X(I,J),Y(I,J)
2310     REM
2320     NEXT J
2330     CLOSE 1
2340     GO TO 2530

2. OUTPUT TO 4924 TAPE DRIVE OR INTERNAL DRIVE
   (NOTE: 4924 ASSUMED AT ADDRESS 2 OF GPIB; SEE LINE 9350)

2350     REM
2360     PRINT "FILE NUMBER FOR CURVE NUMBER ";I;":"
2370     INPUT Dl
2380     D=D0*(L=2)+33*(L=3)
2390     KILL @D:DL
2400     FIND @D:DL
2410     PRINT @D:M(I)
2420     FOR J=1 TO M(I)
2430 GO TO NO OF 2440,2470
2440 REM
2450 PRINT @D:Y(I,J)
2460 GO TO 2490
2470 REM
2480 PRINT @D:X(I,J),Y(I,J)
2490 REM
2500 NEXT J
2510 PRINT @D,2:
2520 NEXT I
2530 PAGE
2540 PRINT @32,21:35,50
2550 PRINT "NO INPUT YET--NOTHING TO SAVE"
2560 HOME
2570 REM
2580 PAGE
2590 PRINT @32,21:35,50
2600 PRINT "INPUT CURVE TYPES"
2610 PAGE
2620 PRINT "CURVE TYPES AVAILABLE:
"2630 PRINT "1.DASHED LINE"
2640 PRINT "2.DASHED-DOTTED LINE"
2650 PRINT "3.DOTTED LINE"
2660 PRINT "4.SOLID LINE"
2670 PRINT "5.CROSSES"
2680 PRINT "6.X'S"
2690 PRINT "7.SQUARES"
2700 PRINT "8.TRIANGLES"
2710 PRINT "9.FLASHES"
2720 PRINT
2730 DELETE L0,C0,A,B,R
2740 DIM L0(N),C0(N),A(N),B(N),R(N)
2750 A=0
2760 B=0
2770 C=0
2780 FOR I=1 TO N
2790 PRINT "TYPE FOR CURVE NUMBER ";I;":"
2800 INPUT L0(I)
2810 NEXT I
2820 PRINT "INPUT LEGENDS"
2830 PAGE
2840 P$=""
FOR I=1 TO N
PRINT "LEGEND FOR CURVE NUMBER ";I;": ";
INPUT W$ 
F$=F$&W$
F$=F$&"#"
NEXT I

INPUT COLORS

PAGE
FOR I=1 TO N
PRINT "COLOR FOR CURVE NUMBER ";I;": ";
INPUT C0(I)
NEXT I

GENERATE X-AXIS DATA IF REQUESTED

IF N0=2 THEN 3330
FOR I=1 TO N 
FOR J=1 TO M(I)
X(I,J)=100*J/(1+M(I))
NEXT J
NEXT I

SORT Y-AXIS DATA IF REQUESTED (USES BUBBLE SORT)

IF M(I)<=1 THEN 3310
FOR J=2 TO M(I)
IF Y(I,J-1)<=Y(I,J) THEN 3290
D1=Y(I,J)
L=J+1
D2=1
REM 
L=L-1
IF L=1 THEN 3240
IF Y(I,L-1)<=D1 THEN 3190
Y(I,L)=Y(I,L-1)
GO TO 3220
REM 
Y(I,L)=D1
D2=0 
REM 
GO TO 3270
REM 
Y(I,1)=D1
D2=0
REM 
IF D2 THEN 3130
REM 
NEXT J
NEXT I
USER KEY 9: GENERATE DATA FROM FUNCTIONS

3340 \texttt{K(4)=1}
3350 \texttt{PAGE}
3360 \texttt{RETURN}

DEFINE FUNCTIONS

3420 \texttt{DEF \texttt{FNX}(T)=R0(I) \times \texttt{SIN}(T)}
3430 \texttt{DEF \texttt{FNY}(T)=R0(I) \times \texttt{SIN}(T) \times \texttt{COS}(T)}
3440 \texttt{PRINT \"DATA TYPE (1=Y ONLY, 2=X&Y):\"};
3450 \texttt{INPUT NO}
3460 \texttt{PRINT \"NUMBER OF CURVES:\"};
3470 \texttt{INPUT N}
3480 \texttt{PRINT \"NUMBER OF POINTS PER CURVE (AT LEAST 2):\"};
3490 \texttt{INPUT M0}
3500 \texttt{DELETE X,Y,M}
3510 \texttt{DIM X(N,M0),Y(N,M0),M(N)}
3520 \texttt{M=M0}
3530 \texttt{PRINT \"MIN AND MAX OF PARAMETRIC VARIABLE:\"};
3540 \texttt{INPUT T0,T1}
3550 \texttt{S=(T1-T0)/(M0-1)}

GENERATE DATA (NOTE: I INDEXES THE CURVES, J THE POINTS)

3560 \texttt{FOR I=1 TO N}
3570 \texttt{   FOR J=1 TO M0}
3580 \texttt{     X(I,J)=\text{FNX}(T0+S*(J-1))}
3590 \texttt{     Y(I,J)=\text{FNY}(T0+S*(J-1))}
3600 \texttt{   NEXT J}
3610 \texttt{NEXT I}
3620 \texttt{GOSUB 2650}
3630 \texttt{RETURN}

USER KEY 10: DRAW MENU

USER KEY 10: DRAW MENU

3640 \texttt{D=32}
3650 \texttt{PAGE @D:}
3660 \texttt{DIM K$}(80)
3670 \texttt{K$=\"LIMITS LABELS FORMAT IO FITS \"
3680 \texttt{K$=K$ \&\" 4051 4662 S&R FUNCTION MENU \"
3690 \texttt{L=60}
3700 \texttt{D2=L}
3710 \texttt{FOR J=1 TO 2}
3720 \texttt{D1=-4}
3730 \texttt{FOR I=1 TO 5}
USER KEY 3: FORMAT DEFINITION

4150 PAGE
4160 PRINT "FRAME TYPE (0=None, 1=AXES, 2=GRID, 3=BORDER):";
4170 INPUT A0
4180 PRINT "COLOR FOR FRAME AND LABELS (1-8):";
4190 INPUT F0
4200 PRINT "PEN SPEED (10-570 MM/S):";
4210 INPUT S0
4220 PRINT " PAPER TYPES: X-AXIS Y-AXIS"
4240 PRINT
4250 PRINT " 1. LINEAR: X  Y"
4260 PRINT " 2. XLOG: LOG(X) X  Y"
4270 PRINT " 3. YLOG: LOG(X) Y"
4280 PRINT " 4. LOGLOG: LOG(X) LOG(Y)"
4290 PRINT " 5. USER: ? ?"
4300 PRINT " 6. UNIFORM: X/100 Y"
4310 PRINT " 7. NORMAL: N(X/100) Y"
4320 PRINT " 8. LOGNORMAL: N(X/100) LOG(Y)"
4330 PRINT " 9. RAYLEIGH: SQR(-2*LOG(1-X/100)) Y"
4340 PRINT "10. WEIBULL: LOG(-LOG(1-X/100)) LOG(Y)"
4350 PRINT
4360 PRINT "PAPER TYPE:"
4370 INPUT P
4380 GOSUB 4410
4390 K(3)=1
4400 RETURN

BRANCH ON PAPER TYPE SELECTED FOR FUNCTION DEFINITION

4410 GO TO P OF 4420, 4460, 4500, 4540, 4580, 4620, 4660, 4740, 4820, 4860
4420 REM
4430 DEF FNA(X)=X
4440 DEF FNB(Y)=Y
4450 GO TO 4890
4460 REM
4470 DEF FNA(X)=LOG(X)
4480 DEF FNB(Y)=Y
4490 GO TO 4890
4500 REM
4510 DEF FNA(X)=X
4520 DEF FNB(Y)=LOG(Y)
4530 GO TO 4890
4540 REM
4550 DEF FNA(X)=LOG(X)
4560 DEF FNB(Y)=LOG(Y)
4570 GO TO 4890
4580 REM
4590 DEF FNA(X)=X
4600 DEF FNB(Y)=Y
4610 GO TO 4890
4620 REM
4630 DEF FNA(X)=X/100
4640 DEF FNB(Y)=Y
4650 GO TO 4890
4660 REM
4670 DEF FNA(X)=FNC((1-X/100)*(X>50)+X/100*(X<=50))
4680 DEF FNC(X)=FND(X)-FNE(FND(X))/FNF(FND(X))
4690 DEF FND(X)=SQR(LOG(1/X*X))
4700 DEF FNE(X)=2.515517+(0.802853+0.010328*X)*X
4710 DEF FNF(X)=1+(1.432788+(0.189269+0.001308*X)*X)*X
4720 DEF FNB(Y)=Y
4730 GO TO 4890
4740 REM

63
4750 DEF FNA(X)=FNC((1-X/100)*(X>50)+X/100*(X<=50))*((X>50)-(X<=50))
4760 DEF FNC(X)=FND(X)-FNE(FND(X))/FNF(FND(X))
4770 DEF FND(X)=SQR(LOG(1/(X*X)))
4780 DEF FNE(X)=2.515517+(0.802853+0.010328*X)*X
4790 DEF FNF(X)=1+(0.432788+(0.189269+0.001308*X)*X)*X
4800 DEF FNB(Y)=LOG(Y)
4810 GO TO 4890
4820 REM
4830 DEF FNA(X)=SQR(-2*LOG(1-X/100))
4840 DEF FNB(Y)=Y
4850 GO TO 4890
4860 REM
4870 DEF FNA(X)=LOG(-LOG(1-X/100))
4880 DEF FNB(Y)=LOG(Y)
4890 REM
4900 PAGE
4910 RETURN

USER KEY 8: STORE AND RETRIEVE PLOTS

4920 PAGE
4930 PRINT "STORE (1) OR RETRIEVE (2):";
4940 INPUT L
4950 PRINT "UNIT NUMBER (1=4907, 2=4924, 3=INTERNAL TAPE):";
4960 INPUT D1

BRANCH ON STORAGE OR RETRIEVAL

4970 GO TO L OF 4980,5310
4980 REM
4990 IF SUM(K)<>5 THEN 5240

BRANCH ON DEVICE TYPE

5000 GO TO 1*(D1=1)+2*(D1=2 OR D1=3) OF 5010,5110

1. STORAGE ON 4907 FILE MANAGER

5010 REM
5020 PRINT "FILE NAME:";
5030 INPUT W$
5040 KILL W$
5050 CREATE W$;845+8*(N1+N3+N*(2*M0+5)),0
5060 OPEN W$;1,"F",U$
5070 WRITE #1:N1,N2,N3,N4,A$,B$,X$,Y$,Z$,N,M0,F$,A0,F0,S0,P,C
5080 WRITE #1:X1,Y1,X,Y,M,L0,C0,A,B
5090 CLOSE 1
5100 GO TO 5210
2. STORAGE ON 4924 TAPE DRIVE OR INTERNAL DRIVE
(NOTE: 4924 ASSUMED AT ADDRESS 2 OF GPIB; SEE LINE 9350)

5110 REM
5120 PRINT "FILE NUMBER:";
5130 INPUT D2
5140 D=D0*(D1=2)+33*(D1=3)
5150 KILL @D:D2
5160 FIND @D:D2
5170 WRITE @D:N1,N2,N3,N4,A$,$B,$,$X,$,$Y,$,$Z,$,$N,$,$M0,$,$F$,,$A0,$,$F0,$,$S0,$,$P,$,$C$
5180 WRITE @D:X1,Y1,X,Y,M,L0,C0,A,B
5190 PRINT @D:2:
5200 CLOSE
5210 REM
5220 PAGE
5230 GO TO 5290

ERROR MESSAGE IF STORAGE ATTEMPTED BEFORE PLOT IS READY

5240 REM
5250 PAGE
5260 PRINT @32,21:30,50
5270 PRINT "PLOT NOT COMPLETE--NOT STOREABLE"
5280 HOME
5290 REM
5300 GO TO 5540
5310 REM
5320 DELETE X1,Y1,X,Y,M,L0,C0,A,B,R

BRANCH ON DEVICE TYPE

5330 GO TO 1*(D1=1)+2*(D1=2 OR D1=3) OF 5340,5430

1. RETRIEVAL FROM 4907 FILE MANAGER

5340 REM
5350 PRINT "FILE NAME:";
5360 INPUT W$
5370 OPEN W$;1,"R",US$
5380 READ #1:N1,N2,N3,N4,A$,,$B$,,$X$,,$Y$,,$Z$,,$N$,,$M0$,,$F$,,$A0$,,$F0$,,$S0$,,$P$,,$C$
5390 DIM X1(N1),Y1(N3),X(N,M0),Y(N,M0),M(N),L0(N),C0(N),A(N),B(N),R(
5400 READ #1:X1,Y1,X,Y,M,L0,C0,A,B
5410 CLOSE 1
5420 GO TO 5510

2. RETRIEVAL FROM 4924 TAPE DRIVE OR INTERNAL DRIVE (NOTE: 4924 ASSUMED AT ADDRESS 2 OF GPIB; SEE LINE 9350)

5430 REM
5440 PRINT "FILE NUMBER:";
5450 INPUT D2
5460 D=D0*(D1=2)+33*(D1=3)
USER KEY 5: CURVE FITS

TRANSFORM DATA VIA FUNCTIONS DEFINING PAPER TYPE

BRANCH ON CURVE FIT SELECTED
CALCULATE R-SQUARE

6060  Z0=SUM(Y0)/M(I)
6070  Z0=Y0-Z0
6080  Z0=Z0*Z0
6090  R(I)=1/SUM(Z0)
6100  Z0=A(I)*X0
6110  Z0=B(I)+Z0
6120  Z0=Z0-Z0
6130  Z0=Z0*Z0
6140  R(I)=100*(1-SUM(Z0)*R(I))
6150  NEXT I

PRINT OUT RESULTS OF CURVE FITS

6160  PAGE
6170  FOR I=1 TO (34-(N+3))/2
6180    PRINT
6190  NEXT I
6200  PRINT USING "8X,4(10A,5X)
6210  IMAGE 8X,4(10A,5X)
6220  PRINT
6230  FOR I=1 TO N
6240    PRINT USING "8X,5X,2D,3X,3(5X,7D.2D)":I,A(I),B(I),R(I)
6250  NEXT I
6260  HOME
6270  GO TO 6300
6280  REM
6290  PAGE
6300  REM
6310  K(5)=1
6320  GO TO 6370

ERROR MESSAGE IF FIT ATTEMPTED BEFORE DATA INPUT

6330  REM
6340  PRINT @32,21:25,50
6350  PRINT "NO DATA INPUT YET--CURVE FIT IMPOSSIBLE"
6360 HOME
6370 REM
6380 RETURN

USER KEYS 6 AND 7: PLOT ON 4051 OR 4662

6390 PAGE @D:

CHECK FOR MISSING PLOT PARAMETERS

6400 IF K(1) THEN 6420
6410 GOSUB 100
6420 REM
6430 IF K(2) THEN 6450
6440 GOSUB 1310
6450 REM
6460 IF K(3) THEN 6480
6470 GOSUB 4150
6480 REM
6490 IF K(4) THEN 6510
6500 GOSUB 1410
6510 REM
6520 IF K(5) THEN 6540
6530 GOSUB 5560
6540 REM

SELECT PEN COLOR AND SPEED

6550 PRINT @D,8:F0
6560 PRINT @D,32:"BY";S0

DEFINE WINDOW IN UDU'S

6570 U1=FNA(X1(1))
6580 U2=FNA(X1(N1))
6590 U3=FNB(Y1(1))
6600 U4=FNB(Y1(N3))
6610 WINDOW U1,U2,U3,U4

DEFINE VIEWPORT IN GDU'S

D1 = HORIZONTAL LOCATION OF LOWER-LEFT CORNER
D2 = HORIZONTAL EXTENT
D3 = VERTICAL LOCATION OF LOWER-LEFT CORNER
D4 = VERTICAL EXTENT

6620 D1=26*(D<>32)+40*(D=32)
6630 D2=45*(D<>32)+60*(D=32)
6640 D3=15*(D<>32)+20*(D=32)
6650 D4=45*(D<>32)+60*(D=32)
6660 VIEWPORT D1,D1+D2,D3,D3+D4
CALCULATE SCALES AND TICK LENGTHS

6670 X2=(U2-U1)/D2
6680 Y2=(U4-U3)/D4
6690 X3=X2*(D2 MAX D4)/75
6700 Y3=Y2*(D2 MAX D4)/75

DEFINE DEFAULT HARDWARE CHARACTER SIZES

6710 C1=1.792*(D<>32)+1.79*(D=32)
6720 C2=1.195*(D<>32)+1.195*(D=32)
6730 C3=2.816*(D<>32)+2.6*(D=32)
6740 C4=1.721*(D<>32)+2.2*(D=32)

DEFINE RELATIVE CHARACTER SIZES FOR TICK MARK LABELS, AXIS LABELS, PLOT TILE, AND LEGENDS

6750 S1=0.8*(D<>32)+1*(D=32)
6760 S2=1*(D<>32)+1*(D=32)
6770 S3=0.7*(D<>32)+1*(D=32)

DEFINE OFFSETS FOR AXIS LABELS AND PLOT TITLE

6780 F1=7*(D<>32)+10*(D=32)
6790 F2=10*(D<>32)+14*(D=32)
6800 F3=7*(D<>32)+9*(D=32)

BRANCH ON FRAME TYPE (ZERO MEANS NO FRAME OR LABELS)

6810 IF A0=0 THEN 8060
6820 GO TO A0 OF 6830, 6990, 7190

1. DRAW AXES

6830 REM
6840 MOVE @D:U1,U4
6850 FOR I=N3 TO 2 STEP -1
6860 D2=FNB(Y1(I))
6870 DRAW @D:U1,D2
6880 DRAW @D:D1,U3+Y3
6890 NEXT I
6900 NEXT I
6910 DRAW @D:U1,U3
6920 FOR I=2 TO N1
6930 D1=FNA(X1(I))
6940 DRAW @D:D1,U3
6950 DRAW @D:D1,U3+Y3
6960 NEXT I
6970 NEXT I
6980 GO TO 7570
2. DRAW GRID

6990 REM
7000 MOVE @D:U1,U3
7010 DRAW @D:U1,U4
7020 D2=U4
7030 FOR I=2 TO N1
7040 D1=FNA(X1(I))
7050 DRAW @D:D1,D2
7060 D2=U3*(D2=U4)+U4*(D2=U3)
7070 DRAW @D:D1,D2
7080 NEXT I
7090 DRAW @D:U2,U3
7100 DRAW @D:U1,U3
7110 D1=U1
7120 FOR I=2 TO N3
7130 D2=FNB(Y1(I))
7140 DRAW @D:D1,D2
7150 D1=U1*(D1=U2)+U2*(D1=U1)
7160 DRAW @D:D1,D2
7170 NEXT I
7180 GO TO 7570

3. DRAW BORDER

7190 REM
7200 MOVE @D:U1,U3
7210 IF N1=2 THEN 7280
7220 FOR I=2 TO N1-1
7230 D1=FNA(X1(I))
7240 DRAW @D:D1,U3
7250 DRAW @D:D1,U3+Y3
7260 DRAW @D:D1,U3
7270 NEXT I
7280 REM
7290 DRAW @D:U2,U3
7300 IF N3=2 THEN 7370
7310 FOR I=2 TO N3-1
7320 D2=FNB(Y1(I))
7330 DRAW @D:U2,D2
7340 DRAW @D:U2-X3,D2
7350 DRAW @D:U2,D2
7360 NEXT I
7370 REM
7380 DRAW @D:U2,U4
7390 IF N1=2 THEN 7460
7400 FOR I=N1-1 TO 2 STEP -1
7410 D1=FNA(X1(I))
7420 DRAW @D:D1,U4
7430 DRAW @D:D1,U4-Y3
7440 DRAW @D:D1,U4
7450 NEXT I
7460 REM
7470 DRAW @D:U1,U4
7480 IF N3=2 THEN 7550
7490 FOR I=N3-1 TO 2 STEP -1
7500 D2=FNB(Y1(I))
7510 DRAW @D:U1,D2
7520 DRAW @D:U1+X3,D2
7530 DRAW @D:U1,D2
7540 NEXT I
7550 REM
7560 DRAW @D:U1,U3
7570 REM

PRINT X-AXIS LABEL

7580 PRINT @D,17:S1*C1,S1*C3
7590 PRINT @D,25:0
7600 MOVE @D:U1+U2-S1*X2*(C1*(LEN(X$)-1)+C2))/2,U3-F1*Y2
7610 PRINT @D:X$

PRINT Y-AXIS LABEL

7620 IF D=32 THEN 7670
7630 PRINT @D,25:90
7640 MOVE @D:U1-(F2-S1*C4)*X2,(U3+U4-S1*Y2*(C1*(LEN(Y$)-1)+C2))/2
7650 PRINT @D:Y$
7660 GO TO 7730
7670 REM
7680 FOR I=1 TO LEN(Y$)
7690 MOVE U1-F2*X2,(U3+U4+Y2*S1*(C3*(LEN(Y$)-1)+C4))/2-Y2*(C4+C3*(I-1))
7700 WS=SEG(Y$,I,1)
7710 PRINT WS
7720 NEXT I
7730 REM

PRINT AND UNDERLINE PLOT TITLE

7740 IF LEN(Z$)=0 THEN 7830
7750 PRINT @D,17:S2*C1,S2*C3
7760 PRINT @D,25:0
7770 MOVE @D:U1+U2-S2*X2*(C1*(LEN(Z$)-1)+C2))/2,U4+F3*Y2
7780 PRINT @D:Z$
7790 MOVE @D,21:(U1+U2+S2*X2*(C1*(LEN(Z$)-1)+C2))/2,U4+(F3-0.2*S2*C3)*Y2
7800 MOVE @D,20:(U1+U2-S2*X2*(C1*(LEN(Z$)-1)+C2))/2,U4+(F3-0.2*S2*C3)*Y2
7810 MOVE @D,21:(U1+U2-S2*X2*(C1*(LEN(Z$)-1)+C2))/2,U4+(F3-0.4*S2*C3)*Y2
7820 MOVE @D,20:(U1+U2+S2*X2*(C1*(LEN(Z$)-1)+C2))/2,U4+(F3-0.4*S2*C3)*Y2
7830 REM
7840 PRINT @D,17:S3*C1,S3*C3
7850 PRINT @D,25:0

PRINT TICK MARK LABELS ON X AXIS

7860 IF N2=0 THEN 7950
7870 US=AS
7880 FOR I=1 TO N2
7890 WS=SEG(US,1,POS(US,"#"),1)-1)
US=SEG(U$ , POS(U$, "#", 1) + 1, LEN(U$) - POS(U$, "#", 1))
D1=FNB(VAL(W$))
MOVE @D:D1-S3*X2*(C1*(LEN(W$)-1)+C2)/2 , U3-S3*Y2*(1.25*C4)
PRINT @D:W$
NEXT I

PRINT TICK MARK LABELS ON Y AXIS

IF N4=0 THEN 8050
FOR I=1 TO N4
WS=SEG(U$, 1, POS(U$, "#", 1)-1)
US=SEG(U$, POS(U$, "#", 1)+1, LEN(U$)-POS(U$, "#", 1))
D1=FNB(VAL(W$))
MOVE @D:U1-S3*X2*(C1*LEN(W$)-0.2*(C1-C2)),D1-S3*Y2*(1.125*C4)/2
PRINT @D:W$
NEXT I
REM
PRINT @D,17:S3*C1,S3*C3
PRINT @D,25:0
US=F$

LOOP OVER N DATA CURVES

FOR I=1 TO N

1. SELECT COLOR FOR I' TH CURVE
PRINT @D,8:C0(I)

2. BRANCH ON CURVE TYPE
GO TO 1*(LO(I)<=3)+2*(LO(I)=4)+3*(LO(I)>=5) OF 8130,8710,8810

2. A DASHED LINES (CURVE TYPE 1 THROUGH 3)

2. A.1 LOAD IN DASHED LINE PARAMETERS (IN GDU'S)
(NO T E : 1'ST DASHED LINE HAS 3 ELEMENTS,
2' ND HAS 5, 3' RD HAS 3)

RESTORE 8160
DATA 3,0.2,0.6,0.2,5,0.2,0.6,0.01,0.6,0.2,3,0.005,0.6,0.005
FOR J=1 TO LO(I)
READ L
DELETE P0
DIM P0(L)
READ P0
NEXT J
2.A.2 TRANSFORM DATA

8230 DELETE X0,Y0
8240 DIM X0(M(I)),Y0(M(I))
8250 FOR J=1 TO M(I)
8260 X0(J)=FNA(X(I,J))
8270 Y0(J)=FNB(Y(I,J))
8280 NEXT J

2.A.3 CALCULATE CURVE LENGTH IN GDU'S

8290 T0=0
8300 FOR J=2 TO M(I)
8310 T0=T0+SQR(((X0(J)-X0(J-1))/X2)^2+((Y0(J)-Y0(J-1))/Y2)^2)
8320 NEXT J

2.A.4 CALCULATE ADJUSTED DASHED LINE PARAMETERS

8330 M1=1 MAX INT(T0/SUM(P0)+0.5)
8340 P0=T0/(M1*SUM(P0))*P0

2.A.5 MOVE TO START OF CURVE

8350 J=1
8360 D1=X0(J)
8370 D2=Y0(J)
8380 MOVE @D:D1,D2

2.A.6 LOOP OVER M1 PATTERNS AND L ELEMENTS IN EACH PATTERN

8390 FOR I1=1 TO M1
8400 FOR J1=1 TO L
8410 D3=0
8420 D4=0
8430 REM

2.A.7 CALCULATE DISTANCE TO NEXT DATA POINT; IF GREATER THAN PATTERN ELEMENT, INTERPOLATE TO FIND WHERE TO GO AND SET FLAG TO INDICATE DONE WITH ELEMENT--IF LESS, GO TO NEXT DATA POINT

8440 D5=(X0(J+1)-D1)/X2
8450 D6=(Y0(J+1)-D2)/Y2
8460 D7=SQR(D5^2+D6^2)
8470 IF D4+D7=>P0(J1) THEN 8530
8480 J=J+1
8490 D1=X0(J)
8500 D2=Y0(J)
8510 D4=D4+D7
8520 GO TO 8590
8530 REM
8540 IF D7<=1.0E-4 THEN 8570
\begin{verbatim}
8550  D1=D1+X2*(P0{J1)-D4)*D5/D7
8560  D2=D2+Y2*(P0{J1)-D4)*D6/D7
8570  REM
8580  D3=1
8590  REM
8600  2.A.8 IF EVEN-NUMBERED ELEMENT BEING PROCESSED,
8610     MOVE; IF ODD-NUMBERED, DRAW
8620     IF J1=2*INT(J1/2) THEN 8630
8630     DRAW @D:D1,D2
8640     GO TO 8650
8650  REM
8660  2.A.9 TEST IF DONE WITH CURRENT ELEMENT
8670     IF D3<>1 THEN 8430
8680     NEXT J1
8690     NEXT I1
8700  GO TO 9180
8710  REM
8720  2.B SOLID LINE (CURVE TYPE 4)
8730  D1=FNA(X(I,1))
8740  D2=FNB(Y(I,1))
8750  MOVE @D:D1,D2
8760  FOR J=1 TO M(I)
8770     D1=FNA(X(I,J))
8780     D2=FNB(Y(I,J))
8790  NEXT J
8800  GO TO 9180
8810  REM
8820  FOR J=1 TO M(I)
8830     D1=FNA(X(I,J))
8840     D2=FNB(Y(I,J))
8850  GO TO L0(I)-4 OF 8860,8920,8980,9050,9110
8860  REM
8870  2.C SYMBOLS (CURVE TYPES 5 THROUGH 9)
8880     FOR J=1 TO M(I)
8890       D1=FNA(X(I,J))
8900       D2=FNB(Y(I,J))
8910       GO TO L0(I)-4 OF 8860,8920,8980,9050,9110
8920  REM
8930  2.C.1 CROSSES
8940     MOVE @D:D1+1.5*X3,D2
8950     DRAW @D:D1-1.5*X3,D2
8960     MOVE @D:D1,D2-1.5*Y3
8970     DRAW @D:D1,D2+1.5*Y3
8980  GO TO 9160
8990  GO TO 9180
\end{verbatim}
2.C.2 X-SHAPED

REM
MOVE @D:D1+X3,D2+Y3
DRAW @D:D1-X3,D2-Y3
MOVE @D:D1-X3,D2+Y3
DRAW @D:D1+X3,D2-Y3
GO TO 9160

2.C.3 SQUARES

REM
MOVE @D:D1-X3,D2-Y3
DRAW @D:D1-X3,D2+Y3
DRAW @D:D1+X3,D2+Y3
DRAW @D:D1-DX3,D2-Y3
DRAW @D:D1+X3,D2-Y3
GO TO 9160

2.C.4 TRIANGLES

REM
MOVE @D:D1,D2+2*Y3/SQR(3)
DRAW @D:D1+X3,D2-Y3/SQR(3)
DRAW @D:D1-X3,D2-Y3/SQR(3)
DRAW @D:D1/D2+2*Y3/SQR(3)
GO TO 9160

2.C.5 UPSIDE-DOWN TRIANGLES

REM
MOVE @D:D1,D2-2*Y3/SQR(3)
DRAW @D:D1-X3,D2+Y3/SQR(3)
DRAW @D:D1+X3,D2+Y3/SQR(3)
DRAW @D:D1,D2-2*Y3/SQR(3)
REM
NEXT J
REM

3. PRINT LEGEND FOR I'TH CURVE

WS=SEG(U$,1,POS(U$,"#",1)-1)
US=SEG(U$,POS(U$,"#",1)+1,LEN(U$)-POS(U$,"#",1))
D1=FNA(X(I,M(I)))
D2=FNB(Y(I,M(I)))
MOVE @D:D1+3*X3,D2-0.5*S3*Y2*(1.125*C4)
PRINT @D:W$

4. PLOT CURVE FIT IF REQUIRED

IF C=0 THEN 9280
MOVE @D:U1,A(I)*U1+B(I)
DRAW @D:U2,A(I)*U2+B(I)
9280 REM
9290 NEXT I

RETURN PEN TO HOLDER AND EXIT

9300 PRINT @D,8:0
9310 HOME @D:
9320 RETURN

INITIALIZATION ROUTINE

ARRAY K IS USED TO KEEP TRACK OF WHICH USER KEYS
HAVE BEEN DEPRESSED; LINE 9350 DEFINES THE ADDRESS OF
THE 4924 TAPE DRIVE

9330 DIM K(5),R$(1)
9340 R$=REP("",1,0)
9350 D0=2
9360 IF LEN(R$)>0 THEN 9390
9370 K=0
9380 R$=" "
9390 REM
9400 RETURN
<table>
<thead>
<tr>
<th>No. of Copies</th>
<th>Organization</th>
<th>No. of Copies</th>
<th>Organization</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>Commander</td>
<td>5</td>
<td>Commander</td>
</tr>
<tr>
<td></td>
<td>US Army Materiel Development and</td>
<td></td>
<td>US Army Armament Research</td>
</tr>
<tr>
<td></td>
<td>Readiness Command</td>
<td></td>
<td>and Development Command</td>
</tr>
<tr>
<td></td>
<td>ATTN: DRCDM-S</td>
<td></td>
<td>ATTN: DRDAR-SE</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRCDE-SD</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRCDE-SA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>5001 Eisenhower Avenue</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alexandria, VA 22333</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Commander</td>
<td>2</td>
<td>Commander</td>
</tr>
<tr>
<td></td>
<td>Defense Technical Information</td>
<td>1</td>
<td>US Army Aviation Research</td>
</tr>
<tr>
<td></td>
<td>Center</td>
<td></td>
<td>and Development Command</td>
</tr>
<tr>
<td></td>
<td>ATTN: TCA</td>
<td></td>
<td>ATTN: DRDAV-B</td>
</tr>
<tr>
<td></td>
<td>Cameroon Station</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Alexandria, VA 22314</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>HQDA (SAUS-OR)</td>
<td>1</td>
<td>HQDA (DAMO-RQA)</td>
</tr>
<tr>
<td></td>
<td>WASH DC 20310</td>
<td></td>
<td>WASH DC 20310</td>
</tr>
<tr>
<td>2</td>
<td>Commander</td>
<td>2</td>
<td>Commander</td>
</tr>
<tr>
<td></td>
<td>US Army Concepts Analysis Agency</td>
<td></td>
<td>US Army Electronics Research</td>
</tr>
<tr>
<td></td>
<td>ATTN: CSCA-MR</td>
<td></td>
<td>and Development Command</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>ATTN: DRDEL-ST-SA (A. Sambuco)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>8120 Woodmont Avenue</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Bethesda, MD 20014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Commander</td>
<td>2</td>
<td>Commander</td>
</tr>
<tr>
<td></td>
<td>US Army Operational Test and</td>
<td></td>
<td>US Army Combat Developments</td>
</tr>
<tr>
<td></td>
<td>Evaluation Agency</td>
<td></td>
<td>Experimentation Command</td>
</tr>
<tr>
<td></td>
<td>ATTN: CSTE-STS-L</td>
<td></td>
<td>ATTN: ATEC-PL-M</td>
</tr>
<tr>
<td></td>
<td>5600 Columbia Pike</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Falls Church, VA 22041</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Director</td>
<td></td>
<td>Director</td>
</tr>
<tr>
<td></td>
<td>US Army TRADOC Systems Analysis</td>
<td></td>
<td>US Army TRADOC Systems Analysis</td>
</tr>
<tr>
<td></td>
<td>Activity</td>
<td></td>
<td>Activity</td>
</tr>
<tr>
<td></td>
<td>ATTN: ATAA-PL</td>
<td></td>
<td>ATTN: ATAA-TG</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. of Copies</td>
<td>Organization</td>
<td>No. of Copies</td>
<td>Organization</td>
</tr>
<tr>
<td>--------------</td>
<td>--------------------------------------------------</td>
<td>--------------</td>
<td>--------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Commandant</td>
<td>1</td>
<td>AFELM, The Rand Corporation</td>
</tr>
<tr>
<td></td>
<td>US Army Air Defense School</td>
<td></td>
<td>ATTN: Library-D</td>
</tr>
<tr>
<td></td>
<td>ATTN: ATSA-CD-A</td>
<td></td>
<td>1700 Main Street</td>
</tr>
<tr>
<td></td>
<td>FT Bliss, TX 79916</td>
<td></td>
<td>Santa Monica, CA 90406</td>
</tr>
<tr>
<td>1</td>
<td>Commander</td>
<td>1</td>
<td>Tektronix, Inc.</td>
</tr>
<tr>
<td></td>
<td>US Army Aviation Center and Fort Rucker</td>
<td></td>
<td>Information Display Division</td>
</tr>
<tr>
<td></td>
<td>ATTN: ATZQ-CD</td>
<td></td>
<td>Applications Library</td>
</tr>
<tr>
<td></td>
<td>FT Rucker, AL 36362</td>
<td></td>
<td>Group 451</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>P.O. Box 500</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Beaverton, Oregon 97077</td>
</tr>
<tr>
<td>1</td>
<td>President</td>
<td>2</td>
<td>Aberdeen Proving Ground</td>
</tr>
<tr>
<td></td>
<td>US Army Air Defense Board</td>
<td></td>
<td>Cdr, USATECOM</td>
</tr>
<tr>
<td></td>
<td>ATTN: ATZC</td>
<td></td>
<td>ATTN: DRSTE-CT</td>
</tr>
<tr>
<td></td>
<td>FT Bliss, TX 79916</td>
<td></td>
<td>DRSTE-AD</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>DRSTE-CM</td>
</tr>
<tr>
<td>2</td>
<td>Commander</td>
<td>1</td>
<td>Dir, HEL</td>
</tr>
<tr>
<td></td>
<td>US Army White Sands Missile Range</td>
<td></td>
<td>ATTN: DRXHE-SP</td>
</tr>
<tr>
<td></td>
<td>ATTN: STEWS-TE-ML</td>
<td></td>
<td>DRDAR-BLB</td>
</tr>
<tr>
<td></td>
<td>STEWS-NR-PA</td>
<td></td>
<td>DRDAR-TSB-S (STINFO)</td>
</tr>
<tr>
<td></td>
<td>White Sands Missile Range, NM 88002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Commander</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>US Army Tank-Automotive Command</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ATTN: DRDTA-V</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Warren, MI 48090</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Commander</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>US Army Missile Command</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ATTN: DRSMI-DS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Redstone Arsenal, AL 35809</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Commander</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>US Army Armament Materiel Readiness Command</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ATTN: DRSAR-IEP-L</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rock Island, IL 62199</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Copies</td>
<td>Organization</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------------------</td>
<td>--------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>Dir, AMSAA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ATTN: DRXSY-A (D. O'Neill)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-AD (H. Peaker)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-AA (T. Coyle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-ADG (J. Meredith)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-ADG (D. Drake)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-ADG (J. Foulkes)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-ADG (K. Frounfelker)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-ADG (B. Lufkin 5 cys)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-ADG (R. Sebra)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-ADG (J. Wald)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-AAM (J. Passamonte)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-AAM (P. Hill)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-AAM (J. Hennessey)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-AA (T. Coyle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-GI</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-GS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-GA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-GB</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-GP</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-CC</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-CS</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-CM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-CR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-CI</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-CA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-RW</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-RE</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-RV</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-RM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-FA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-FX</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-FM</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-FR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-FO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-FLSO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-FIRO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-P</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-J</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-DA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-PRO</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-HEL</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>DRXSY-A (Editorial Ofc)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>