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TECHNICAL REPORT ARPAD-TR-77006

TECHNIQUE FOR COMPUTER AIDED ANALYSIS
OF BALLISTIC SHELL RADIOGRAPHS

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JANUARY 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
PRODUCT ASSURANCE DIRECTORATE
DOVER, NEW JERSEY

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER Technical Report ARPAD-TR-77006	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE *(and Subtitle)* TECHNIQUE FOR COMPUTER AIDED ANALYSIS OF BALLISTIC SHELL RADIOGRAPHS		5. TYPE OF REPORT & PERIOD COVERED 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(*s*) Joel Glaser		8. CONTRACT OR GRANT NUMBER(*s*)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Product Assurance Directorate ARRADCOM Dover, NJ 07801		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS ARRADCOM ATTN: DRDAR-TSS Dover, NJ 07801		12. REPORT DATE January 1979
		13. NUMBER OF PAGES 25
14. MONITORING AGENCY NAME & ADDRESS(*if different from Controlling Office*) ARRADCOM, PAD ATTN: DRDAR-QA Dover, NJ 07801		15. SECURITY CLASS. *(of this report)* Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT *(of this Report)*

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT *(of the abstract entered in Block 20, if different from Report)*

18. SUPPLEMENTARY NOTES

19. KEY WORDS *(Continue on reverse side if necessary and identify by block number)*

Radiograph   AXNAP
Ballistics
Artillery
Computer

20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

An improved method of analyzing radiographs has been developed to satisfy the requirement for 100% inspection of ballistic shells at the loading plant. The new automated technique incorporates rapid processing and the reduction of human interaction; consequently, the possibility of human error is sharply reduced.

DD FORM 1 JAN 73 **1473** EDITION OF 1 NOV 65 IS OBSOLETE

20. ABSTRACT (Continued)

The improved technique was developed for specific application to the Amatex alternate-fill program. Much of the manual manipulation of the radiographs and handling of data was automated using a Tektronix 4014-1 graphics terminal, an opaque Tektronix 4954 graphics tablet, and a telephone link to a CDC 6600 computer. If the technique were modified to incorporate a dedicated minicomputer and a transparent graphics tablet, it would be suitable for use in loading plants.

No improvement has been made in the initial analysis of the radiograph. An experienced X-ray technician is still required to read the radiograph, mark the defect boundaries, and make annotations. However, research is also being conducted to automate this portion of the analysis.

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INTRODUCTION

The software package for the Automatic X-Ray Negative Analysis Program (AXNAP) was developed by Edward Josephs of the Army Armament Research and Development Command. Although it was made expressly for 105 mm, 155 mm, and 8-inch shells, it can be modified for use with other shell types.

The hardware used in the program (Fig 1) consisted of:

    1. Tektronix 4014-1 terminal with 021-0065-00 asynchronous interface tied to a CDC 6600 computer by a telephone line.

    2. Tektronix 4954 tablet, 40 in. x 30 in. (101.6 cm x 76.2 cm)

    3. Tektronix 4631 hard copy unit.

    4. Menu.

RADIOGRAPH ANALYSIS

Analysis of ballistic-shell radiographs starts with evaluation of the negatives by X-ray technicians. The negatives are placed on bright viewers (limitations of the present technology necessitates high exposure of the film to bring out detail), and defect boundaries are marked with grease pencils. Additional information (e.g., base separation) is annotated on the negatives at this time. Up to this point, both the original and the improved procedures are identical.

In the old procedure, the next step required inspectors to lay grids over the radiographs and: (1) figure the location of the defects in each shell, (2) compute the area inside the defects by counting the number of squares on the grid contained inside defect boundaries, (3) measure the greatest width between opposite points on the boundary of each defect, and (4) tabulate the number of defects in critical shell areas.

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The improved procedure automates all of these operations. An inspector logs in on a Tektronix terminal at the beginning of the day. He attaches a menu[1] to the lower left corner of the tablet, then places the radiograph on the tablet.

The inspector enters two points at the lower periphery of the menu (Fig 2) using the graphics pen. The first point becomes the origin of the menu coordinate system; the second point establishes the orientation of the menu coordinate system relative to the tablet coordinate system. All computations are performed by the CDC 6600.

Using the menu and the graphics pen, the inspector enters the date and the shell type, serial number, and lot number. Data is continuously displayed on the terminal CRT as it is entered and, if an error has been made, it can be corrected immediately.

Two points on the shell in the radiograph are entered next (Fig 3). The first point is at the intersection of the upper part of the annular ring and the interior of the shell. The second point may be anywhere on the axis of the inner portion of the left threads at the shell apex. An algorithm computes the shell orientation (translation and rotation) relative to the menu coordinate system (Appendix A).

The inspector inputs a defect classification from the menu, then traces the boundary of the specific defect. The location of the defect in the shell and the area contained within the boundary are computed and displayed in a table on the CRT (Fig 4). To minimize errors from overshoot or failure to complete the trace of a defect boundary, a special algorithm was devised (Appendix B).

The inspector then touches the graphics pen to two opposite points on the defect boundary which represent the maximum width (Fig 5) , and the width is computed and displayed on the CRT.

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[1]The menu is a collection of commands, numbers, and letters which allows the inspector to communicate with the CDC 6600 computer using only the graphics pen.

Maximum width calculations could be made directly from data points entered during the tracing of defect boundaries, but are not because it would significantly increase the required computer time and cause long operational delays. The computer would have to calculate the distances between each pair of points to find the greatest value; for example, a defect boundary recorded as 500 points would require 124,750 repetitions of the distance algorithm and 124,750 comparisons. The inspector, meanwhile, would have to wait, after entering the points, for the computer to get to his job and make the necessary calculations. (The CDC buffer normally can accept data from the Tektronix terminal without using central processor time.) Furthermore, there would be no improvement in accuracy, because the defect boundaries are marked with relatively wide lines from grease pencils and even the original boundaries are obscure (a property of radiographs).

Certain defects have widths too small to be accurately measured with the graphics pen or marked with a grease pencil and require width estimation. For these defects, the inspector indicates the position in the shell by touching the graphics pen to the center of the defect, then indicating the width of the defect by selecting an appropriate box in block VII of the menu (Fig 2). He performs this estimation for cracks, annular rings, and base separation only. Other types of defects are large enough to trace with the graphics pen.

The inspector continues until the last defect in the shell is completed. Then he has the option of selecting a new shell of the same type, a new shell of a different type, or terminating the analysis. A selection is made by touching the graphics pen to one of the boxes in Block VI designated "New Type Shell," "Same Type Shell," or "Finish."

If the inspector chooses the box designated "Same Type Shell," he starts the analysis with Block IV of the menu. If the shell number, group number, or lot number remains unchanged from the previous shell, the inspector touches the graphics pen to the box labeled "Same," in Block V. If a number increments by one, the "Next" box is selected. For other numbers, each digit is entered. After selecting the proper box, the inspector repeats the procedure used for the previous shell.

If the inspector decides to terminate the analysis, he touches the graphics pen to the box in Block VI labeled "Finish," and the final page of the hard copy report is provided by the Tektronix 4631 copy unit.

To protect data from loss during power failure or malfunction of the Tektronix 4631 copy unit, all report data are stored on a CDC disc unit at the central computer facility until it is erased by the inspector when a new report is started. If a power failure occurs and the hard copy unit becomes inoperable, the report can be written by the lineprinter in the computer terminal facility at completion of the radiograph processing.

DISCUSSION

Mode of Data Transmission of Tektronix Terminal

Since the Tektronix 4014-1 terminal is used with an asynchronous interface, individual data points (X,Y) are separately transmitted to the CDC 6600. Depressing the button on the graphics cursor initiates transmission of data to the computer. A waiting period then elapses before the CDC 6600 buffer replies that the data point has been received with correct parity. Activation of the ready light on the Tektronix data unit follows, indicating that another data point can be accepted from the cursor.

A disadvantage of asynchronous operation is that the inspector must watch the ready indicator light when entering points. Usually the indicator relights within a small fraction of a second after a data transmission, but sometimes a longer period of time is required. If the inspector continues to enter points while the ready indicator is unlighted, data points are lost and inaccuracies result.

A synchronous buffer interface is available from Tektronix for the 4014-1 graphics terminal. With this interface, 960 characters can be stored prior to transmission to the CDC 6600 buffer. Since data are stored at the Tektronix graphics terminal, there is no necessity for the inspector to constantly monitor the ready indicator while tracing defect boundaries. Delays associated with the CDC buffer affect only the final transmission of a block of data and not individual points as in the asynchronous mode.

With synchronous operation, a continuous point entry mode would be used. Coordinate points would be continuously transmitted to the synchronous buffer interface from the graphics cursor whenever the button on the cursor was pressed. If the 960 character capacity of the synchronous buffer were exceeded, a warning beep would be emitted from the graphics terminal and the inspector would wait until the ready indicator relighted before continuing to trace a defect boundary.

Data Reduction

The procedure used for processing radiographs is completely amenable to on-line statistical analysis of data. As an inspector processes radiographs, the CDC 6600 would collate data to check for distributions and trends. This method would provide a significant improvement over earlier methods which required punching data from tabulations onto computer cards.

Application to Loading Plants

This method of processing radiographs needs further improvement to be adaptable to loading plants. A dedicated minicomputer could perform the functions of the large general-purpose computer and a transparent graphics tablet could remove the limitations associated with the opaque tablet.

Two operations are required to process a radiograph with the original method. First, an experienced technician interprets the radiograph and marks defect boundaries with a grease pencil. Other pertinent information is also enscribed. Second, an inspector processes the radiograph on an opaque graphics tablet with the assistance of a large general-purpose computer.

With a transparent tablet and a dedicated minicomputer, each radiograph could be processed in one step while the technician analyzes it. The transparent tablet would contain strong backlighting and a thin diffusing screen. As the technician marks each radiograph with a graphics pen, the minicomputer would collect data and check it against test criteria. Every ballistic shell on production lines could be checked providing 100% inspection. In all previous production runs, only limited inspection was performed because of the complexity of processing radiographs.

An additional benefit would be the elimination of time sharing delays. The graphics tablet would be operable in an asynchronous, continuous data-input mode. The operator would no longer be required to monitor the ready light while tracing defect boundaries. Data points would be continuously transmitted to the minicomputer while the cursor button is depressed. Both simplification of processing and reduction of human error would result.

RESULTS

Computer-assisted processing of several carefully drawn geometric figures was performed to check area and width computation accuracy. Then several marked radiographs were processed in a dry run. All of the results were checked against manual calculations to determine accuracy.

The area and width computations were found to be accurate. Errors were in the several thousandths of a square inch (or several square millimeters) region and could easily be explained by errors in the cursor position on the geometric figures (the ink lines were approximately 0.016-inch (0.406 mm) thick, and the accuracy of the tablet cursor was 0.001 inch (0.025 mm)).

The dry run with several marked radiographs was made successfully. The results were in the expected ranges and spot checks of various defects showed good accuracy. Overall performance was very satisfactory.

CONCLUSIONS

The computer-assisted radiograph processing technique is suitable for application to programs which require rapid analysis of ballistic shell radiographs and statistical studies of data. Modification of the technique to accommodate a dedicated minicomputer and transparent tablet would make the method amenable to 100% inspection at loading plants.
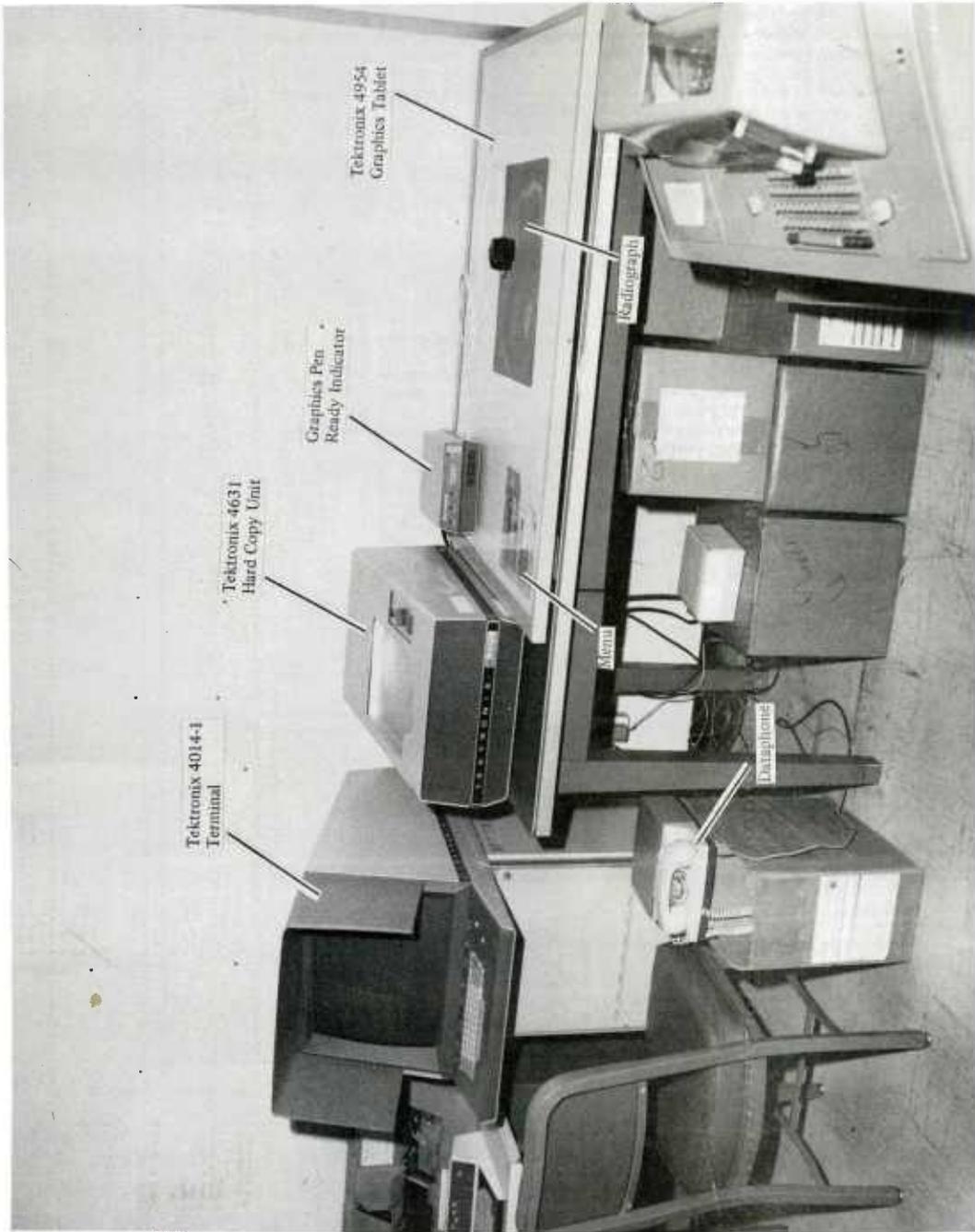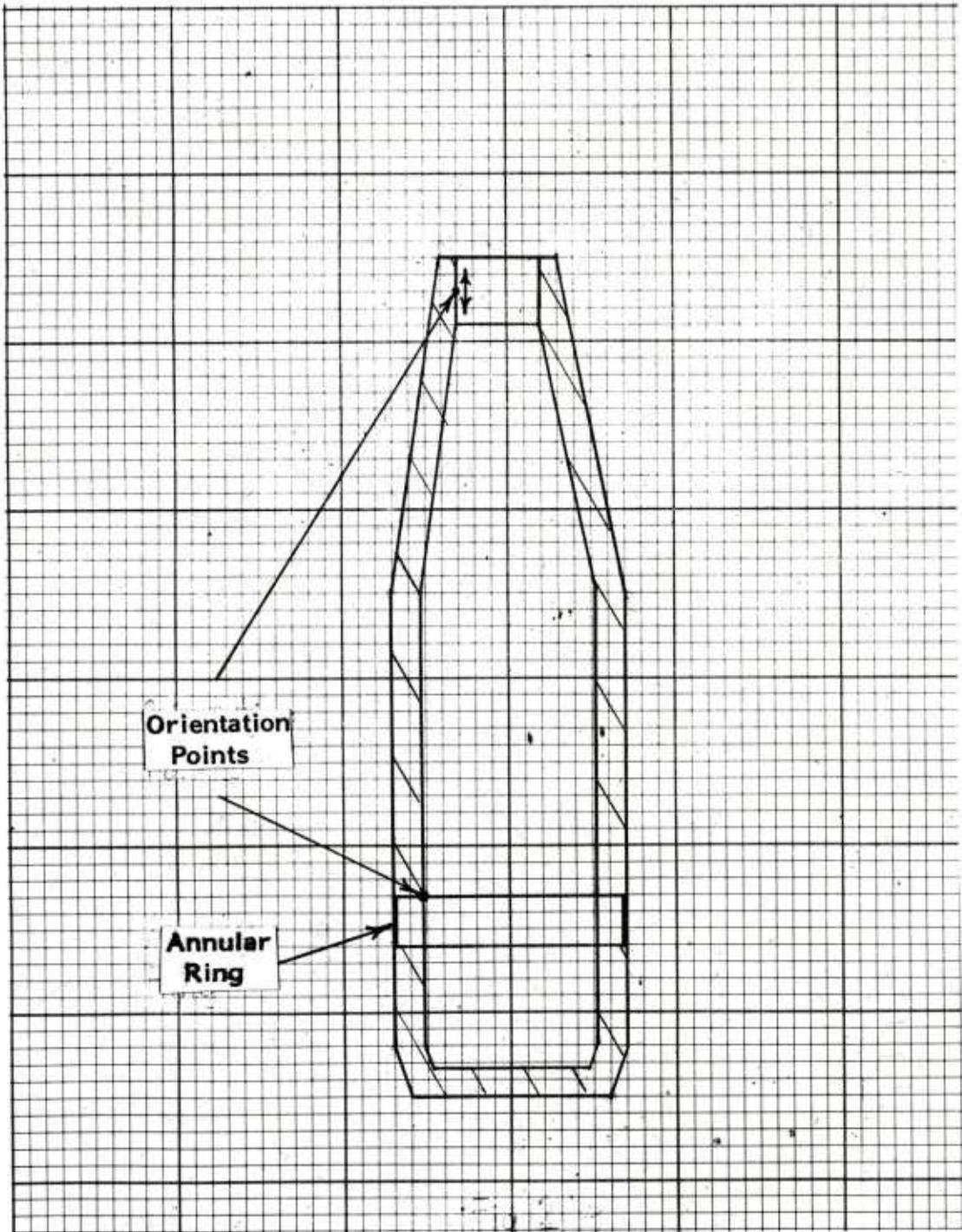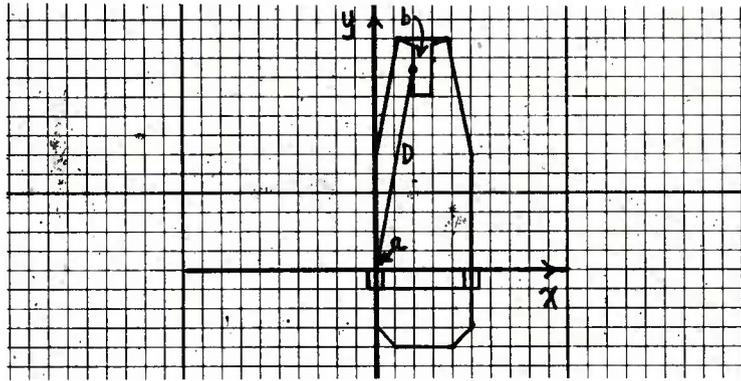
Figure 1. AXNAP hardware setup

Tektronix 4954
Graphics Tablet

Graphics Pen
Ready Indicator

Tektronix 4631
Hard Copy Unit

Tektronix 4014-1
Terminal

Radiograph

Menu

Dataphone

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Figure 2. Menu

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Figure 3. Shell orientation points

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APPENDIX A

ALGORITHM COMPUTATION FOR
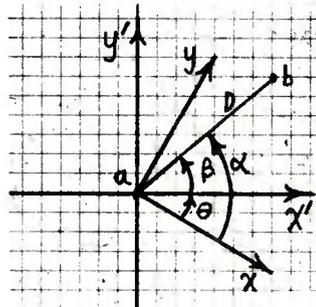SHELL ROTATION

Algorithm for Shell Rotation

a   –   point of intersection of top of annular ring and inside of shell

b   –   any point on the threads

D   –   length of line from point a to point b

Rotation Formulas
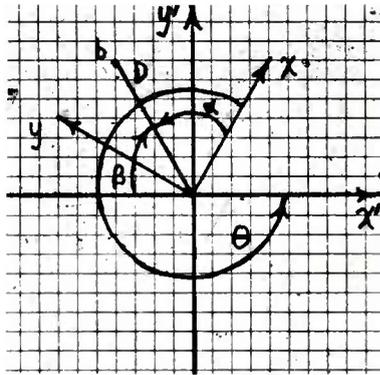
When D is in quadrant 1 of tablet coordinate system X', Y'

Quad 1

Θ =   angle of rotation needed to align the two coordinate systems

β =   angle between line ab and tablet coordinate system

α =   angle between line ab and shell coordinate system
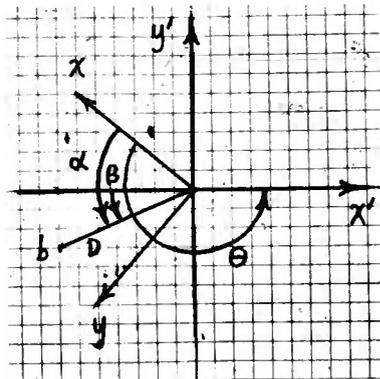
$$\Theta = \alpha - \beta$$
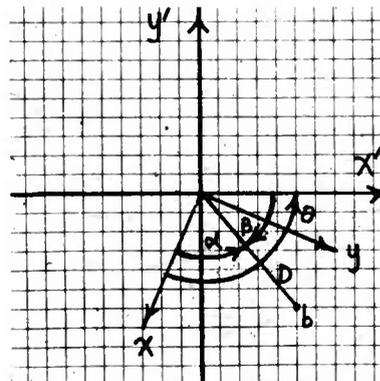
15

Quad 2

$$\Theta = \alpha + \beta + \Pi$$

β is measured from the negative portion of the X axis because the transe-
dental algorithm used by the CDC 6600 could not distinguish quadrants.

Quad 3

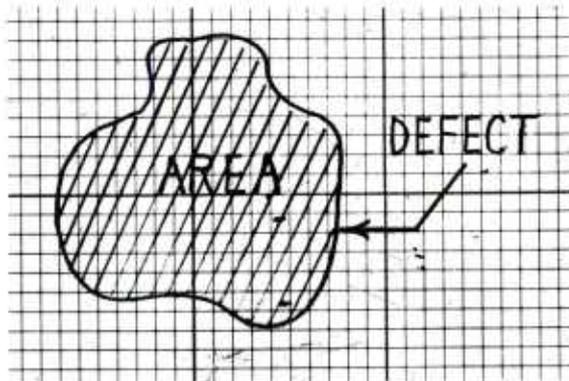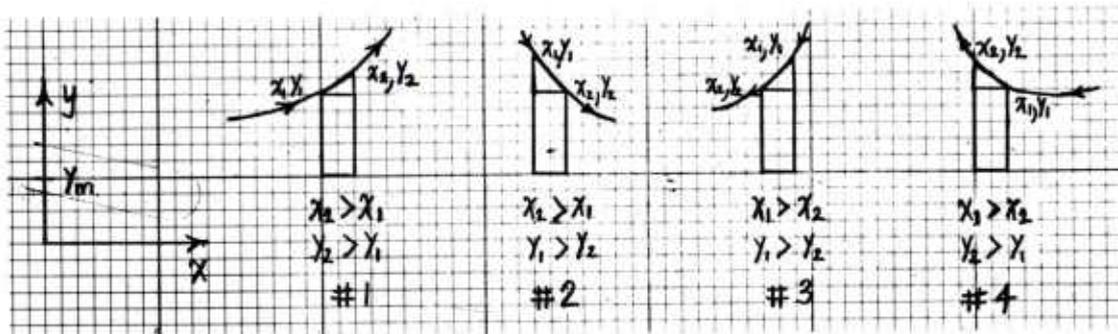$$\Theta = \Pi + \alpha - \beta$$

Quad 4

$$\Theta = \alpha + \beta$$

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APPENDIX B

AREA COMPUTATION ALGORITHM

1. All coordinate points are collected and the lowest value of Y determined. Let this minimum value of Y be designated Y_m.

2. The area is computed in segments. There are four possible cases which are listed below with the corresponding area segments.

3. The algorithms for each case are as follows:

Case 1   X2>X1   Y2>Y1

$$A = (X2-X1)(Y1-Ym) + \tfrac{1}{2}(X2-X1)(Y2-Y1)$$
$$= (X2-X1)\left[Y1-Ym + \frac{Y2}{2} - \frac{Y1}{2}\right]$$
$$= (X2-X1)\left(\frac{Y1+Y2}{2} - Ym\right)$$

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<u>Case 2</u> $X2 > X1$ $Y1 > Y2$

$A = (X2-X1)(Y2-Ym) + \frac{1}{2}(X2-X1)(Y1-Y2)$
$\quad = (X2-X1)\left[Y2-Ym + \frac{Y1}{2} - \frac{Y2}{2}\right]$
$\quad = (X2-X1)(\frac{Y1+Y2}{2} - Ym)$

<u>Case 3</u> $X1 > X2$ $Y1 > Y2$

$A = (X1-X2)(Y2-Ym) + \frac{1}{2}(X1-X2)(Y1-Y2)$
$\quad = (X1-X2)\left[Y2-Ym + \frac{Y1}{2} - \frac{Y2}{2}\right]$
$\quad = (X1-X2)(\frac{Y1+Y2}{2} - Ym)$

<u>Case 4</u> $X1 > X2$ $Y2 > Y1$

$A = (X1-X2)(Y1-Ym) + \frac{1}{2}(X1-X2)(Y2-Y1)$
$\quad = (X1-X2)\left[Y1-Ym + \frac{Y2}{2} - \frac{Y1}{2}\right]$
$\quad = (X1-X2)(\frac{Y1+Y2}{2} - Ym)$

So
$A' = (X2-X1)(\frac{Y1+Y2}{2} - Ym)$ if $X2 > X1$
$A'' = (X1-X2)(\frac{Y1+Y2}{2} - Ym)$ if $X2 < X1$

4. As the operator traces the boundary of a defect the path he follows will change direction as shown below.
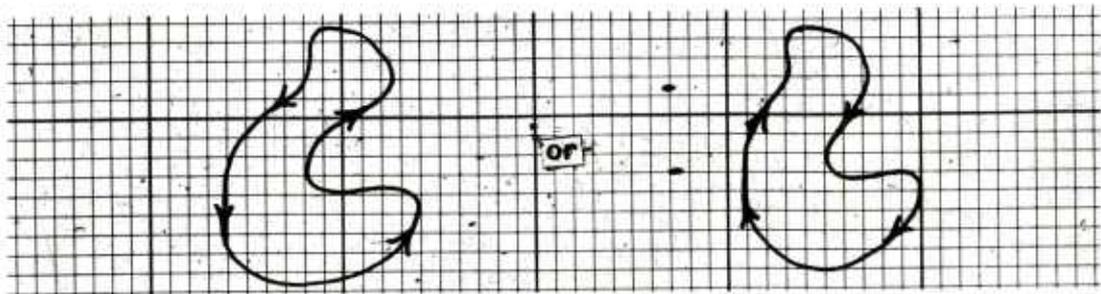
The direction of the path can be found by testing (X_2-X_1) for polarity.

5. The area A enclosed within the boundary is

$$A = \left| \quad A' \quad - \quad A'' \quad \right|$$

$$= \left| \sum_{i=2}^{n} (X_i - X_{i-1}) \left(\frac{Y_i + Y_{i-1}}{2} - Ym \right) - \sum_{j=2}^{m} (X_{j-1} - X_j) \left(\frac{Y_j + Y_{j-1}}{2} - Ym \right) \right|$$

$$X_i > X_{i-1} \qquad\qquad\qquad X_j < X_{j-1}$$

$$= \left| \sum_{i=2}^{n} (X_i - X_{i-1}) \left(\frac{Y_i + Y_{i-1}}{2} - Ym \right) + \sum_{j=n+2}^{m} (X_j - X_{j-1}) \left(\frac{Y_j + Y_{j-1}}{2} - Ym \right) \right|$$

$$X_i > X_{i-1} \qquad\qquad\qquad X_j < X_{j-1}$$

SO

$$A = \left| \sum_{k=2}^{n+m} (X_k - X_{k-1}) \left(\frac{Y_k + Y_{k-1}}{2} - Ym \right) \right|$$

For $X_k > X_{k-1}$ and $X_k < X_{k-1}$

where
n = the number of coordinates with $X_i > X_{i-1}$

$\left[m-n \right]$ = the number of coordinates with $X_j < X_{j-1}$

6. The operator is instructed to start tracing the boundary from a point close to the bottom (Ym). Therefore, errors from overshoot or from failure to close the loop will have a minimum effect. The erroneous or missing area segments are very small because

$$\lim_{Y \to Ym} \left[\frac{Y_k + Y_{k-1}}{2} - Ym \right] = \frac{Ym + Ym}{2} - Ym$$

$$= 0$$

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