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PROGRAMMING THE IBM 650 COMPUTER FOR PREPARATION OF FLIGHT PROGRESS STRIPS IN CAA AIR ROUTE TRAFFIC CONTROL CENTERS

FOR LIMITED DISTRIBUTION

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SUMMARY

This report describes the development and preparation of a detailed program for an IBM 650 Digital Computer to process flight-plan information and produce flight progress strips for the Indianapolis Air Route Traffic Control Center.

A description is given of the types and quantities of flight plans which must be processed, the program logic used for processing both airway and direct route off-airway flight plans, and the special techniques needed for input and output of the data.

INTRODUCTION

In Air Route Traffic Control Centers (ARTCC), flight plans received from pilots are processed and posted on flight progress strips for the controller's display board A flight progress strip is prepared for each fix over which a flight will pass. Manual handwriting of these strips is a time-consuming workload, and during busy periods, assistant controllers frequently are so occupied with this task that they have little time to assist the controller in other duties. Machine preparation of these strips appears very desirable and several equipments have been or are being evaluated for this purpose.

In December 1955, the Electronic-Accounting Machine Division of the International Business Machine (IBM) Corp. proposed that a Model 650 Computer be used to process flight plans and prepare the fix-posting strips. The Civil Aeronautics Administration(CAA) Office of Federal Airways subsequently leased an IBM 650 Computer for evaluation in the ARTC Center at Indianapolis in conjunction with other computer development work being carried on by the CAA Technical Development Center(TDC).

This report describes the preparation of the detailed program for the computer by airways operations specialists of TDC and the Indianapolis ARTC Center with the assistance of IBM Corp. personnel. A subsequent report will be issued covering the evaluation of the computer.

THE PROBLEM

Indianapolis Area.

The Indianapolis ARTC Center is one of 26 CAA ARTC Centers in the United States assigned responsibility for control of instrument flight rule(IFR) air traffic The Indianapolis control area is shown in Fig. 1. This area is approximately 350 nautical miles long east-to-west and 250 nautical miles wide north-to-south There are more than 100 airways designated within the Indianapolis area, with a total length of more than 11,000 miles. In many cases airways overlap each other for some distance. There are 32 principal navigational aids defining these airways, and flights are posted at 38 fixes on the control boards. In addition to these primary fixes, there are about 110 secondary radio fixes, such as intersections of VOR radials, which are used in control and may be used by pilots to define their route of flight. Many of the navigational aids and fixes are common to more than one airway due to crossings or junctions of routes. The control area is subdivided into 16 sectors, with one controller and one assistant controller normally assigned to each sector.

Types of Flights.

Approximately 65 per cent of the flights through the Indianapolis area are via designated airways. The remaining 35 per cent of the flights are from point-to-point via direct routes or via a combination of airway and direct routes Approximately one-half of the flights in the Indianapolis area originate within the area, with the other half entering the area from adjacent control areas.

Flight-Plan Composition.

Flight plans filed with the Center include the following items of information

1 Flight identity.

2. Type of aircraft (and number if more than one aircraft are in a flight).

3. Point of departure.

4. Route of flight.

5. Destination.

6. Proposed time of departure for flights departing from within the area or estimated time over the last fix in an adjacent area for flights entering the area.

7. Altitude.

8. Airspeed.

Item 4, the route of flight, may specify one or more designated airways, or it may specify radio fixes with direct route of flight between these fixes. If direct routes are filed, the fixes specified by the pilot must be within 200 miles of each other.

Radio fixes normally are assigned a three-letter alphabetical designator. This designator is used on the flight progress strips and also in transmission of flight plans via teletypewriter. Most flight plans are received over voice interphone circuits, however, some plans are received via teletypewriter.

Fix-Posting Strips

Typical handwritten fix-posting strips for one flight are shown in Fig. 2. In addition to the basic flight-plan information which is repeated on all strips, the fix designator and estimated time over the fix also are entered on each strip. When preparing these strips for airway flights, the assistant controller must determine the fixes over which the flight will pass and prepare a strip for each of these fixes. He also must compute the estimated time the flight will pass over the fix based on the estimated ground speed and the mileage between fixes

For direct-route flights, it frequently is necessary to refer to a large plotting map to determine the primary fixes near which the flight will pass so that a posting may be prepared for these fixes. On these postings, the direction and distance from the fix, as well as the time the flight will pass the fix, must be entered

Volume.

The average number of fix postings per flight in the Indianapolis area is 3.8. On an average day approximately 4,300 postings are prepared during a 24-hour period, whereas on a peak day more than 6,000 fix-posting strips are prepared. It is estimated that about 600 fix postings are prepared during the peak hour

IBM 650 COMPUTER

Equipment.

The IBM 650 Computer is a relatively high-speed, medium-sized digital computer. To acquaint the reader with the various components of the computer system, a brief description of the equipment used at the Indianapolis ARTC Center follows. The equipment includes.

4 - 826 Typewriter Punch-Card Units

1 - 533 Input-Output Card Read/Punch Unit.

1 - 650 Computer Console

1 - 655 Power Supply.

1 - 407 High-Speed Printer.

The 826 unit, Fig 3, includes an electric typewriter and a punch-card unit. As information is typed on the electric typewriter in plain language, a card is punched simultaneously. If the operator makes an error, he may automatically duplicate the punched card up to the point at which the error occurred It is essential, of course, that all information is inserted correctly in the proper card columns.

The 533 input-output unit of the system, Fig 4, reads information into the computer from punched cards and delivers its ouput in punched-card form The 533 unit is capable of reading a maximum of 200 input cards per minute into the computer, and of punching output cards at a maximum of 100 cards per minute. Wiring panels within the 533 unit permit rearrangement of the data read from input cards for most convenient insertion into the computer input area. Similarly, output wiring panels permit reorganization of data from the computer output area to any desired format on the output cards.

The 650 computer console, Fig. 5, includes a magnetic storage drum, program control registers, calculating units, and a control console. With a detailed program of instructions inserted into the machine, various data-processing steps and mathematical computations can be performed at high speed. Power is supplied from the 655 power unit to both the 650 and 533 units.

The 407 accounting machine, Fig. 6, is a medium-speed printer capable of printing 150 lines per minute from punched-card inputs. The format of the printing from the punched cards is controlled by a wiring panel. In this application each input card is read three times, so that flight plan information may be printed on the flight progress strips in three lines. Thus, approximately 50 flight progress strips can be printed per minute.

Data Flow.

Figure 7 shows how a flight plan is processed through the system. Flight plans filed with the Indianapolis Center are copied by an assistant controller on an 826 typewriter punch-card machine. The punched card is hand-carried to the 533 input-output unit and placed in the input hopper, where the information is read into the 650 computer unit and processed. For each fix requiring a posting strip, the 650 computer unit causes an output card to be punched by the 533 unit. The computer operator removes the punched cards from the output of the 533 unit and places them in the input hopper of the 407 printer, where the flight progress strips are printed on a perforated roll of paper After printing, the strips are separated and inserted in strip holders, and hand-carried to the proper control boards in the Center

The equipments described above are general-purpose, "off-the-shelf" items and were not specifically designed for air traffic control purposes.

PROGRAM LOGIC

Requirements.

A system requirement specified that the computer process as many flight plans as possible and prepare most of the flight progress strips needed by the Indianapolis ARTC Center. To accomplish this, three data-processing tasks were required:

1. To determine the fixes which require posting strips.

2. To compute the estimated time of the flight over each of these fixes, or in the case of direct-route flights, to determine distance, direction, and the estimated time of passing each fix.

3. To organize and print out all flight-plan information in the proper format on the posting strips.

Task 3 is a relatively simple task of organizing certain items of flight-plan information for printing in the format desired. Tasks 1 and 2 are more difficult and will be described in more detail.

In the first approach to a written program, all fixes on airways with the intervening mileages were converted to tabular form and stored on the drum of the computer to become an integral part of its memory. It was found that a total of 72 airways with their associated fixes and mileages were required as a part of the computer's memory, if all airways designated at that time in the Indianapolis area were considered.

After these airways tables were completed, it was obvious that the storage requirements could not be met by the magnetic drum associated with the 650 Computer. Considerable duplication was evident. Frequently, the same fix was found on a number of airways. In one case, 13 different airways pass over the same radio navigational aid. Since each of these fixes must be repeated in memory for each of these airways, this duplication was expensive in terms of general storage. Before the direct or point-to-point type of flight was considered, one-half of the drum storage area had been used for the airway-type of flight plans. After further study, it appeared that if a suitable coordinate system could be selected, the computer might be used to develop the mileages needed for either airway or direct flights, thus eliminating the need to store mileages in the airway tables.

Coordinate System

After a study of various methods, it was decided to set up a coordinate system for the Indianapolis area including those portions of adjacent control areas within 200 miles of the Indianapolis area boundary, in order to include all fixes which might be specified on direct-route flight plans.

A rectangular coordinate system, Fig. 8, was used with a point of origin 40 nautical miles south-southwest of Shreveport, La. The coordinate grid extends 700 nautical miles to the east and 650 nautical miles to the north, with the northern edge of this grid extending into Canada and the eastern boundary touching the east coast of the United States. The basic grid is one nautical mile on a side. It was superimposed on a Lambert Conformal Chart with the y-axis parallel to the meridian nearest the center of the Indianapolis control area.

Each radio fix within the Indianapolis area was assigned a unique x-value of three digits. This three-digit group is used to identify the fix in some data-processing steps which will be described. Slight adjustments were made as necessary to insure a discrete x-value for each fix In addition to its x-value, each fix has a y-value, which is not necessarily unique for each fix. All fixes outside but within 200 miles of the Indianapolis area also have an x- and y-value on the coordinate grid These fixes outside the Indianapolis area do not have unique values of x. Both x- and y-values are positive for all fixes.

Stored Tables.

In addition to the coordinate system, study indicated that it would be desirable to have several files, or tables, of reference data stored in the computer for processing of flight-plan information. Due to the limited amount of storage, it was not always possible to set up these files in the most straightforward manner Longer and more involved data-processing steps are required to overcome the limitations in storage.

A description of each table used follows:

1. Airway/Fix Table. This table is an addressable file of airways in the Indianapolis area. Each airway listed is followed by a list of successive fixes on the airway as identified by the unique x-value assigned to each fix. The fixes are listed in order starting with the first fix in the Indianapolis area, and ending with the last fix in the area. East/West airways are filed with the fixes in order from west to east, or in increasing values of x. North/South airways are filed with fixes in order from south to north Table I, part of the actual table stored on the drum, shows how several airways are stored For example, Amber 6 airway is coded as 1 006 000 000 and is stored in the first word in the table in drum location 1050. The next word in the table, drum location 1051, gives the unique x-values of the first three fixes on Amber 6, that is, 419, 424, and 423 starting right to left. In the next word, drum location 1052, the next three fixes are listed as 426, 468, and 484. Drum location 1053 has the last two fixes of importance to the Indianapolis area which are 519 and 532. With this technique, all of the fixes on airways in the Indianapolis area may be packed into a relatively small amount of storage. Drum locations 1050 to 1249 are used for the Airway/Fix Table When an airway is specified in the route of flight, the computer performs a look-up operation on the first four digits of the Airway/Fix Table to locate the airway. When the airway is located, the list of fixes is transferred into a temporary storage location for further processing

2. Indianapolis Area Fix/Coordinate Table. This table is an addressable file of all fixes in the Indianapolis area. It includes both

primary fixes (compulsory reporting points) and secondary fixes (on-request reporting points). The table begins with the fix in the Indianapolis area having the lowest value of x (286) and continues through the fix having the highest value of x (690). Each ten-digit word in this table contains the x-value of the fix as the first three digits (from left to right) with the y-value in the next three digits. In the seventh digit position, an eight is entered if this is a primary fix which requires a posting on the flight progress boards, or a nine is entered if this is a secondary fix which is not posted. The final three-digit group is used as an address to a word on the drum where the alphabetical three-letter designator for that fix is stored.

Table II is a part of the actual table stored on the drum. For example, assume that it has been determined from the Airway/Fix Table that 345 is one of the intermediate fixes to be posted on airway V12. Starting at drum location 1350, a table look-up operation progresses through the list of fixes beginning with 286 until fix 345 in drum location 1358 is reached The x-value (345) in the coordinate system is followed by the y-value (531) of the fix. This is followed by a control digit 8 and a three-digit group 274. By adding 1000 to the last three-digit group the drum address (Location 1274) is obtained where the three-letter designator of this fix is stored. The Indianapolis area Fix/Coordinate Table is stored in drum locations 1350 through 1483.

3. Fix/Drum Address Table This is a table of all fixes within the Indianapolis area with the address of the drum location on the Indianapolis area Fix/Coordinate Table where the x- and y-values are stored. It is used primarily in processing direct-route flight plans

Table III is a portion of the complete table stored on the drum. The first six digits in the word comprise the computer code for the alphabetical three-letter identifier for the fix. The next four digits are the address of the drum location on the Indianapolis area Fix/Coordinate Table where the x- and y-values of the fix are stored. For example, if the fix HUF for Terre Haute, Indiana, is specified in a direct-route flight plan, a table look-up operation on the first six digits would be made until 68 84 66 was found. The next four digits (1358) in the word are the drum address on the Indianapolis area Fix/Coordinate Table where the x- and y-values of this fix are stored. The Fix/Drum Address Table is stored in drum locations 1250 through 1346 on the drum.

4. Fixes Outside Area/Coordinate Table. This table is a list of all fixes outside the Indianapolis area within 200 miles of its boundary, with their x- and y-coordinate values. These fixes may be specified in flight plans defining the route of direct off-airway flights, and they are also used as entry fixes for airway flights. Table IV is a part of this table The first four digits of each word represent a discrete identifier for the fix followed by three digits for the x-value and three digits for the y-value. The fixes specified in the flight plan consist of three alphabetical

characters, which in the 650 computer code require six digits. Since there are only four-digit spaces available in the word to identify the fix, a discrete four-digit number was obtained by squaring the six-digit numerical code for the fix, and using the sixth through the ninth digits in this number. By inspection of the squares of all the numbers for all the fixes under consideration, it was determined that there were duplicates if the last four digits were used. This also was true for digits 8 through 11 and 7 through 10. By using digits six through nine, a discrete four-digit number could be assigned to each fix. For example, Vandalia, Ill., is identified by three letters as VLA. The machine code for these three alphabetical characters is 85 73 61. This number squared is 735067884321. All digits except 7884 are discarded. In Table IV the Vandalia fix identified by the number 7884 is stored in drum location 1684. The x- and y-coordinates are 260 and 513, respectively. The Fixes Outside Area/Coordinate Table is stored in drum locations 1500 through 1720.

Determining Fixes and Computing Estimates.

1. Airway Flights. A simplified flow chart for processing airway flights is shown in Fig. 9. First, a table look-up operation is performed on the Airway/Fix Table. When the airway is located, the x-value of all fixes which lie on the segment of airway specified in the flight plan are stored temporarily on the drum in locations 0950-59.

A table look-up operation is then performed for each of these fixes on the Indianapolis area Fix/Coordinate Table. As each x-value is located, the y-value of the fix is read out of the table. X-values then are stored temporarily in drum locations 1030-39 and y-values in locations 1040-49. The three-letter identifier for the fix, which also must be printed on the strip, is derived by going to the drum address specified as the last three digits of the words on the Indianapolis area Fix/Coordinate Table. The six-digit identifiers for the fixes are temporarily stored in drum locations 1020-29.

From the x- and y-values, the mileage between the fixes is calculated by use of right angle triangle formulas, that is

$$D = \sqrt{(x_b - x_a)^2 + (y_b - y_a)^2} \qquad (1)$$

where D = distance between Fix a and Fix b

x_a, y_a = the x- and y-coordinate values of Fix a

x_b, y_b = the x- and y-coordinate values of Fix b.

The estimated ground speed punched on the flight-plan input card is used to compute the estimated elapsed time between fixes by the formula

$$T = 60 \left(\frac{D}{S} \right) \qquad (2)$$

where T = time in minutes
D = distance in nautical miles, and
S = ground speed in knots.

If the aircraft is in flight, the estimated time over the fix will be computed by adding the elapsed time to the time over the preceding fix If the aircraft is a proposed departure from within the area, only the elapsed time between fixes is computed for output.

When there is a turn or bend on an airway, and there is no radio fix associated with the turn, a fix is entered in the airway table for the turn These fixes are not printed as output fix postings, but merely serve to derive the actual mileage via a dog-leg airway

The control digits eight or nine in the seventh digit position of the word in the Indianapolis area Fix/Coordinate Table indicate which fixes are to be posted After all information for one fix posting is developed, a card is punched out in the 533 output for that fix posting The computer processes each fix in turn and causes a card to be punched out for each required posting on an airway.

Since many aircraft will proceed over segments of several airways while going through the Indianapolis area, it also is necessary to have a program routine which isolates only those fixes requiring posting for a given airway segment On the flight-plan input card the fixes where a flight will enter and leave an airway are punched in as part of the flight-plan route by the 826 operator The direction of flight along each airway also is inserted by digits added to the flight-plan card. From this information the computer can determine where to start and stop processing fixes for a given airway.

2 Direct-Route Flights. Several processing steps are involved in handling direct-route flights These include

a Determine all possible fixes in the Indianapolis area which are on, or adjacent to, the route of flight
b. Compute the perpendicular distance from these fixes to the route of flight. Reject all fixes more than 35 miles away
c Determine the direction the flight will pass from each fix which is within 35 miles of the route of flight.

(1) Determine heading of flight path
(2) Determine direction of perpendicular line from the fix to the flight path

d Determine the estimated time the flight will pass each fix which is within 35 miles of the route of flight
(1) Compute the distance from the preceding fix specified in the flight plan to the intersection of the perpendicular line from the adjacent fix with the flight path.
(2) Compute elapsed time using estimated ground speed

e Print out a fix-posting strip for each fix which is within 35 miles of the route indicating the direction, distance, and estimated time the flight will pass from the fix

The techniques used are described in more detail in the following paragraphs

The fixes filed in the flight plan to define a direct route of flight are used with the stored tables to determine which fixes require posting for direct-route flights For example, assume that a flight plan specifies a route of flight as Peoria, Ill. (PIA) directoto Indianapolis (IND) First the six-digit computer code identity for PIA (77 69 61), is squared and the discrete four-digit code 8395 is obtained A table look-up operation on the first four digits of the words stored in the Fixes Outside Area/ Coordinate Table is performed The x-(235) and y-(615) coordinate values of PIA are found with this operation and temporarily stored.

A table look-up operation then is performed on the first six digits of the Fix/Drum Address Table which lists all fixes in the Indianapolis area, until the code for IND (69 75 64) is located. The last four digits of this word give the drum address on the Indianapolis Area Fix/Coordinate Table where the x- and y-coordinate values for the IND fix are stored Going to this drum location (1374), the x-(392) and y-(546) coordinate values for IND are obtained. These values are temporarily stored on the drum

It then is necessary to determine all of the possible fixes in the Indianapolis area which are on the route of flight, or are within 35 miles of the route of flight, so that postings may be prepared for these fixes An inspection of a map of the Indianapolis area indicated that, if all fixes within 35 miles of any direct path through the area were posted, all of the necessary postings for each sector would be obtained. In many cases, unwanted postings for some fixes also are obtained and must be filtered out before delivery to the flight progress boards

A table look-up operation is performed on the first three digits of the Indianapolis area Fix/Coordinate Table starting with the low value of x minus 35 and stopping with the high value of x plus 35 In this example, the table look-up would start with 200 (x-value of PIA minus 35) and end with 417 (x-value of IND plus 35). Referring to Table II, this will include 34 fixes beginning at drum location 1350 through drum location 1383. However, since fix posting strips are required only for those fixes within 35 miles either side of the flight path, many of the fixes obtained from this table look-up operation must be eliminated. To eliminate the unwanted fixes, the following processing is performed. The slope and y-intercept values of a line through the two fixes, PIA and IND, shown in Fig. 11, are derived by use of the formulas

$$m = \frac{(y_a - y_b)}{(x_a - x_b)} \tag{3}$$

$$C = y_a - mx_a \tag{4}$$

where m = slope of line through Fixes a and b
x_a and y_a = coordinates of Fix a
x_b and y_b = coordinates of Fix b
C = y-intercept

The perpendicular distance Pd to the route of flight of a third fix F is determined by

$$Pd = \frac{(y_F - mx_F - C)}{(\sqrt{m^2 + 1})} \tag{5}$$

where x_F and y_F = coordinate values of Fix F
m = the slope of the route of flight
C = the y-intercept of the route of flight
Pd = the perpendicular distance of Fix F to the route of flight

By substituting the x- and y-coordinate values of all of the fixes obtained from the table look-up of fixes with x-values between the two limits, all fixes which will be within 35 miles of the route of flight can be determined. Those fixes which are beyond 35 miles are rejected. Those fixes within 35 miles are stored temporarily with the actual distance the aircraft will pass from the fix.

The controller also requires the direction from a fix that the flight will pass at the nearest point. A series of logical steps is used to determine this direction within eight points of the compass.

First, the x-coordinate values of Fix a and Fix b on a direct-route flight are compared to determine if the flight is eastbound or westbound, remembering that no two fixes have the same x-value, thus, there is never a flight due north or south with respect to the coordinate system. Next, the algebraic sign of the perpendicular distance Pd is examined If this value is positive, Fix F lies north of the route of flight, if it is negative, Fix F is south of the route of flight From the slope m of the route of flight, the approximate heading in degrees along the route of flight is next determined This heading angle could be determined exactly by use of a tangent table, however, because of limited storage this was not done. It was found that the approximate heading could be obtained with sufficient accuracy by the following process. The slope of the route of flight m, if less than plus or minus 1, is multiplied by 48 The product is the angle of inclination with respect to the x-axis within 3^o When the slope is greater than plus or minus 1, the reciprocal of the slope $\frac{1}{m}$ is multiplied by 48 This product will give the angle of inclination with respect to the y-axis within 3^o Rules of logic are used to determine the actual heading

For example, in Fig 12, assume a flight route from west-to-east for which the slope is determined as plus 1/2. Multiplying this by 48, the approximate angle of inclination with the x-axis is determined to be 24^o In this case the actual navigational heading is between 45^o and 90^o. A heading of 45^o would produce a slope of plus 1 and 90^o (the x-axis) a slope of zero Since the angle with respect to the x-axis is known, then if 24^o is subtracted from 90^o, the approximate compass heading plus 66^o of the route of flight will be obtained.

Similarly, if a west-to-east flight route was determined to have a slope of minus 1/2, the actual heading with respect to the compass rose is southeast, and multiplying minus 1/2 by 48, gives minus 24^o, which when subtracted from 90^o becomes plus 114^o In Fig. 13, if an east-to-west flight route has a slope of minus 2, it is known that the flight path is headed northwesterly between 315^o and 360^o magnetic Multiplying the reciprocal of the slope minus 1/2 by 48 gives minus 24^o, which is the angle with respect to the y-axis Thus, 360^o minus 24^o will provide the heading of 336^o, which is within 3^o accuracy. Similar logic is applied to all of the quadrants, and the correction angle is applied to either the x- or y-axis as appropriate.

Since the direction that the flight will be passing from the fix at the nearest point must be written on the flight progress strip, it is then necessary to add or subtract 90^o from the flight route heading to obtain the direction from the fix For example, in Fig. 14, if Fix F is south of a west-to-east flight path, Pd is negative, and by subtracting 90^o from the heading of the flight path the direction of the perpendicular line from the fix to the flight path is obtained. If the fix is north of a west-to-east flight path, Pd is positive, and 90^o is added to the flight path direction. As necessary, values are adjusted to lie within the range of 1^o to 360^o Once the direction of the perpendicular line from the fix to the flight route is obtained in degrees, the geographical direction to eight points of the compass is obtained from a Degrees/Geographical

Direction Table, Table V. The first three digits of the words in this table represent limit values in degrees for a table look-up operation, with the last four digits used for the computer code for the alphabetical characters for geographic direction For example, in Fig. 14 the direction of a perpendicular line from Fix F to the route of flight is 336°. A table look-up operation performed on the first three digits would stop at 337 (drum location 1007) since this is the first value listed which is equal to, or greater than, the value desired The geographic direction for headings between 292° and 337° is northwest. The computer code for northwest 75 86 is available from the last four digits of the word in location 1007

To determine the mileage from a fix specified in the route of flight to the point nearest a fix adjacent to the route of flight, the following computations are performed

Referring to Fig. 15, assume a direct-route flight from Fix A to Fix B. Fix F has been determined to be within 35 miles of this route. A fix-posting strip must be prepared for Fix F and the time the aircraft will pass point E must be determined If a perpendicular line to the flight-plan route is drawn through Fix A to the y-axis, its slope will be $-\frac{1}{m}$ where m is the slope of the flight-plan route The intercept of this line with the y axis at point D can be determined by means of Equation (4), and the perpendicular distance P_F then may be determined by use of Equation (5). Distance P_F is equal to the distance from A to E. A speed computation then is made to obtain the elapsed time of flight from A to E This is repeated for all fixes within 35 miles either side of the route of flight from A to B

The following steps are used to reject unwanted fix postings. As indicated under the previous discussion, it is necessary to look up all fixes having x-values plus or minus 35 miles from the Fix A and Fix B to insure proper postings for flights that are in a more north-south direction Referring to Fig. 16, if a flight is proceeding from Fix A to Fix B, a posting would be required for Fix F, but not for Fix G, which is before the origin of this route segment. To eliminate the posting for Fix G, the following test is made

The perpendicular distance from Fix G to a perpendicular line through Fix B is determined This is compared with the distance from Fix A to Fix B If the distance from Fix G to the line through Fix B is greater than the distance from Fix D to Fix B, then Fix G is rejected and a posting is not prepared. In the program, two miles first are subtracted from the distance between Fix A and Fix B to make this test, to eliminate preparation of duplicate postings for Fixes A and B. A simplified flow chart for the processing of direct route off-airway flights is shown in Fig. 17.

OTHER FACTORS

IBM Punch Cards

There are 80 vertical columns across an IBM punch card. Each vertical column has 12 identifiable positions or locations where punches may be made These punch locations include the 10-digit positions 0 through 9 plus two extra positions known as the high order, or the 11 and 12 positions Since it is not possible to represent the 26 alphabetical characters and 10 numerical digits by single punches in only 12 positions, two punches are used in a column to denote an alphabetical character with one punch denoting numerical digits from 0 through 9.

Input Cards.

Fig 18A shows a typical input card used to encode flight-plan data. The flight plan is entered on the card in the order normally used for interphone transmission. Certain columns of the card are designated for alphabetical data and others for numerical data A unit of information, such as flight identity or an airway, may include both numerical and alphabetical characters One or more columns on the card used for entering particular units of information are called fields. For proper processing, a particular unit of information of a flight plan always must be in its proper field The fields of the card are described below with their operational use

1. Column 1 Aircraft operator (A, American Airlines, X, itinerant, and so forth). Either alphabetical or numerical information may be entered in this field or it may be left blank

2. Columns 2 through 6: Aircraft Identification Either alphabetical or numerical information may be entered or it may be left partially blank.

3 Columns 7 through 9. Type of Aircraft This field can handle both alphabetical and numerical information, and may be left partially blank.

4. Columns 10 through 12 Ground Speed. Only numerical information may be entered and no part of this field may be left blank.

5. Columns 13 through 15. Point of Departure This is an alphabetical field for the three-letter designator

6. Columns 16 through 20. Flight Plan Route - Airways.
Columns 24 through 28 Flight Plan Route - Airways.
Columns 32 through 36. Flight Plan Route - Airways.
Columns 40 through 44 Flight Plan Route - Airways.
Columns 48 through 52. Flight Plan Route - Airways.

These are numerical fields. Alphabetical airway prefixes (V, G, A, R, or B) or suffixes for alternate Victor airways (N, S, E, W) are automatically coded to numerical in the 533 wiring, since there are a limited number of letters used. For direct-route flights these fields are left blank, and zeros are inserted automatically through the wiring panel in the 533 unit. When these cards are being read by the 533 input, sampling of card columns 16, 24, 32, 40, and 48 determines the absence or presence of information and provides the necessary cue to transmit zeros into the computer when these fields on the card are blank, The airway suffix location may be blank with an airway in the first part of these fields When there is no suffix associated with the airway, a zero is placed in the suffix column by wiring. The automatic alphabetical coding for airway prefixes and suffixes is accomplished by column splitting This consists of reading only the digit positions of a column in the input card and disregarding the high order positions With the exception of N for north and E for east as airway suffixes, discrete digits were available on the card to accomplish this coding. In the cases of north and east, further selection is made using the high-order positions and the 5 representing E is changed to an 8 With this change, a discrete single digit is available for all the alphabetical characters in these two areas This coding is automatic, and the 826 operator enters normal alphabetical airway prefixes and suffixes.

7 Columns 21 through 23 Fix designators of airway junctions or fixes on direct-route flights.
Columns 29 through 31 Fix designators of airway junctions or fixes on direct-route flights
Columns 37 through 39 Fix designators of airway junctions or fixes on direct-route flights
Columns 45 through 47 Fix designators of airway junctions or fixes on direct-route flights.
These fields are alphabetical, and may be left blank.

8. Columns 53 through 55 Destination These are alphabetical data.

9 Columns 56 through 58: Entry fix (exit fix of adjacent control area) This field is alphabetical and can be left blank A blank field indicates to the computer that the flight plan is for a proposed departure from within the control area

10. Columns 59 through 62: Estimated time over entry fix or proposed departure time for flights departing within the area This is a numerical field and no part of it can be left blank.

11. Columns 63 through 65: Altitude. This is a numerical field and cannot be left blank When the altitude is specified as "on-top-of-clouds," three zeros are punched in this field by the 826 operator The 407 printer is wired to print OTP on the flight progress strip, however, when the altitude is read out as three zeros.

12. Columns 66 through 70 Airway Direction Code. These columns are numerical and are used to enter a direction code for each airway (8 for East and Northbound, 9 for West or Southbound). When there is an airway route segment there must be an airway direction code. Column 66 is associated with the first airway field, columns 16 through 20, column 67 with the second airway field, columns 24 through 28, and so forth When there is no airway entered for the

route segment, that is, for a direct-route flight, columns 66 through 70 are left blank. Zeros then are automatically entered in these locations by the wiring panel on the 533 input panel

13. Columns 71 through 80 Unused.

Of the 70 columns used, a column designated as alphabetical may be left blank, since a special alphabetical device in the 533 read-in unit will enter zeros automatically into the computer when a blank alphabetical field is encountered However, a column designated as numerical must normally contain a punch. It may be left blank only if special wiring of the 533 input panel has been accomplished to insert zeros when a blank condition is encountered in that column. The 650 computer unit will stop if a blank condition is encountered in any word by the arithmetic unit.

IBM 650 Computer.

The IBM 650 Computer basically is a numerical machine The magnetic drum storage is capable of storing 2,000 10-digit words plus an algebraic ± sign for each word. By use of two digits, for example, 61 for A, 62 for B, and so forth, the computer is able to work with alphabetical characters. However, alphabetical characters use up the general storage area twice as fast as numerical characters Thus, the drum storage unit of the computer is capable of storing 20,000 numerical digits or 10,000 alphabetical characters.

The input and output areas of the computer are restricted to 10 words or 100 digits each With a special alphabetical device on the 533 input-output unit, it is possible to designate 6 of these 10 words, or 60 digits for alphabetical information.

Referring to Fig. 18A, the flight plan coded on an input card has 40 alphabetical and 30 numerical characters Since the computer can read in only 30 alphabetical characters (60 digits when converted to numerical), the 10 extra alphabetical characters are coded automatically to single numerical digits and entered into the computer through single digit positions. This is possible since the number of different letters used in certain columns of the card is limited to less than 10 as in the example of airway prefixes. These alphabetical/numerical conversions are made automatically by wiring of the 533 input panel. With the output wiring panel these numbers are converted back to the appropriate alphabetical characters

In the basic 2,000 words of storage in the computer, 20 words are used for reading into and out of the computer. This allows 1,980 drum locations, or words, to store the program instructions, the reference tables, and the intermediate results during computations Certain constants also are stored to initialize the program, that is, return the program to normal before processing each subsequent flight plan Approximately one-half of the storage locations are used for tables, while the other one-half are used for program instructions, intermediate results, and constants

It is necessary to rearrange a flight plan considerably, with the wiring panel of the 533 input, to pack all of the data required into the 10 words available in the input area of the drum. Figure 18B illustrates how these flight-plan data are rearranged with unrelated information entered into various words. The first step in computer processing restores the flight plan to a suitable form. This consists of placing in successive drum locations the departure point, the first airway, the first junction, the second airway, the second junction, and last the destination. The information taken from the input area always is treated as though a five-route segment flight plan were being handled. Zeros are stored in areas of the flight plan when less than five route segments are encountered.

A flight plan is processed by route segments. For example, if there are three route segments specified in a flight plan, three iterations of this portion of the program are required. During each of these iterations, a route segment is tested to determine whether it is via airways or direct. This is done by testing the location containing route information for zeros. If zeros are found, the route segment is direct, if zeros are not found, the route segment is via airways. By checking route segments successively, it is possible to handle airway flights, direct flights, or a combination of these in the same flight plan.

Information in the entry fix (last fix in adjacent control area) location of an input card is used to determine whether a flight is en route or proposed. When there are zeros in this location, the computer recognizes that the flight will originate within the control area. A proposed departure program routine then is followed. The output card for the first strip posting for the point of departure is prepared by arranging the flight plan in the drum readout area and by use of a specially wired area in the 533 output unit. The estimated departure time is preceded with a P for proposed.

Output Cards

The output card shown in Fig. 19A is the same size as an input card. To distinguish between the two, different colors normally are used. The output card has 46 columns containing alphabetical characters and 34 columns with numerical data. Five numerical characters (the type of airway prefixes) are converted to alphabetical characters by wiring in the 407 printer.

Since the buffer storage readout area on the drum, Fig. 19B, is limited to 100 digits (10 words) and there are more than 100 digits required for output cards, a technique known as "gang-punching" is used. The common information for each flight progress strip, such as aircraft identification and type, is first read out and punched onto the first output card for a flight. This first output card is used as temporary storage in the 533 unit. The common information is then "gang-punched" into the proper fields on each subsequent card as the computer processes data and punches a card for each fix posting required.

IBM 407 Printer

The 407 accounting machine prints a complete line at a time with 120 type wheels. Each wheel has 47 characters, including all of the letters of the alphabet, the 10 numerical characters, and 11 special characters. The characters are 1/10-inch wide, and a complete line of type is 12 inches in length. All the type wheels are properly positioned before the machine prints a line, and one full line is printed by one print command. The format in which data are printed from the punched cards is controlled by a wiring panel, a paper programming loop, and the fields in which characters are punched in the card. The order of readout of information from the output card can be controlled completely by the wiring panel.

By proper wiring of the input panel and use of the paper programming loop for line-feed control, a single output card is read three times to produce three lines of type on the flight progress strips. This "multiple-line-read," as it is called, permits data in various fields on the punched cards to be printed during each of three "reads" for printing on any of the three lines.

Each fix-posting output card developed by the computer has a maximum of 80 significant characters which may be printed by the 407 printer on a flight progress strip. Special characters, which are the same for each strip, are generated by means of the wiring panel in the 407. For example, when the speed is read from the computer, it is rounded to two digits, that is, 31 indicates a speed of 305 to 314 miles per hour. To print out the speed as 310 on the strip, a zero is generated by proper wiring of the 407 printer.

By use of selectors on the 407 printer, numerical characters may be converted to their original alphabetical form, zeros in the altitude column may be changed to OTP, and the format of the flight progress strips may be changed for proposed departures, and so forth.

Error Checking

Data processing by the computer is subject to two kinds of errors: machine and human. Most of the human errors will be associated with entry of information on the input card, such as incorrect data entries, typing errors, or fix information not associated with the permanent memory of the computer.

Checking of certain machine errors is automatic. When a unit of information passes from one component of the machine to another, each character is checked for validity. If the check is invalid, an error is signaled.

Programmed error checks are steps throughout the program which determine whether particular types of errors made by the operators are entering the machine. These errors are detected when the computer encounters information that does not fit a specific pattern established for the program.

When errors are detected, the machine is set to stop automatically By reference to indicator lights on the computer console and the input card, the type of error can be checked by the console operator

The following checks are performed by the internal program to determine if errors exist as information enters the computer.

1. Have all essential items of flight plan been entered in the computer?

2 Are essential items in their proper column?

3 Is the entry fix filed a valid entry fix?

4. Is there correlation between airways specified and entry, junction, or departure fix?

5. On a proposed departure, is the airport of departure a valid fix?

6. On a direct flight, is the junction point a valid junction point?

All of these checks except the first are partial since it is possible for erroneous data to meet the criteria established For example, a flight from St. Louis, Mo. (STL) direct to Stateline, Ind (XST) might, with a typing error, be typed as XSM (St Marks, Ind.) instead of XST The computer would recognize XSM as legitimate, for it is a part of the computer's memory. Processing of St. Marks, Ind would be accomplished and erroneous output would result. But, should the typing error have resulted in an identification not in memory, the computer would stop and signal an error In the case of the flight-plan input check, all units of information except the identification and the type of aircraft are examined With the aid of programmed checks and manual examination of the output before delivery to the flight progress boards, it is improbable that erroneous output from the computer will reach the control board

TABLE I

AIRWAY/FIX TABLE

Airway	Word Stored					Drum Location
A6	1	006		000	000	1050
	0	423		424	419	1051
	0	484		468	426	1052
	0	000		532	519	1053
B3	2	003		000	000	1054
	0	000		000	406	1055
B15	2	015		000	000	1056
	0	550		553	569	1057
B34	2	034		000	000	1058
	0	000	0	000	345	1059
B39	2	039		000	000	1060
	0	657		605	603	1061
B44	2	044		000	000	1062
	0	406		396	392	1063
B81	2	081		000	000	1064
	0	598		602	605	1065
	0	000		595	596	1066
B87	2	087		000	000	1067
	0	483		472	475	1068
	0	505		496	484	1069
V4	5	004		000	000	1070
	0	423		373	321	1071
	0	571		475	426	1072
	0	000		690	605	1073
V4S	5	004		200	000	1074
	0	423		321	286	1075
	0	475		451	426	1076
	0	690		653	605	1077
V4N	5	004		800	000	1078
	0	423		371	321	1079
	0	475		453	426	1080

Continuation of this Airway/Fix Table appears in Drum Locations 1081-1249

TABLE II

INDIANAPOLIS AREA FIX/COORDINATE TABLE

Fix Designator	Coordinates x	Coordinates y	Pri 8 Sec 9	Drum Address Fix Designator (add 1000)	Drum Location
APX	286	450	9	000	1350
EVV	321	440	8	266	1351
WCR W/CARLISLE	322	491	9	312	1352
VCN	335	485	9	311	1353
SCL S/CARLISLE	336	490	9	302	1354
XCR CARLISLE	338	499	8	320	1355
XST STATELINE	341	574	8	341	1356
APX	343	566	9	000	1357
HUF	345	531	8	274	1358
OWB	349	428	9	290	1359
XJP JASPER	360	470	9	000	1360
LAF	361	593	8	277	1361
SCJ	366	500	8	301	1362
APX	369	567	9	000	1363
XHL HALSMER	370	588	9	327	1364
XSM ST. MARKS	371	460	9	340	1365
XAP APALONA	373	445	8	315	1366
XCL CLOVERDALE	374	536	9	000	1367
XMC MONTICELLO	375	611	9	000	1368
XRD RADNOR	378	592	9	339	1369
XCX X-V97 & V128	381	580	9	000	1370
XML MITCHELL	384	483	9	332	1371
XPG PARAGON	388	525	9	000	1372
XMV MONROVIA	391	535	9	335	1373
IND	392	546	8	276	1374
XHO HORTON	396	570	9	328	1375
XHU HOUSTON	398	505	9	000	1376
BHL	401	601	9	252	1377
LVX LANESVILLE	405	453	9	282	1378
OKK	406	591	8	289	1379
FTK	407	439	9	000	1380
XCS CASTLETON	409	555	9	000	1381
NMX NW/XMX	410	565	9	288	1382
CLU	412	517	8	257	1383
MZZ	418	590	9	285	1384
HDT	419	418	9	000	1385
GFD	420	552	9	269	1386
XMX	421	552	8	336	1387
XHV HARTSVILLE	422	515	9	000	1388
SDF	423	452	8	303	1389

TABLE II - CON'T

INDIANAPOLIS AREA FIX/COORDINATE TABLE

Fix Designator	Coordinates x	y	Pri. 8 Sec. 9	Drum Address Fix Designator (add 1000)	Drum Location
	2				
SHP	424	4442	9	305	1390
XNA NABB	425	477	9	337	1391
LOU	426	450	8	281	1392
XCB	434	402	8	319	1393
MXE MUNCIE	434	575	9	284	1394
RUX	439	536	9	295	1400
XCO COWAN	440	568	9	000	1401
XHI	442	365	8	326	1402
WNB W/NJO	445	524	9	314	1403
XCP CHAPLIN	451	435	9	000	1404
SWC SW/CWW	452	594	9	307	1405
FFT FRANKFORT	453	453	9	000	1406

Continuation of this Indianapolis area Fix/Coordinate Table appears in Drum Locations 1407 - 1483.

TABLE III

FIX/DRUM ADDRESS TABLE

Fix	Computer Code For Fix Identifier	Drum Location of Fix Coordinates	Drum Location
ADX	616487	1463	1250
APE APPLETON	617765	1455	1251
BHL	626873	1377	1252
BKW	627826	1473	1253
CHW	636886	1469	1254
CIN	636975	1419	1255
CLB CLAIBORNE	637362	1438	1256
CLU	637384	1383	1257
CMH	637468	1450	1258
CRB	637962	1426	1259
CVG	638567	1411	1260
CWW	638686	1410	1261
DAY	646188	1422	1262
DWF	658666	1427	1263
EKN	657275	1482	1264
EUN E/UNN	658475	1418	1265
EVV	658585	1351	1266
FFO	666676	1428	1267
GAY	676188	1471	1268
GFD	676664	1386	1269
GGX	676787	1415	1270
GPM	677774	1481	1271
HTS	688382	1456	1272
HTW	688386	1457	1273
HUF	688466	1358	1274
ILN	697375	1434	1275
IND	697564	1374	1276
LAF	736166	1361	1277
LBX LIBERTY	736287	1420	1278
LCK	736372	1451	1279
LEX	736587	1417	1280

Continuation of this Fix/Drum Address Table appears in Drum Locations 1281-1346

TABLE IV

FIXES OUTSIDE AREA/COORDINATE TABLE

Fix	Identity Code	Coordinates x	y	Drum Location
GSH	7479	417	653	1673
JXN	7500	480	696	1674
FWA	7532	443	624	1675 VOR
FWA	7532	444	617	1676 LF
GPM	7595	669	421	1677
BTP	7654	686	606	1678
NCQ	7678	483	192	1679
CSV	7741	450	308	1680
FTB	7763	736	281	1681
BFD	7768	745	676	1682
FAM	7798	204	433	1683
VLA	7884	260	513	1684
MGE	7965	475	195	1685
MKG	7969	404	750	1686
LAQ	8047	199	498	1687
BLF	8097	634	399	1688
RER	8103	681	593	1689
HIC	8163	428	776	1690
YIP	8198	522	693	1691
SPA	8273	604	264	1692
HBD	8277	655	632	1693
GSO	8332	693	328	1694
MNN	8380	543	597	1700
PIA	8395	235	615	1701
GHM	8411	331	314	1702
API	8537	316	674	1703
OTM	8603	124	647	1704
PUK	8654	267	389	1705
PLL	8781	254	689	1706
JOT	8888	312	661	1707
NYG	9123	816	478	1708
XAL	9125	304	546	1709
CEU	9189	677	583	1710
MGW	9329	692	536	1711 VOR
MGW	9329	691	550	1712 LF

TABLE IV (Cont'd)

FIXES OUTSIDE AREA/COORDINATE TABLE

Fix	Identity Code	Coordinates x	Coordinates y	Drum Location
CRL	9548	524	682	1713
DET	9575	545	704	1714
HRN	9600	807	513	1715
BDF	9649	247	643	1716
HOP	9656	337	370	1717
CAH	9724	842	482	1718
VWV	9929	516	646	1719
	9999	999	999	1720

TABLE V

DEGREES/GEOGRAPHICAL DIRECTION TABLE

Direction	Degrees*	Computer Code Word for Direction	Drum Location
N	022	0000075	1000
NE	067	0007565	1001
E	112	0000065	1002
SE	157	0008265	1003
S	202	0000082	1004
SW	247	0008286	1005
W	292	0000086	1006
NW	337	0007586	1007
N	359	0000075	1008
	999	9999999	1009

*Equal to or greater than the number of degrees on which the table look-up is initiated.

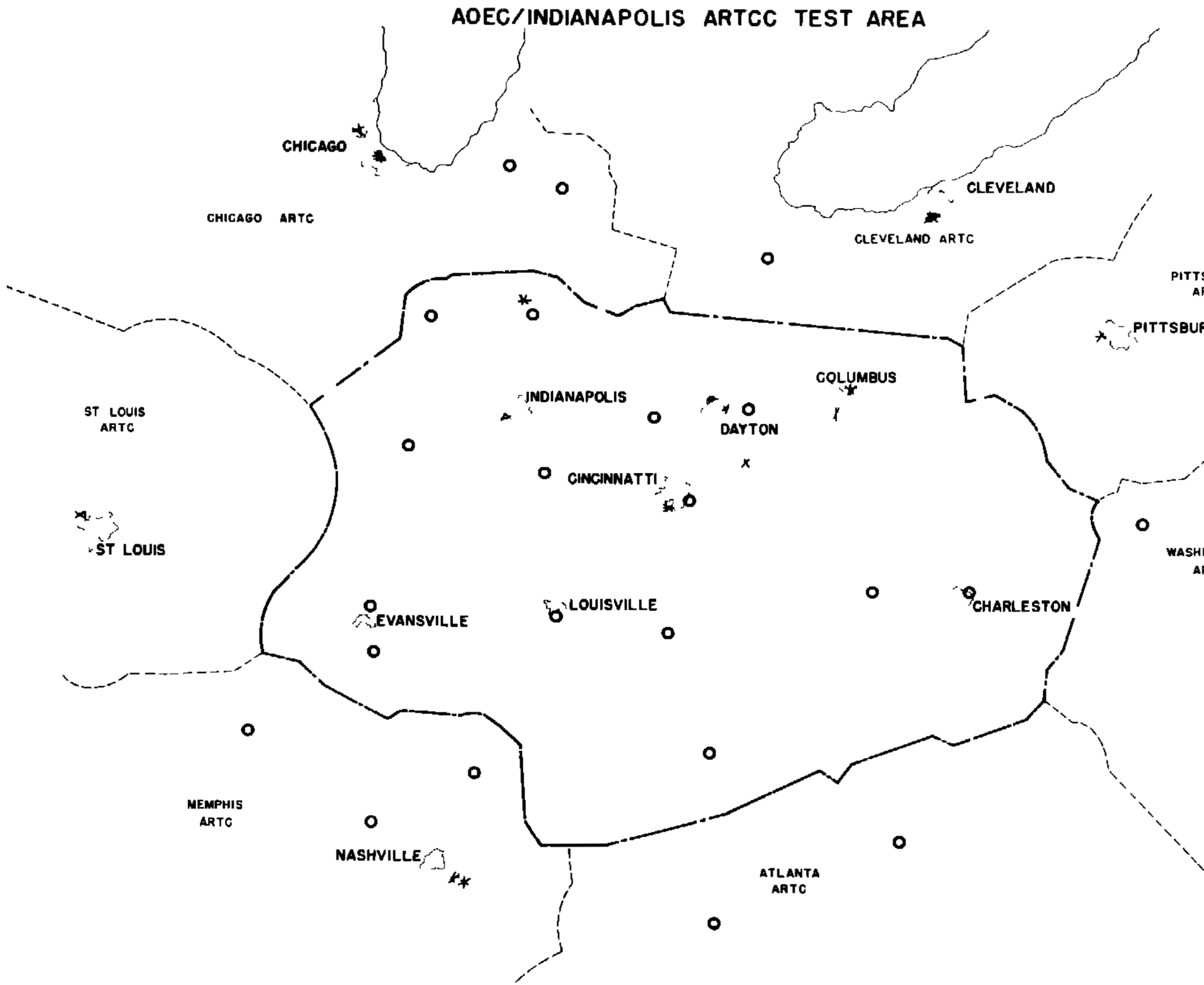


FIG 1 INDIANAPOLIS CONTROL AREA

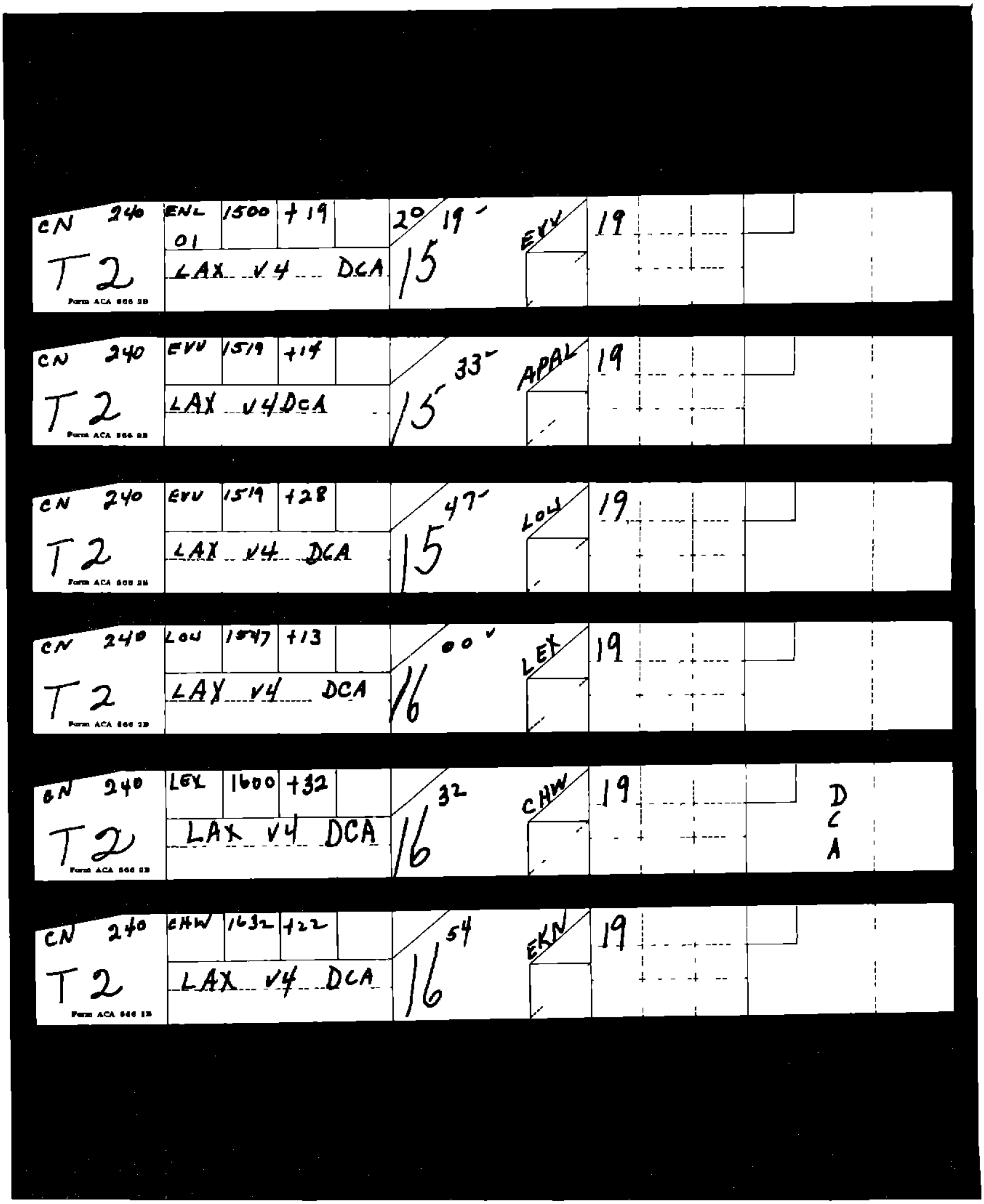


FIG 2 TYPICAL HANDWRITTEN FIX-POSTING STRIPS FOR ONE FLIGHT

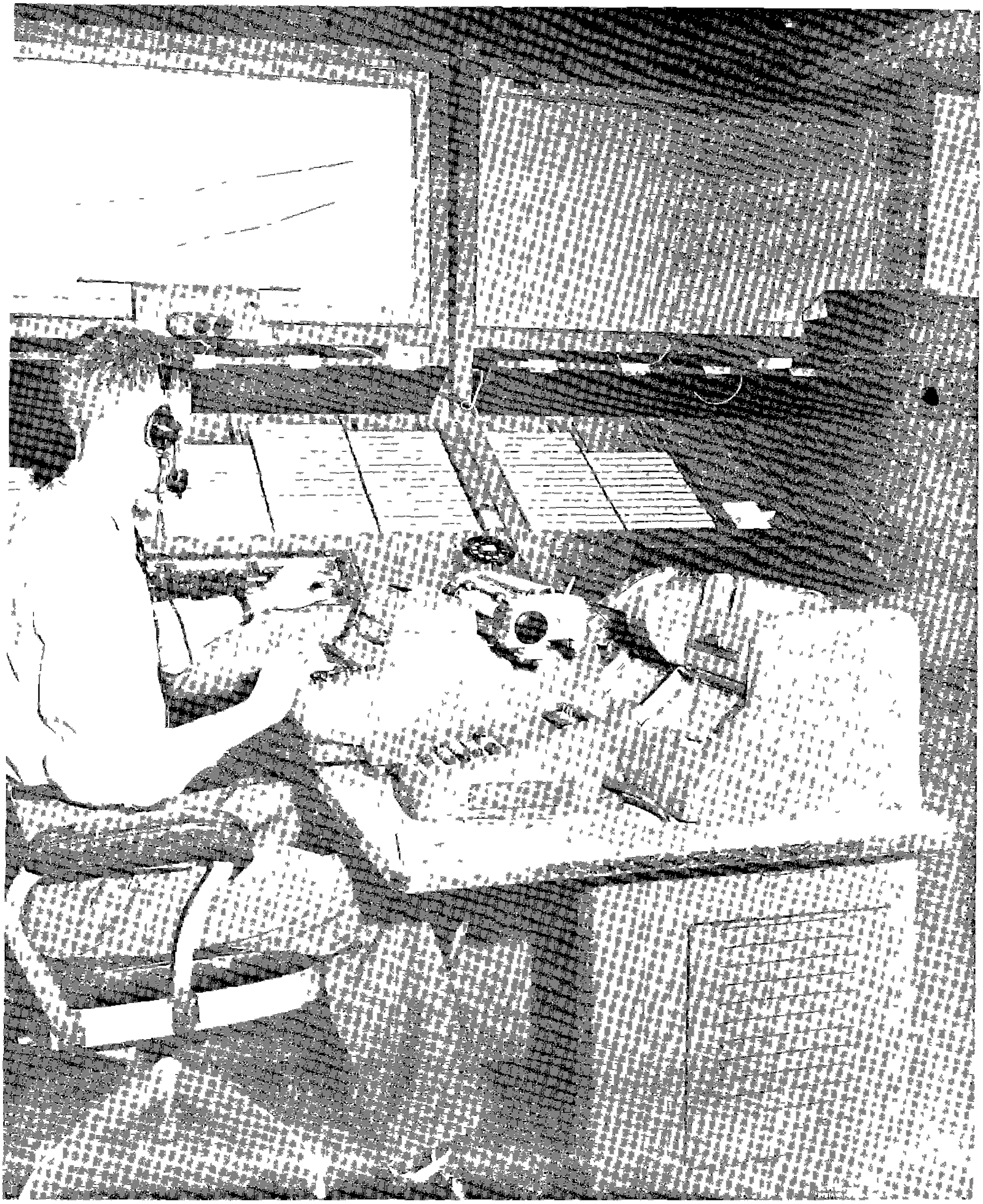


FIG. 5 IBM 026 CARD PUNCH

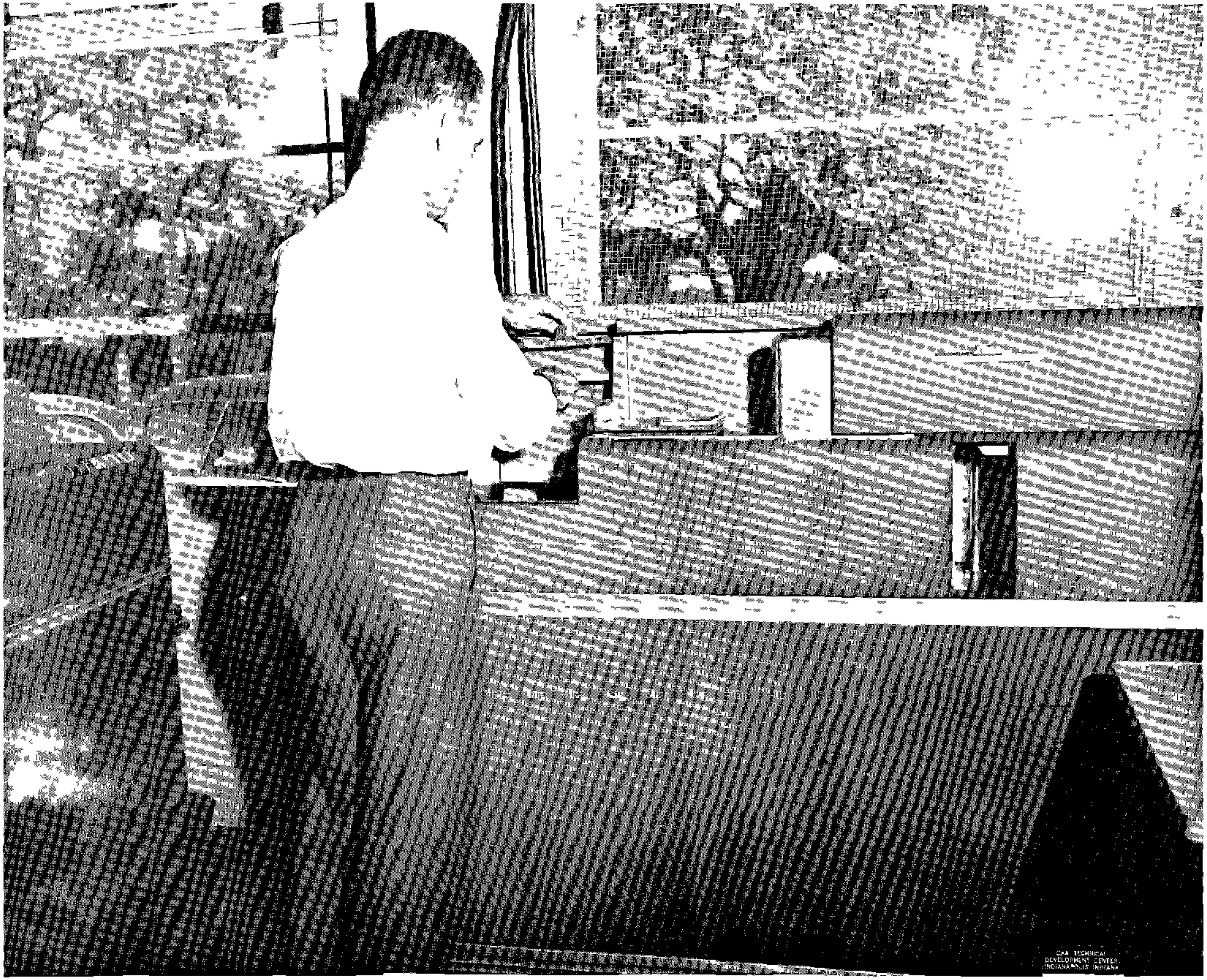
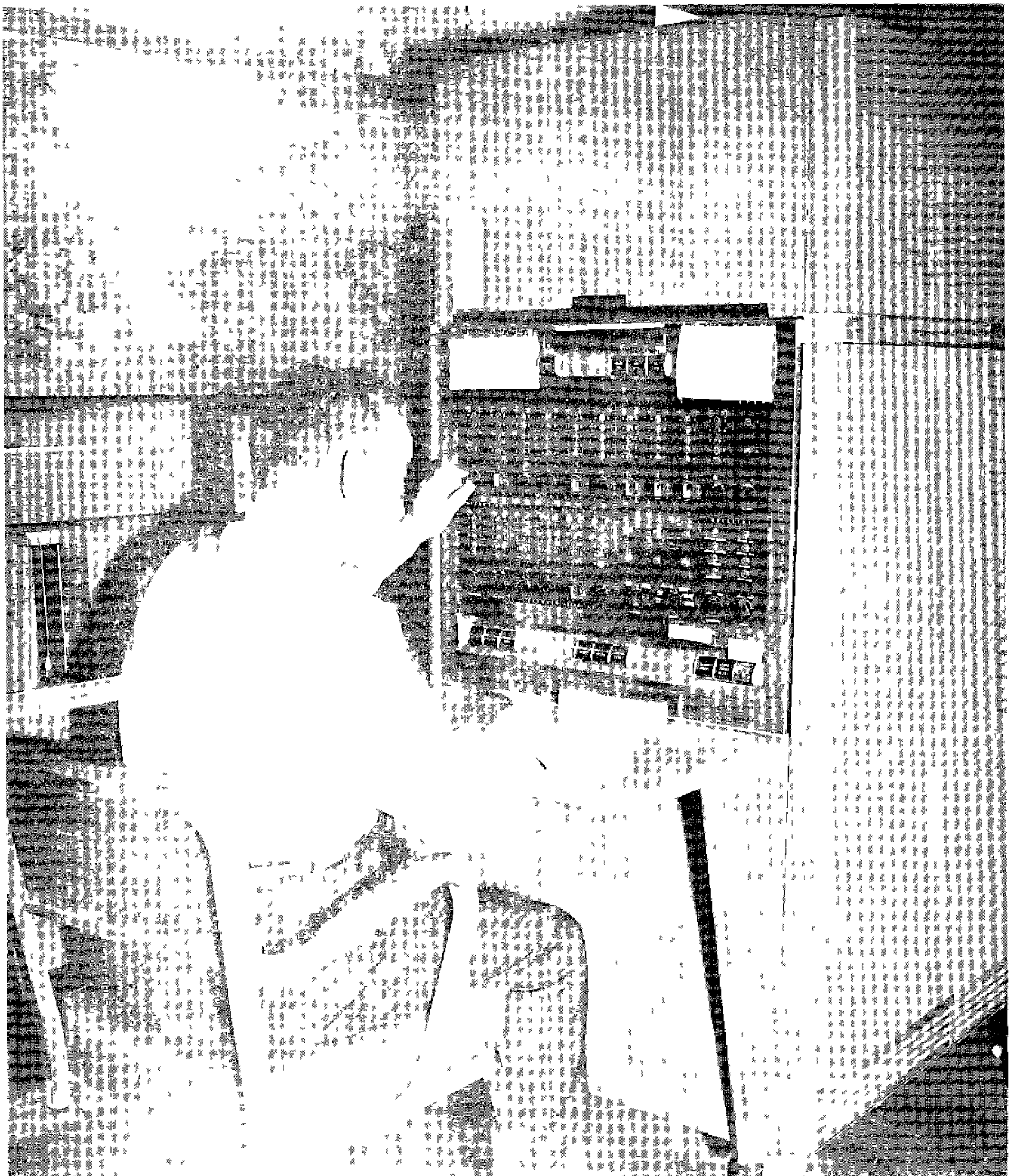


FIG 4 IBM 533 INPUT-OUTPUT UNIT



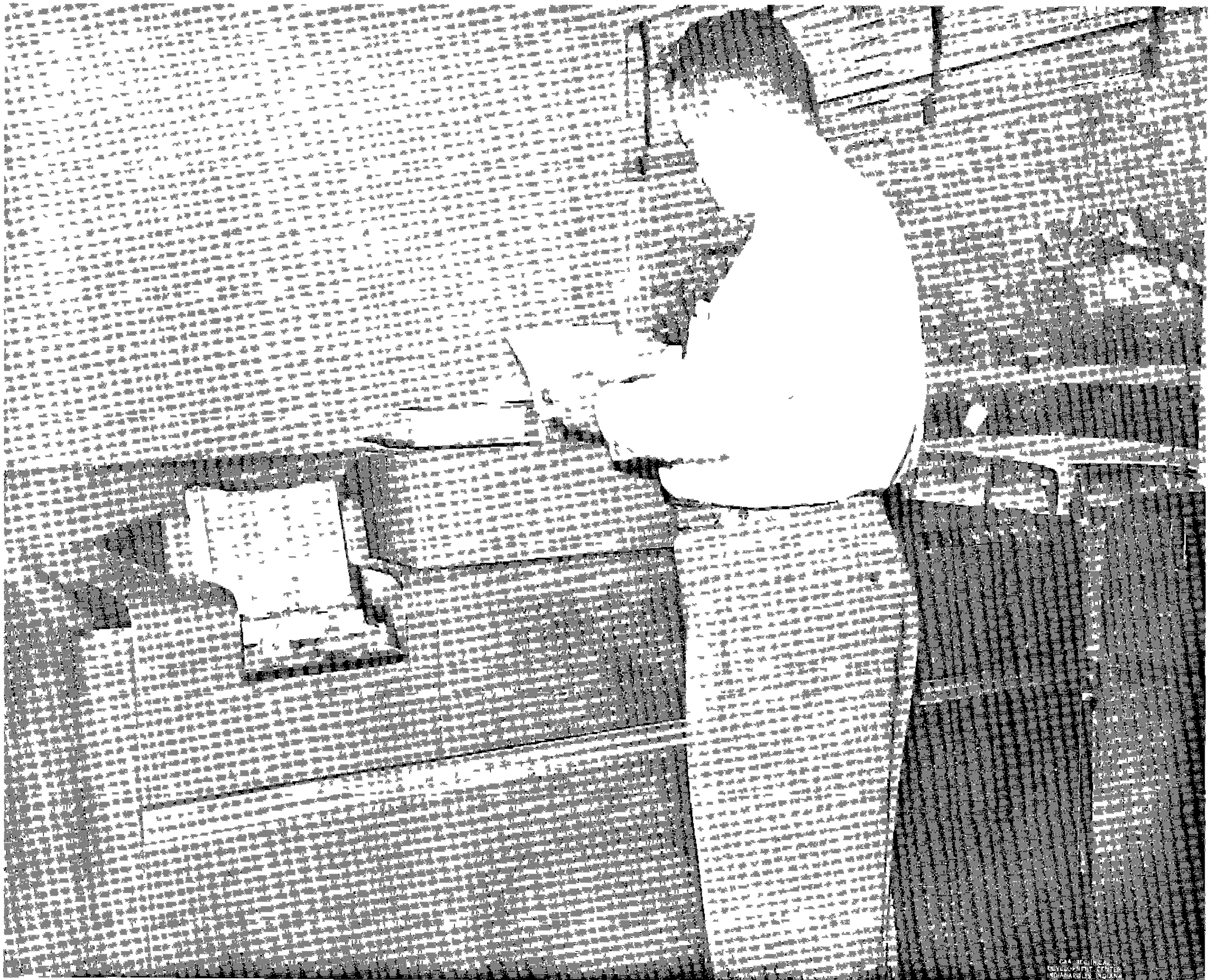


FIG. 6 IBM 407 ACCOUNTING MACHINE PRINTER

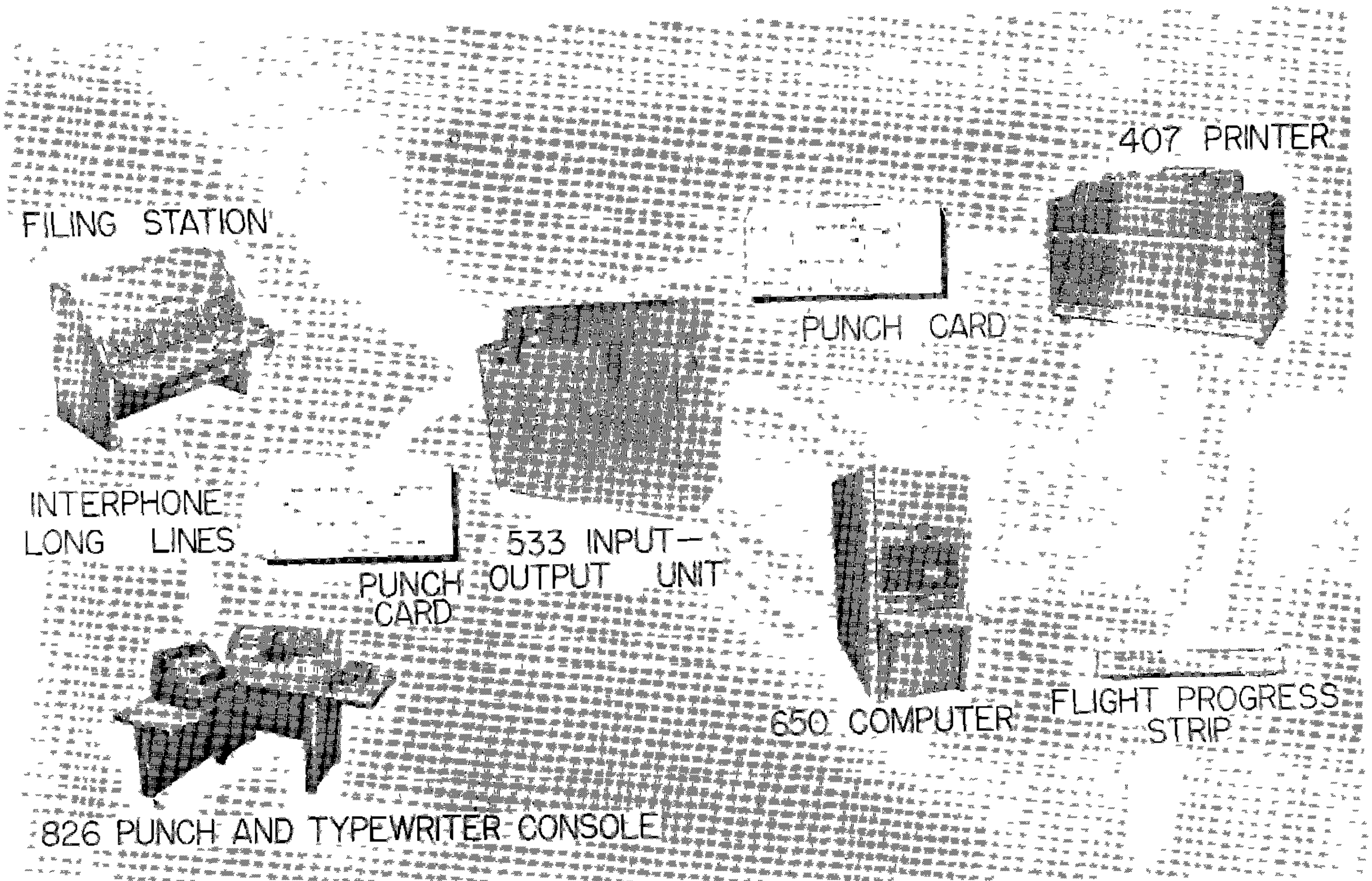


FIG 7 INFORMATION FLOW THROUGH IBM 650 SYSTEM

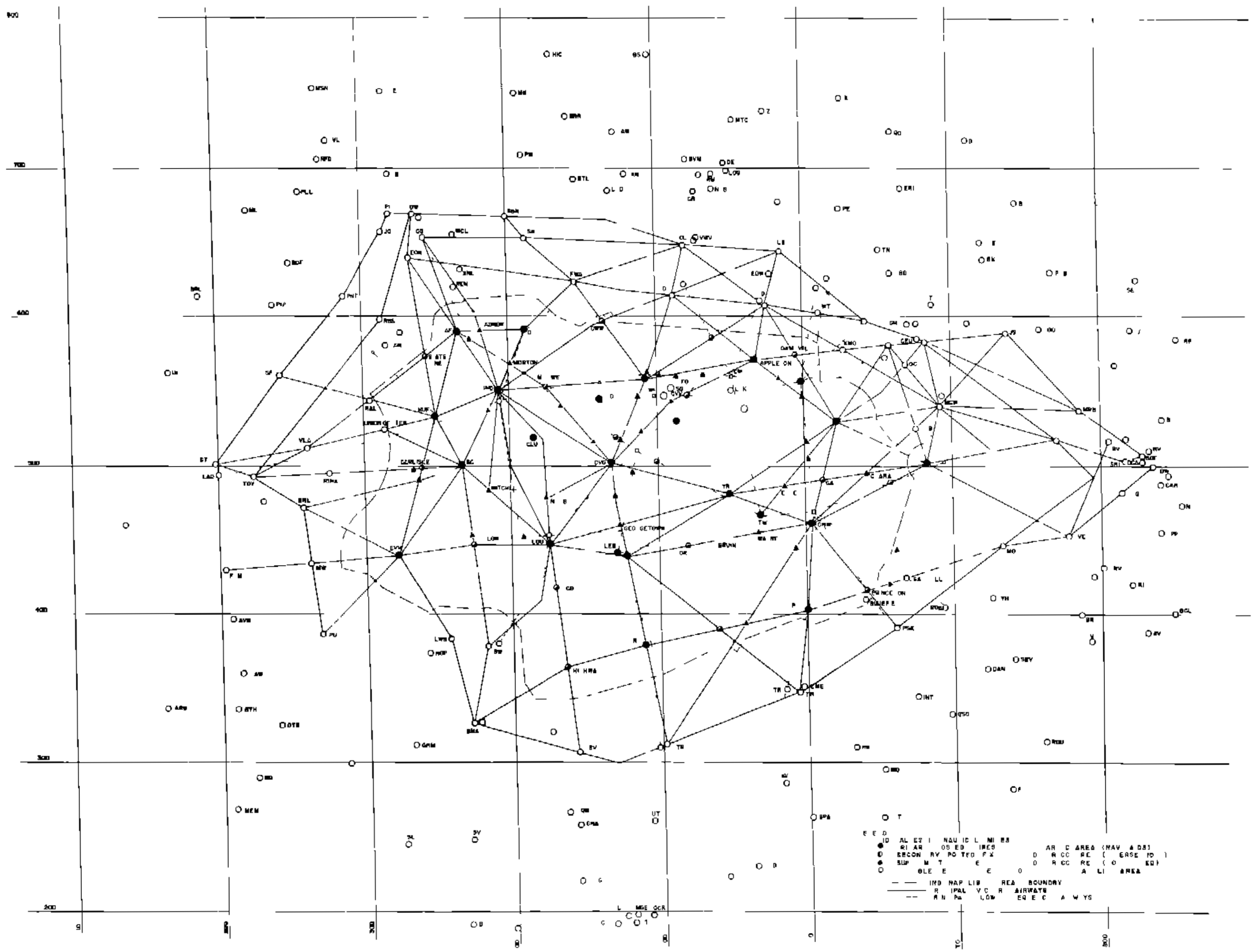


FIG. 8 COORDINATE SYSTEM

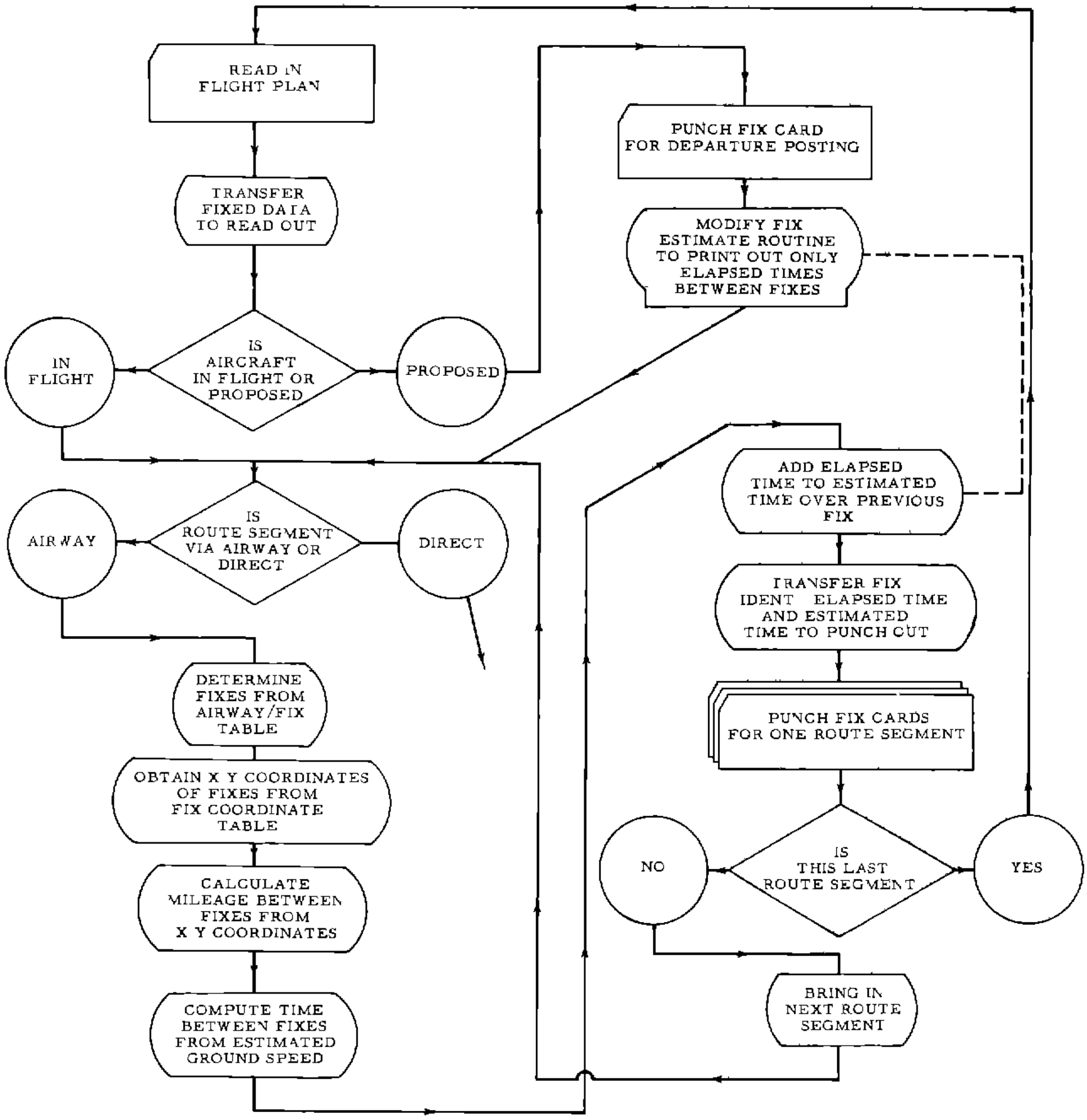


FIG 9 SIMPLIFIED FLOW CHART FOR AIRWAY FLIGHT

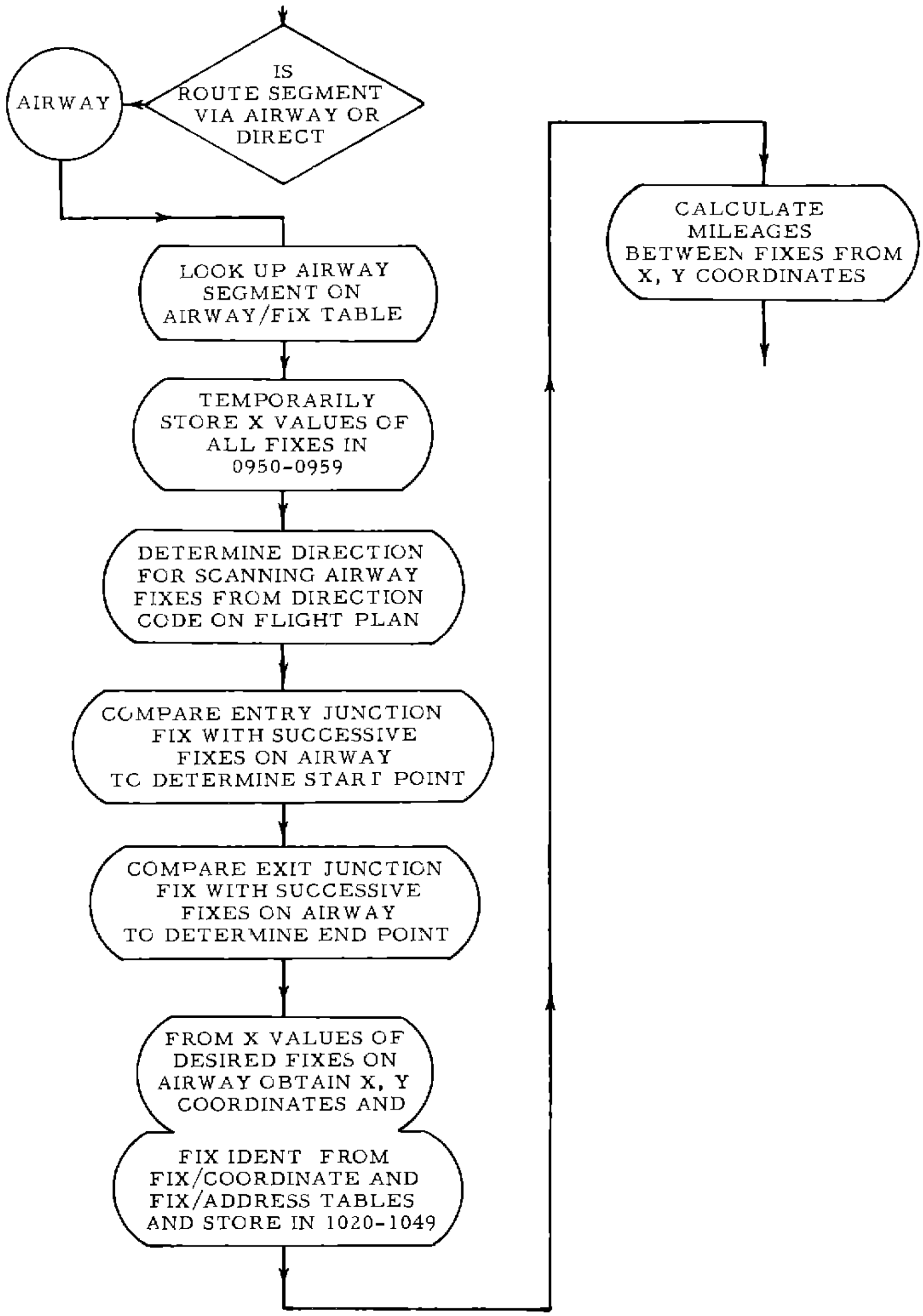


FIG 10 FLOW CHART AIRWAY PROCESSING - DETERMINING FIXES TO BE POSTED

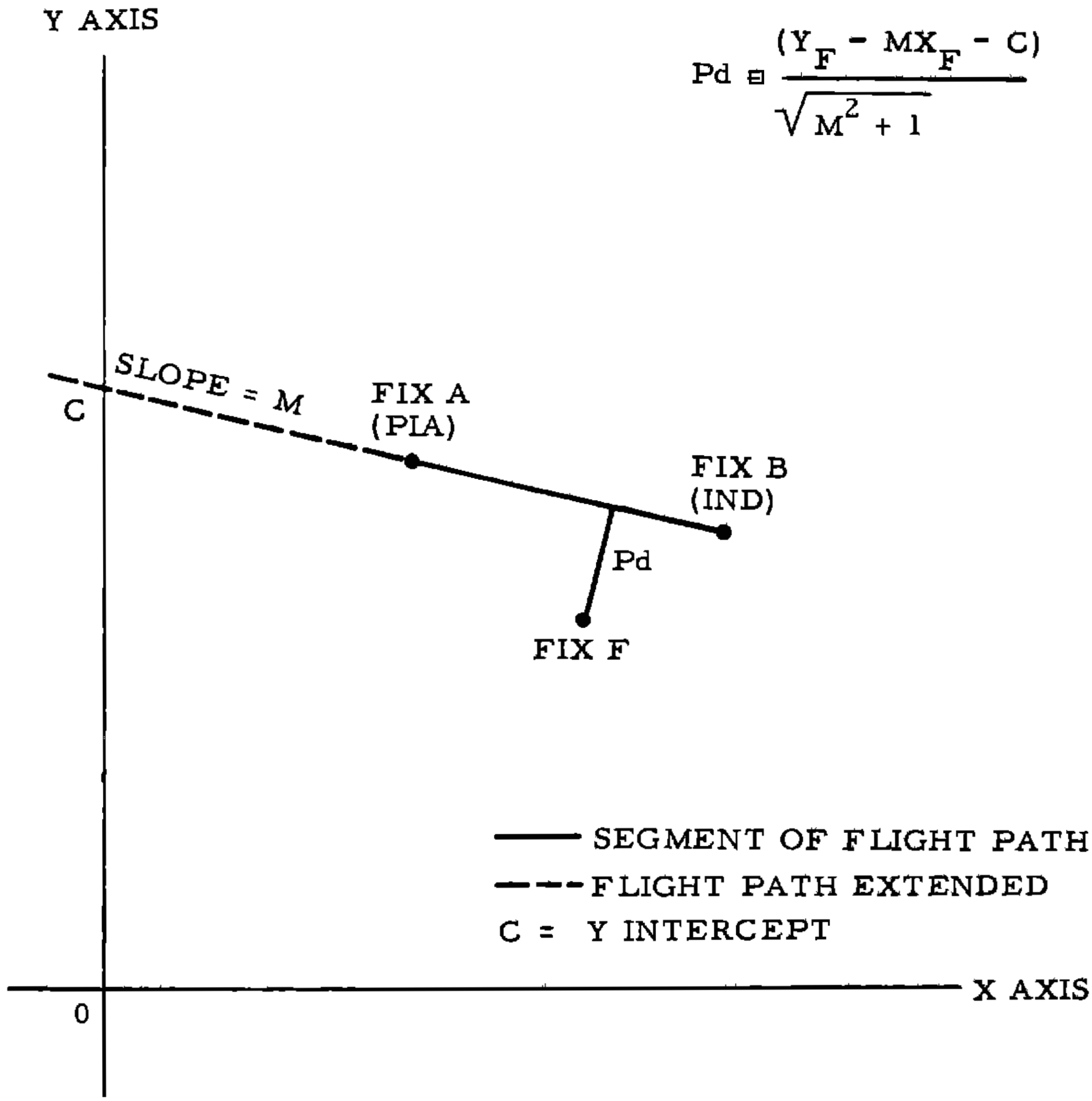


FIG. 11 DETERMINING FIXES ADJACENT TO DIRECT ROUTES

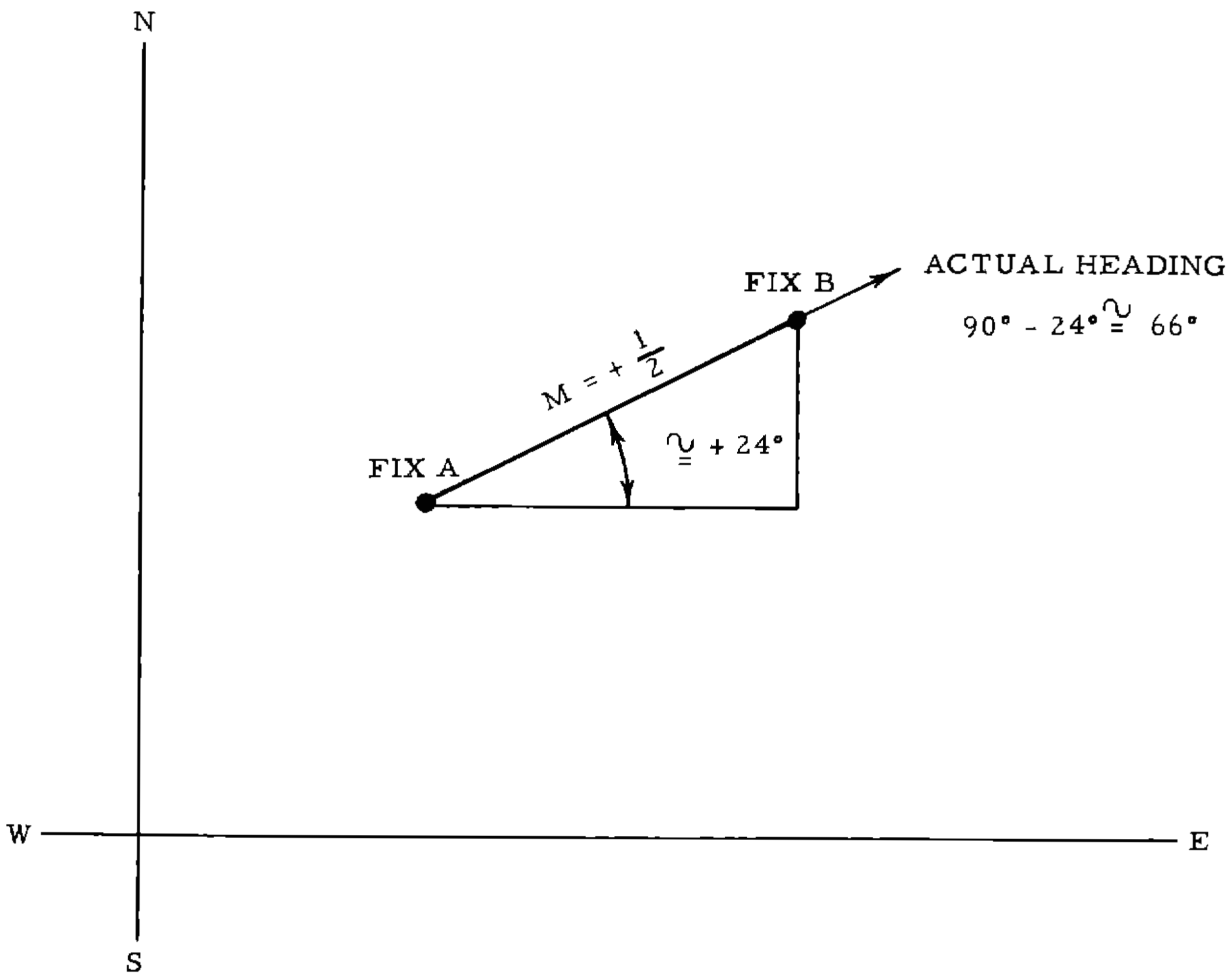


FIG. 12 DETERMINING HEADING OF AIRCRAFT

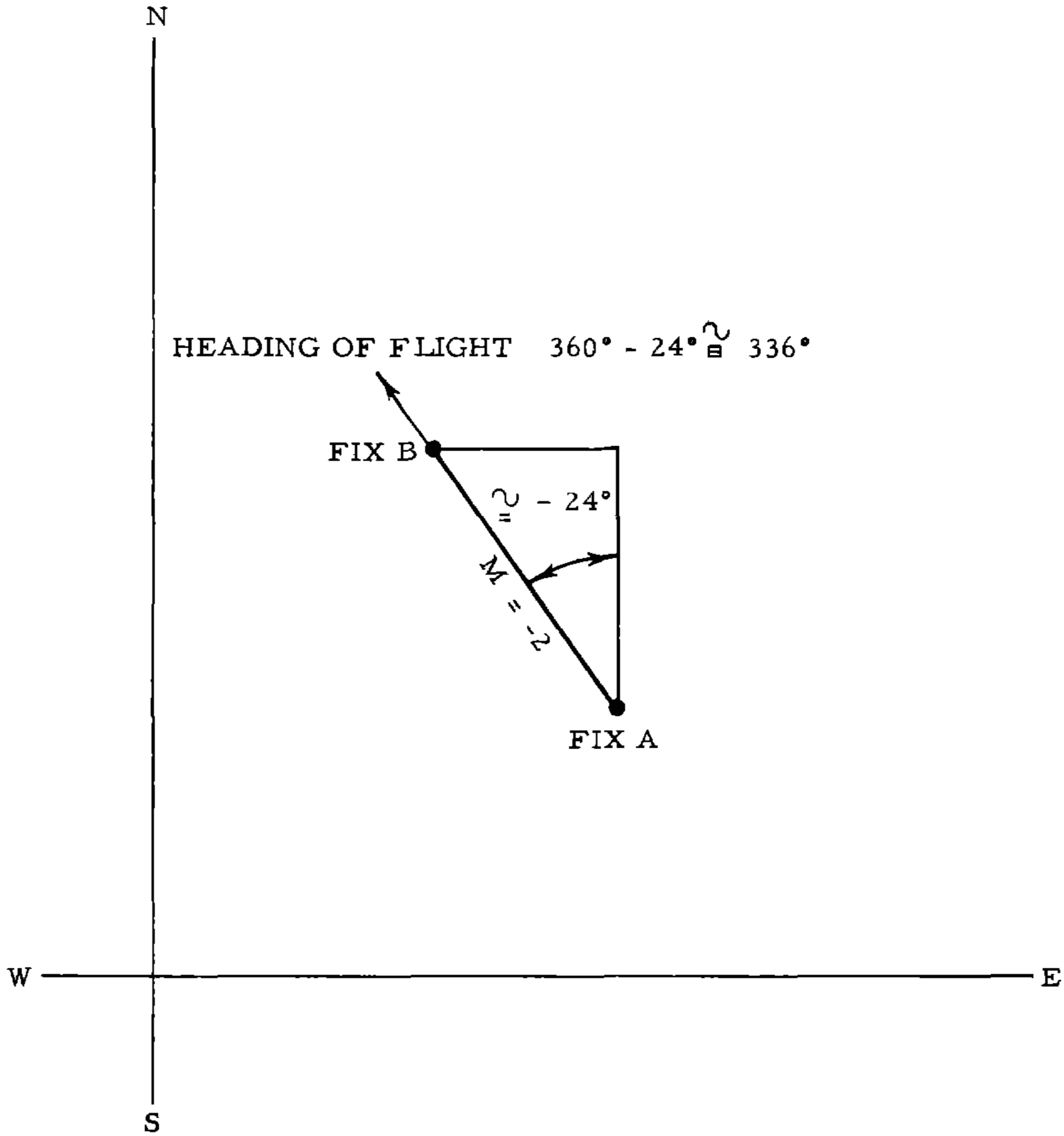


FIG. 13 DETERMINING HEADING OF AIRCRAFT

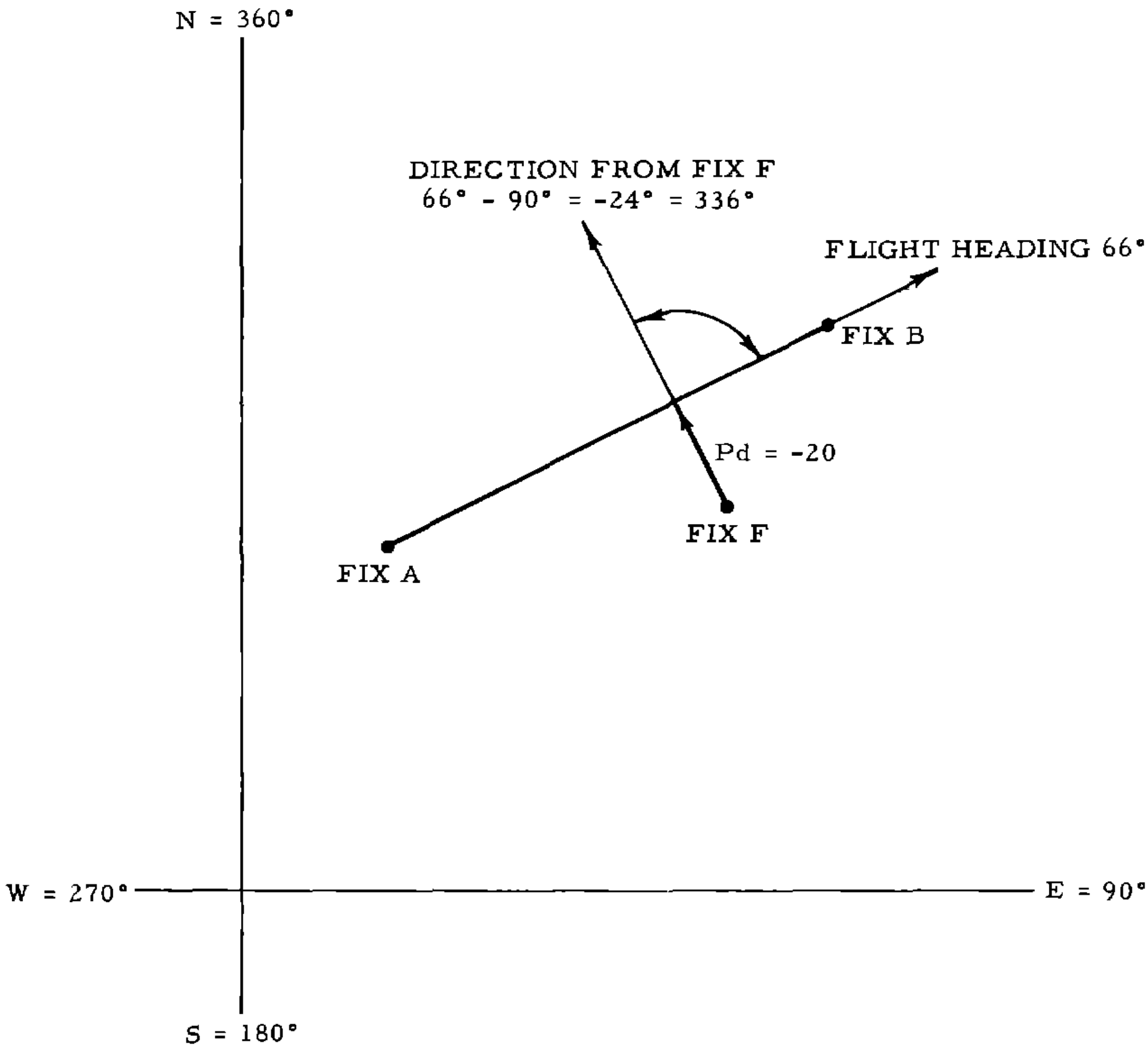


FIG. 14 DIRECTION FROM FIX

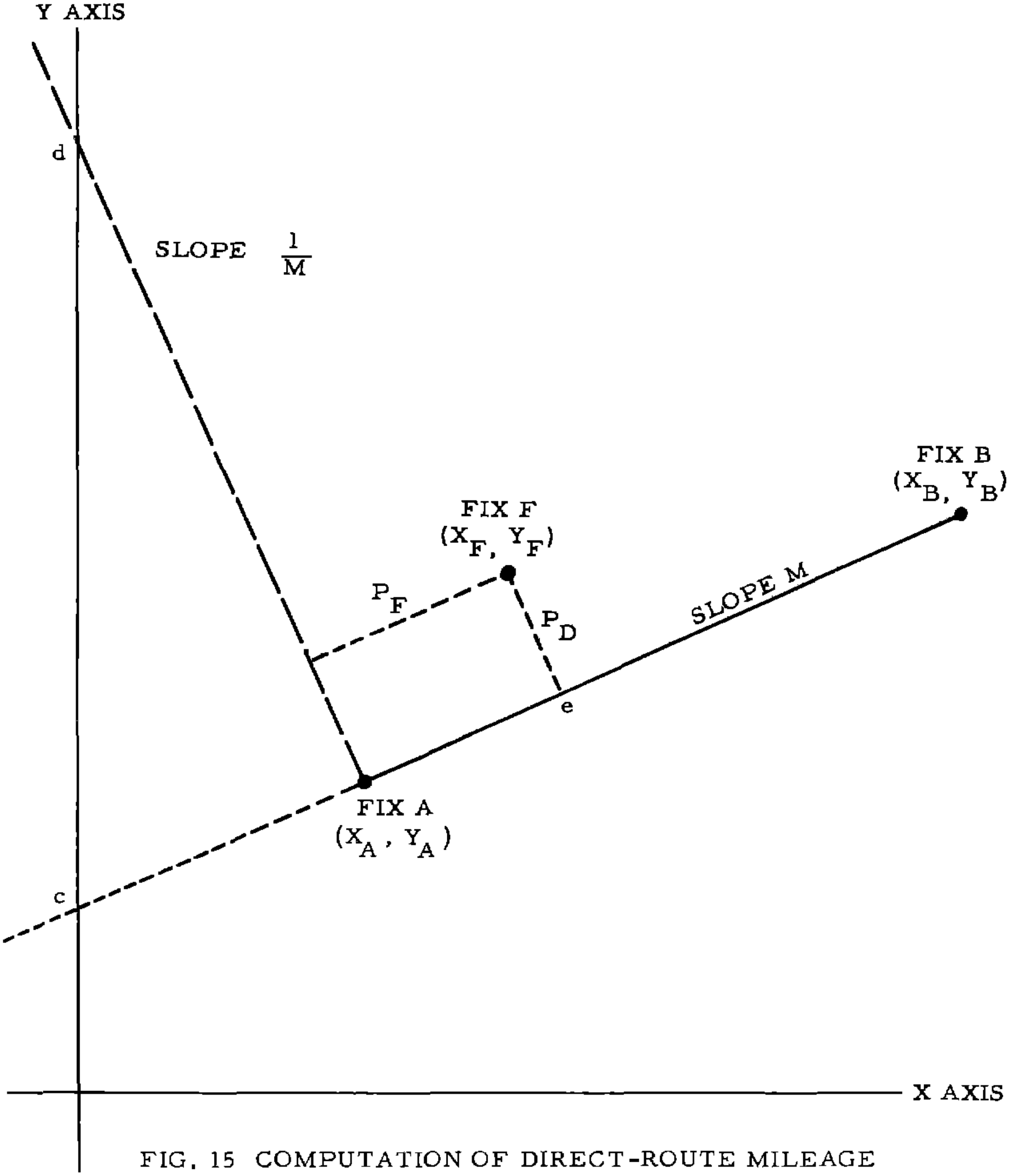


FIG. 15 COMPUTATION OF DIRECT-ROUTE MILEAGE

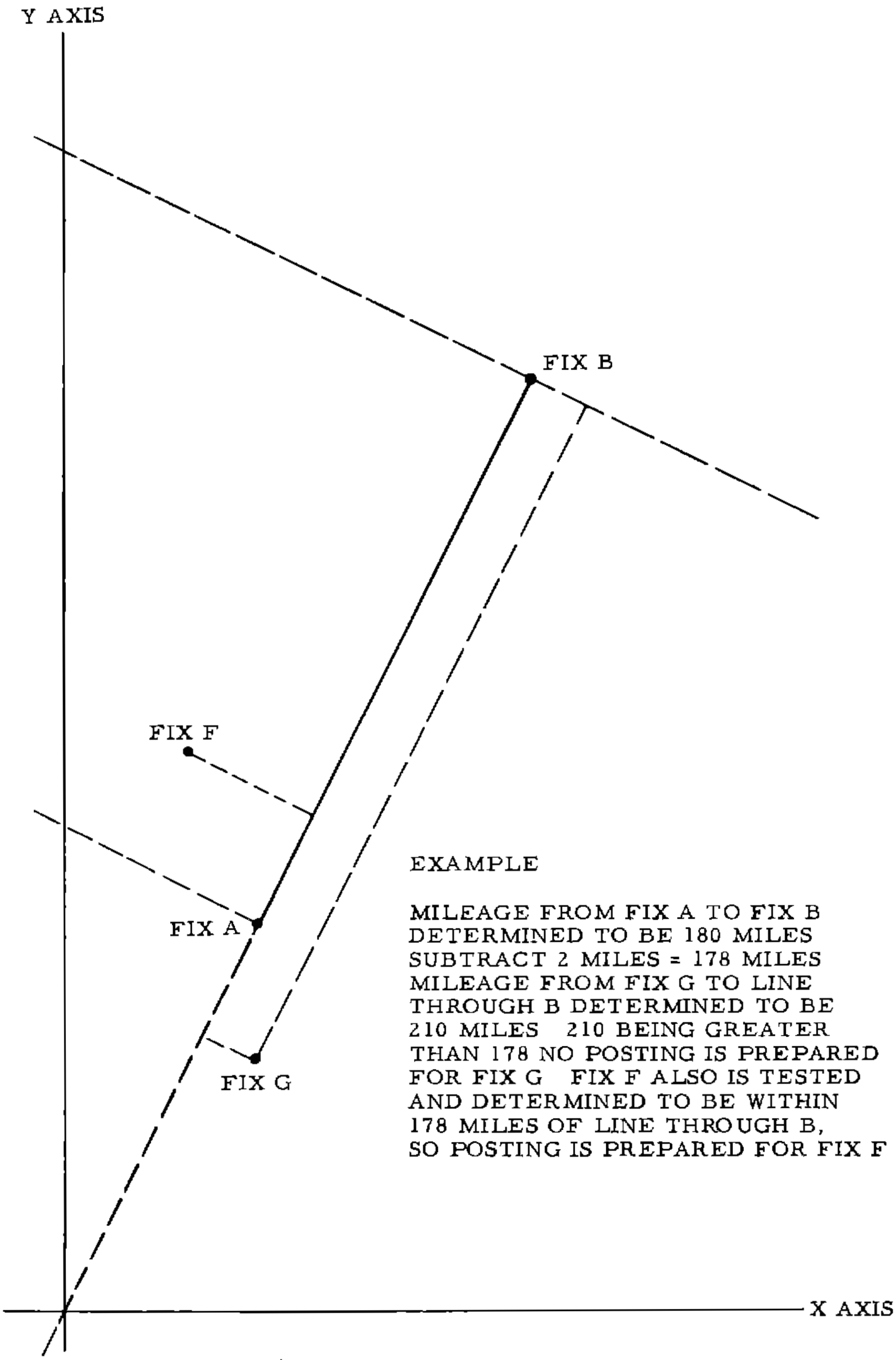


FIG 16 REJECTING UNWANTED FIXES

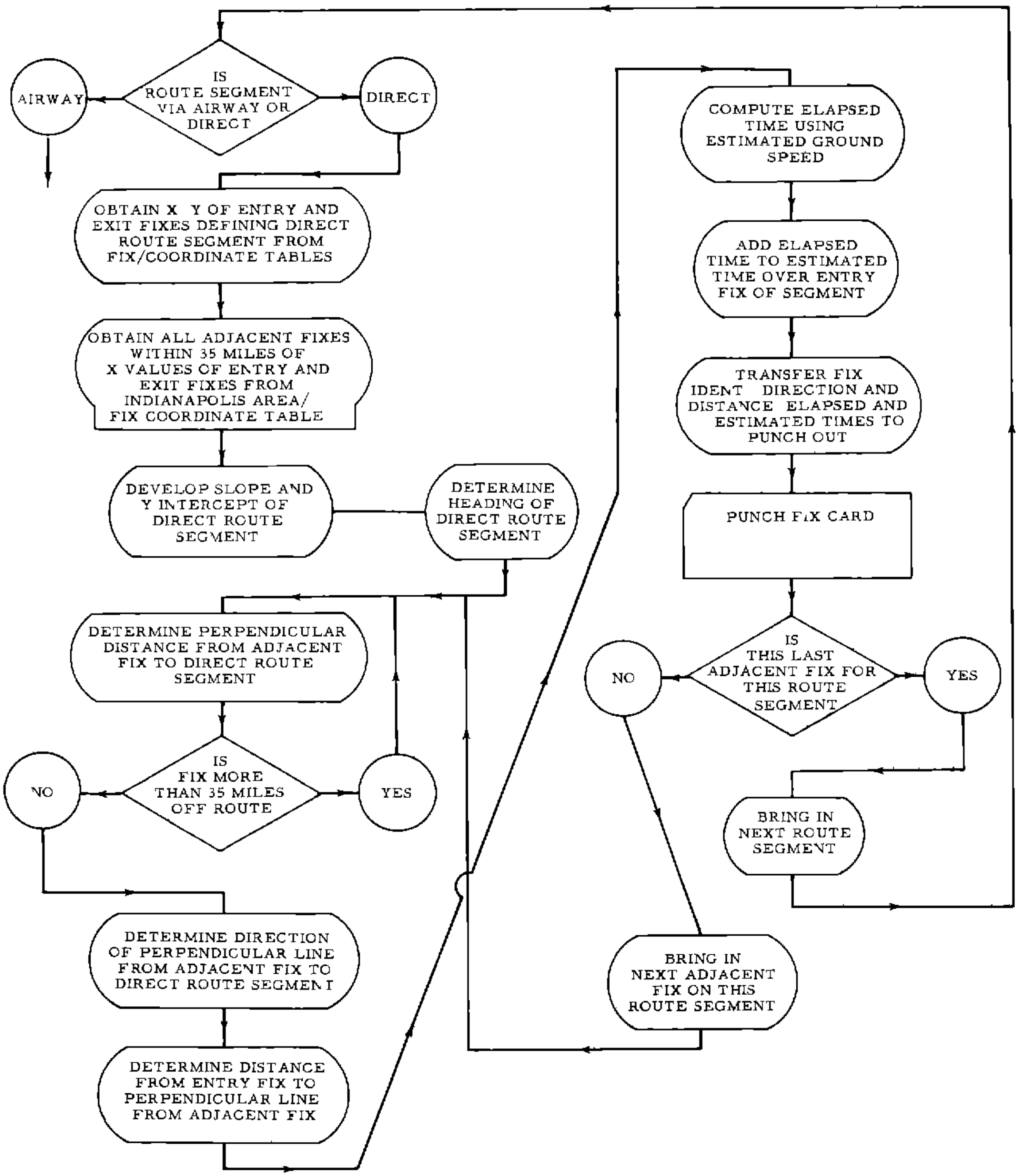


FIG 17 SIMPLIFIED FLOW CHART FOR DIRECT-ROUTE FLIGHTS

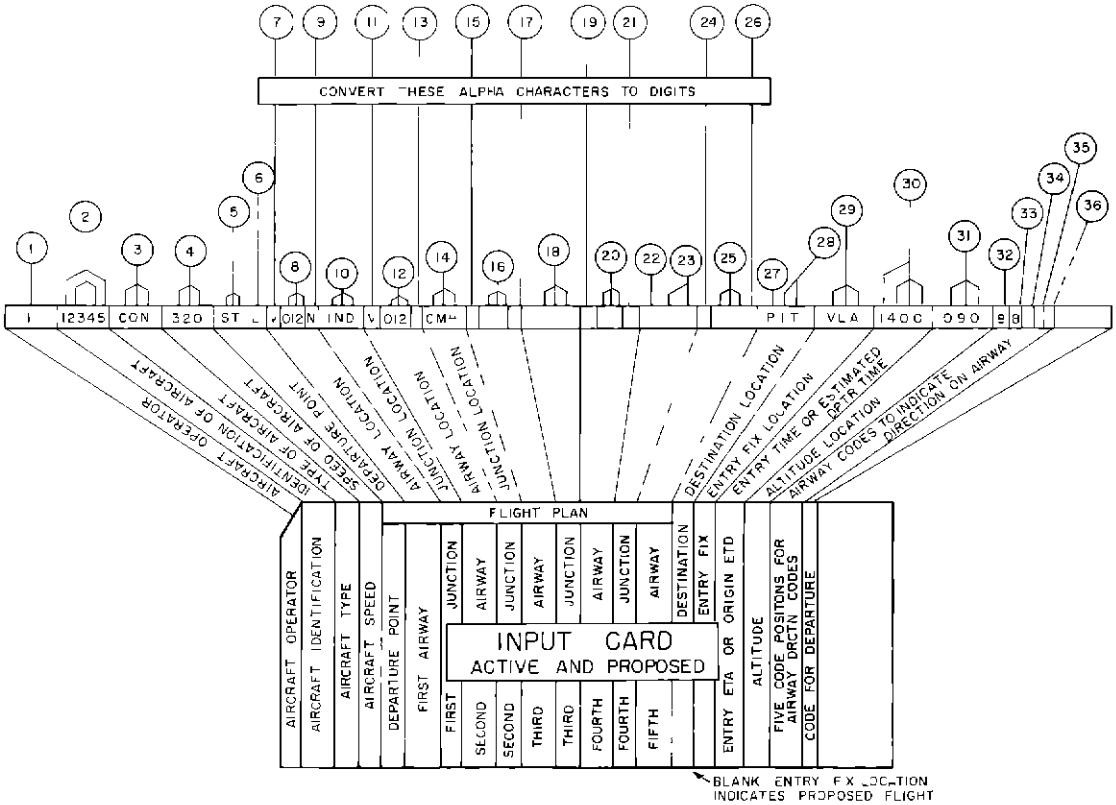


FIG 18 A INPUT CARD

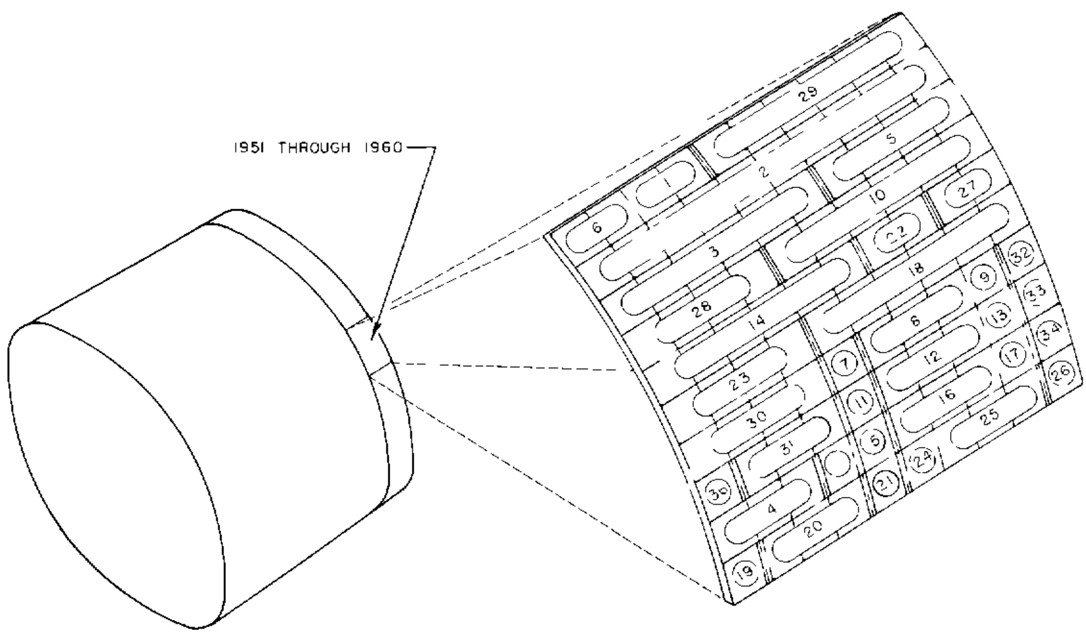


FIG 18 B FLIGHT PLAN ARRANGEMENT AT INPUT BUFFER

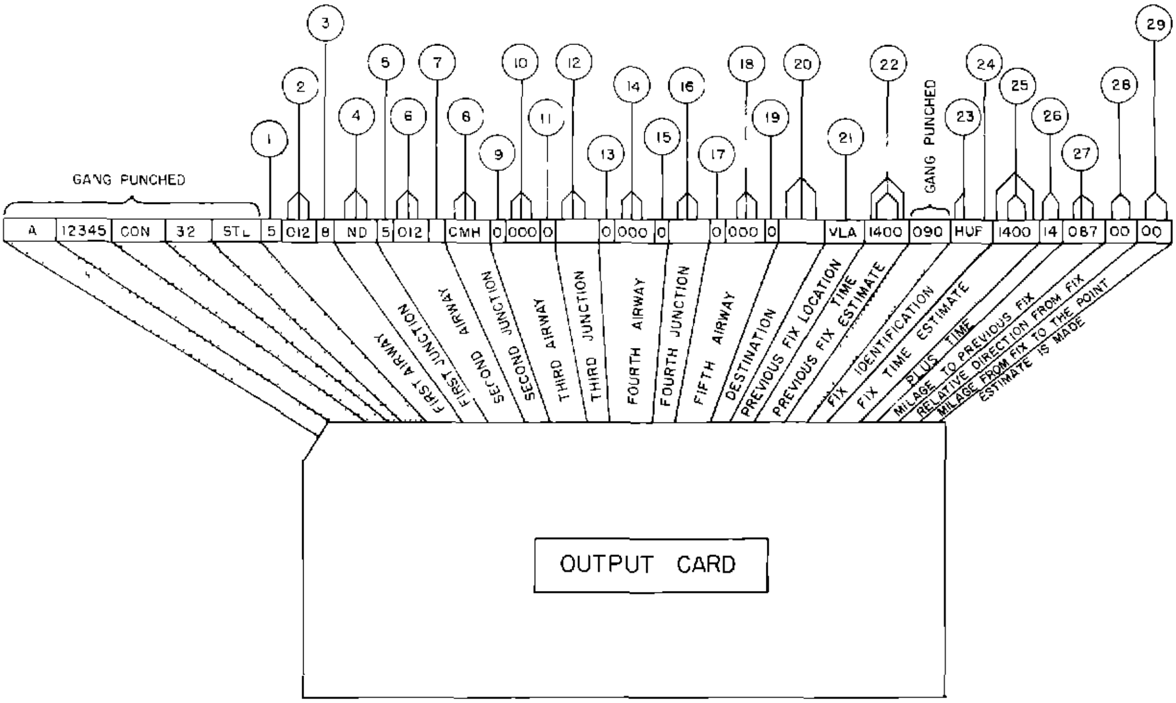


FIG 19A OUTPUT CARD

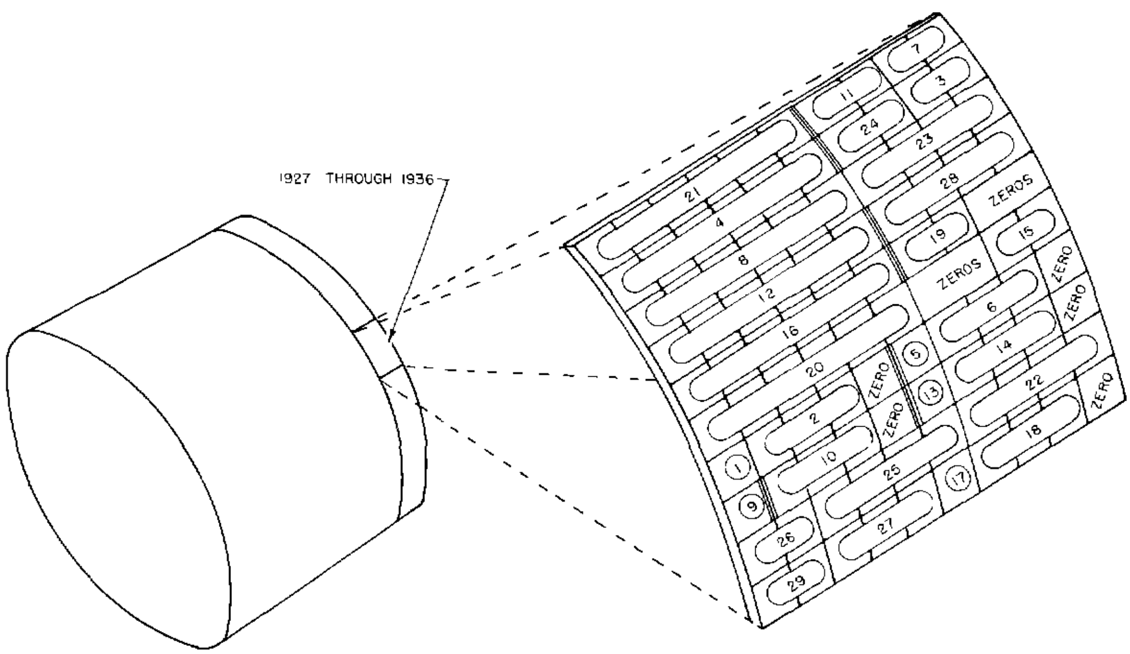


FIG 19B FLIGHT PLAN ARRANGEMENT ON OUTPUT BUFFER