PROGRAMMING IBM 650 RAMAC COMPUTER

FOR

DATA PROCESSING

IN AN

AIR ROUTE TRAFFIC CONTROL CENTER

Federal Aviation Agency

Bureau of Research and Development

NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER

Atlantic City **New Jersey**

FEDERAL AVIATION AGENCY
NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER
ATLANTIC CITY, NEW JERSEY

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RD-440

Director
Federal Aviation Agency
Bureau of Research & Development
Washington 25, D. C.

Subject Programming IBM 650 RAMAC Computer for Data Processing - Indianapolis ARTC Center

Dear Sir

The project of programming the IBM 650 RAMAC computer for Data Processing at the Indianapolis ARTC Center was assigned to the Technical Development Center, Indianapolis, Indiana. The Director of the Technical Development Center assigned this project to the Navigation Evaluation Aids Division under TDC Project No. 59-730

The facilities and personnel of TDC, IBM at Indianapolis, and the Indianapolis Center were utilized to accomplish this task. (All preliminary programming and data collection was accomplished at Indianapolis. The Final Report was written at NAFEC. This report entitled "Preliminary Programming of an IBM Computer for processing data in an Air Route Traffic Control Center" is forwarded herewith.

Sincerely,

Wm S. Cowart, Jr.

William S. Cowart, Jr.
Colonel, USAF
Director, NAFEC

1 Enclosure
May 1, 1959
Preliminary Programming of an IBM 650 RAMAC Computer for processing data in an Air Route Traffic Control Center

FINAL REPORT

PRELIMINARY PROGRAMMING OF AN IBM 650 RAMAC COMPUTER FOR PROCESSING DATA IN AN AIR ROUTE TRAFFIC CONTROL CENTER

RELATED TO

TECHNICAL DEVELOPMENT PROJECT NO 59-730

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OCT 8 1959

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NATIONAL AVIATION FACILITIES EXPERIMENTAL CENTER

ATLANTIC CITY, NEW JERSEY

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ABSTRACT

To fully explore the use of digital computers for data processing and display in Air Traffic Control Centers, the IBM-650 RAMAC system was installed in the Indianapolis ARTC Center in July 1958

PURPOSE

In Air Route Traffic Control Centers (ARTCC), flight plans received from pilots are processed and posted on flight progress strips for the controller display board A flight progress strip is prepared for each fix posting area over which a flight will pass Manual preparation of these strips is a time-consuming task, and during busy periods the assistant controllers are frequently so busy with this task that they have little time to assist the controller

The IBM-650 computer system originally installed at the Indianapolis ARTC Center proved that it is possible for a computer system to process flight information and print flight progress strips, but there were operational limits on what types of flight plans could be processed.[1,2] Since the main limitation was the lack of sufficient storage, it was believed that the addition of the RAMAC 600,000-word storage unit to the IBM-650 would improve processing of flight plans The possibility of additional routines was one of the primary things kept in mind during the development of the program for the new computer system A decision was made to develop the following routines for the IBM-650 RAMAC system.

1 Prepare flight progress strips.
2. Store flight data in the computer.
3 Modify and update stored data
4. Forward flight data between centers and to Air Defense Command (ADC)

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[1] G B. Harwell, C E. Dowling, and F S. McKnight, "Programming the IBM-650 Computer for Preparation of Flight Progress Strips in CAA ARTC Centers", TD Report No. 346, March 1958

[2] F. W. Pickett, C. E. Dowling, and F. S. McKnight, "An Operational Evaluation of the IBM-650 Computer for Air Traffic Control", TD Report No 400, April 1959

This report describes the program for the IBM-650 RAMAC computer, which was prepared by TDC, the IND ARTCC Center, and personnel of IBM Corporation.

SUMMARY

This report describes the development and preparation of a detailed ATC program for an IBM-650/RAMAC computer system. Many portions of this program are predicated on the ability of this system to process all of the many types of flight plan information, to produce flight progress strips, and furnish other information needed for the control of air traffic at the Indianapolis Air Route Traffic Control Center.

A description is given of the types and quantities of flight plans which must be processed A general discussion of the program logic used for processing airway and/or direct route flight plans is included and is illustrated by charts, flow-diagrams, and pictures.

INTRODUCTION

The Indianapolis ARTC Center is one of the 30 centers in the United States assigned the responsibility for the control of instrument flight rule (IFR) air traffic. The Indianapolis control area is shown in Figure 1. This area is approximately 350 nautical miles long, east-to-west, and 250 nautical miles wide, north-to-south.

There are more than 125 airways within the Indianapolis area, with a total length of more than 15,000 miles. In many cases, airways overlap each other for some distances. There are 54 principal navigation aids defining these airways. There are two types of airways existing below 24,000 feet; those using low frequency (LF) navigation aids, and those using an omni-directional system operating on very high (VOR), and ultra high frequency called VORTAC. At 24,000 feet and above, there are three types of airways called jet tracks. The first type is based on LF facilities, the second on VOR facilities, and the third on TACAN facilities. Flights below 24,000 feet are posted at or with respect to 48 fix posting points. Nine of these fix posting points are used for flights 24,000 feet and above. In addition to the 48 fix posting points, there are more than 140 secondary radio fixes which are used for control purposes or by the pilots to define their route of flight. Many of the navigational aids and radio fixes are common to more than one airway. To distribute the workload, the center area is divided into sector areas containing a number of fix posting points. There are 18 sector areas for the control of IFR air traffic below 24,000 feet and three sector areas for 24,000 feet and above.

Approximately 80 per cent of the flights through the area are via airways. The remaining 20 per cent of the flights are from point-to-point via direct routes, or via a combination of airway and direct routes.

Flight plans, filed with the Indianapolis ARTC Center containing the following information, are received via teletype, interphone and direct radio communication:

1. Flight identification.
2. Type of aircraft (and number if more than one aircraft is in the flight).
3. Airspeed, or ground speed if flight is active
4. Altitude.
5. Point of departure.
6. Route of flight
7. Destination.

8. Proposed time of departure or entry fix and estimated time of arrival over the fix.

Item 6, the route of flight, may specify one or more airways, or it may specify radio fixes with the route of flight direct between these fixes.

Radio fix identifiers are composed of either three alphabetical characters or one numeric and two alphabetic characters. These characters are used on the flight progress strips and also in transmission of flight plans via teletype.

Manually prepared strips are less readable than machine produced strips although the same information appears on both types of strips. In addition to the basic flight plan information, which is repeated on all strips, the fix designator and estimated time over the fix is also entered on each strip. When preparing these strips for airway flights, the assistant controller must determine the fix posting points over which the flight will pass and prepare a strip for each of these points. He must also estimate the time a flight will pass over the fix posting point based on the estimated ground speed and the mileage between fixes.

For direct route flights, frequently it is necessary to refer to a large plotting map and, by using some type of a straight edge, determine which of the fix posting point areas the flight enters. A flight progress strip is prepared for each fix posting point area through which the flight passes. The distance and direction from the fix, as well as the estimate of the time the flight will pass this point, must be calculated and posted.

The average number of fix postings per flight in the Indianapolis area is five. On an average day, approximately 5,000 postings are prepared during a 24-hour period, whereas, on a peak day, more than 7,000 fix posting strips are prepared.

650 RAMAC SYSTEM

The IBM-650 RAMAC system installed at Indianapolis ARTCC consists of an IBM-650 computer, a RAMAC disc memory storage unit and other associated equipments listed below. **(Figures 2 - 6)**

1. One Type-047 Tape-to-Card Printing Punch. Type-047 is a printing card punch with a paper tape reading unit mechanically attached It automatically punches and prints on the card the information from the tape
2. One Type-063 Card-Controlled Tape Punch Type-063 is a card reading unit with a paper-tape punch
3. Two Type-838 Inquiry Stations as shown in Figure 2. Type-838 has an electric typewriter with standard keyboard and single case type It is directly connected to the computer as an input-output device. There is a cabinet of control buttons and lights at one side of the station
4. Six Type-826 Typewriter Card Punch Units as shown in Figure 3. Type-826 is an electric typewriter attached to a printing card punch. A small keyboard at the right of the typewriter contains numeric characters and special keys relating to card handling such as card release
5. One Type-655 Power Unit.
6. One Type-652 Control Unit. The Type-652 controls disc storage and the Type-838 units.
7. One Type-653 Storage Unit. The Type-653 has the capacity for 60 words (ten digits plus sign) of immediate access (core) storage, and three four-digit accumulators known as Indexing Registers.
8. One Type-355 Disc Storage Unit as shown in Figure 4. The Type-355, or RAMAC, is a magnetic storage unit with the capability of storing

600,000 words It has three independent access arms which read and write data under programming control on the 50 discs (100 disc faces) available for storage.

9 One Type-407 Accounting Machine as shown in Figure 4 The Type-407 is a card reader and a printer directly accessible to the computer when used 'on-line'. The Type-407 has been modified by.

a The addition of a ribbon shift device, which will permit printing information in either of two colors

b. The modification of the Multiple Line Read (MLR) function for reading a card more than one time to permit the IBM 650 RAMAC computer program to control the MLR function for on-line use

c The replacement of normal print wheels by 11 intermediate-sized and two large-sized print wheels

d. The addition of one group of five pilot selectors and three groups of four co-selectors for the wiring panel.

e. The addition of one group of four co-selectors and of an alpha device which will permit eight words of alphabetic output instead of six.

10 One Type-533 Card Read Punch Unit as shown in Figure 5. The Type-533 is a card reader input device and a card punch output device

11 One Type-650 Console Unit Figure 6. The Type-650 contains a 2,000-word magnetic storage drum, calculating units, and the control console This Type-650 has been modified to include the following instructions·

a Table-Look-Up Equal· This command permits the computer to search general storage for an exact equal

b Branch on Table Overflow This command is used with table-look-up equal to permit the modification of the next instruction without making an arithmetic comparison to determine if an equal was found in the table.

c. Set Format: This command permits the computer to extract from general storage information that is less than the basic ten-digit word length.

d. Branch on Buffer Busy: This command permits the computer to test various input areas and branch to other program routines when no input is available. Without this command the computer will stop when the program requests input and there is none available.

Other modifications and additions include

a. Buzzer Alarm· This alarm indicates to the computer operator that output cards have been punched by the Type-533.

b. Computer Clock. The clock, addressable by the computer, obtains real-time.

Figure 7 is a diagram showing the flow of information in the existing IBM-650/RAMAC system. The flight plan originates either with an interphone message to a Type-826 operator who punches a card and puts it in a station from which it is hand-carried to the Type-407 operator, or it originates with a teletype message, which is converted from teletype tape to an IBM card by the Type-047, and hand-carried to the Type-407 operator. The operator enters the card into the hopper of the Type-407. The on-line Type-407 reads the flight plan from the card into the Type-650, where it is processed by a stored program All arithmetic operations are performed in the Type-650 arithmetic registers. On command of the stored program, the Type-407 prints flight progress strips.

Some processing instructions will be stored in the Type-653 immediate access storage, although this storage is used predominantly for transferring information from RAMAC storage to the drum.

Flight plans are transferred from the Type-650 to RAMAC storage through the Type-653. The Type-533 is used to punch cards containing information in the Type-650 for conversion to teletype tape by the Type-063.

There is thus no human intervention between the time that the flight plan card is put into the hopper on the Type-407 and the time that the strips are printed.

The Type-838 Inquiry Typewriter is used for special input messages and for special output messages. For instance, cancellation of a flight plan would go into the computer through the Type-838.

DISCUSSION

INPUT ROUTINE

Information is entered into the system by means of punched cards. These items of information are punched in a fixed sequence Between each item of information, which may be of varying length, is a space which is used by the Input Routine to determine where each item of information ends.

The Input Routine is the first part of the program to operate on the incoming information. The Input Routine organizes all incoming flight data, which then is used by the Airway Routine and the Direct Routine.

The Input Routine further determines whether the item is of indicative information or one of routing. See Figure 8 All indicative information, which includes, flight identification, type of aircraft, speed, altitude, and the time of departure, is stored in predetermined storage locations which will be referred to by both the Direct Routine and the Airway Routine. Except for identification, these are the locations from which information will be drawn, for printing the Flight Progress Strips. The routing is stored two ways by the Input Routine (1) With space separating each item of routing in the output bands, and (2) With one item per word in the processing table. Figure 8.

The Input Routine is capable of determining some types of errors in the flight plans which enter the computer. These are principally errors in the length of an item, or in its alphabetic and numeric composition.

The tables and bands required for processing the Input Routine are

1 Input Band. The 407 input band consists of drum locations 1339 to 1348 The information in it appears as in Figure 8, with one space separating each item of information.

2 Processing Table. The processing table appears as in Figure 9, with fixes in even locations, airways in odd locations, and one complete item per word.

3 Relative Direction Table The relative direction table is shown in Figure 10. The last digit of the location in which the relative direction appears is the relative direction code which is stored for the Direct Routine.

4 The Print Bands Figure 11A - 11C shows the contents of the print bands for three-line printing and Figures 12A - 12E for five-line printing. These areas of drum bands contain all of the information, which will be printed on the flight progress strips, except the aircraft identification.

The Input Routine is completed when all of the information from the flight plan card has been read into the computer and stored in the proper location for the use of the Airway and Direct Routines

The computer, using a small group of branch instructions, determines whether there is any computer input This input may be from one of the Type-838 Inquiry Typewriters, the Type-533 Read-Punch, a check of the time on the clock, or from the Type-407 accounting machine. As long as there is no information to enter the computer from any of these sources, the computer will repeat this series of instructions. When there is a card in the Type-407 card hopper, the answer to the Type-407 branch instruction "Is there 407 Input" changes to yes, and the computer proceeds to the Input Routine to start processing the flight plan

The flight plan card will be read once, and held by the Type-407 to be read again on command of the processing routine. On the first read instruction, the first 30 card columns are transferred into an input band (drum locations 1339 to 1348).

All of the information in the input band will be processed, then the computer program will determine whether there is more information awaiting the computer in this card. If there is, the next 30 columns will be read into this input band and processed. If there is more information in the card the last 20 card columns are read and processed

After the computer has read the first 30 columns of information, the Input Routine begins to separate the items of information which are now in the input band, determines the type of information, performs necessary modifications on the form of the item, and stores each item of the flight plan.

Since the items of information in a properly punched flight plan card are separated by one space, an item may be separated from the others by serially scanning the input words for a space. When a space is found, the characters between it and the last previous space are stored as one item of information For example, the first word from the input band is put into the accumulator,and shifted two digit positions to the left with a test for a space after each two digit shift When a space is found, the end of the identification has been reached. Four two-digit shifts, a total shift of eight-digit locations, are normally required to locate the space between the identification and the aircraft type. For the fourth item of information, the departure point, a total of four two-digit shifts, is required to locate the space separating it from altitude The three characters between this space, and the one after speed, are stored as departure point in the first location of the processing table

A program switch tells the computer whether it is dealing with indicative information or with routing information. In the case of flight identification, the switch will denote indicative information Unless the flight plan information enters the computer in the proper order, the flight plan is considered erroneous. An indexing register is altered, after each item of indicative information, to remember the type being processed. This ensures that each item of indicative information will be stored in the appropriate location, and, also, that it will be modified as required for the processing routines.

Indentification, which is not printed from the Type-650 drum, is stored in a computer band and assigned a three digit-machine number, which will be used by the computer to identify the flight plan. The machine number is three-digits of the location in which the flight identification is stored, the fourth digit being a constant.

The instructions to search for a space are repeated for type aircraft, speed, departure point, and altitude. The type, speed, and altitude are stored in drum locations 1419, 1420 and 1421, respectively, of the print bands. From these locations type will be printed on line two, speed on line three, altitude on line one of the flight progress strip.

Altitude and speed are converted from the alphabetic form of numeric information to the numeric form prior to being stored for printing Since the maximum number of alphabetic output words on the standard Type-407 is six, this information could not be "read out" in its alphabetic form Also, fewer computer words are required for the numeric form than the alphabetic form.

Departure point is stored in drum location 1900, the first location in the processing table.

There are three types of errors which can be detected by the input routine.

1. If two or more consecutive spaces are reached before the end of a flight plan, there is an error.
2. The number of characters in an item is greater than the maximum number permissible for that item The maximum number of characters permitted are. identification, seven, type, five, speed, three, departure point, three, and altitude, six This character count will detect the omission of a space in punching the indicative information. It is thus a safeguard against erroneously storing indicative information
3 The numeric composition of an item of indicative information varies from that required. Speed and time must be completely numeric. Altitude, must be "OTP", numeric, or numeric plus OTP

There is a safeguard against erroneously storing information which was not properly punched For example, if the space between identification and type were omitted, the departure point would be processed as speed Since it is only three characters instead of four and not completely numeric, the computer would recognize that it was not processing speed It would reject the flight plan due to the card punching error

When the items of indicative information through altitude have been processed, the Input Routine starts the processing routing It determines the type of routing information being processed, i.e , an airway, a fix, longitude-latitude, rho-theta, or relative direction This routing is modified for processing purposes and stored in the processing table as well as in the print out area

The type of routing is determined by the alphabetic and numeric makeup of the item If the first character is alphabetic the item is either an airway or a fix. The first character of an airway is always alphabetic. In an airway identifier, the second character is always numeric (V12), while in a fix identifier, the second character is alphabetic (IND) This variation may be used to differentiate between a fix and an airway.

If the second character is numeric, the item of route is an airway. The airway identification will be modified prior to storing in the processing table in order to condense it to five characters or less This is performed in the following manner.

1 The ten's position of the alphabetic character is dropped, e g , a "V" is 85 in numeric form The eight is dropped, and "V" is represented by the five

2. The nine's are dropped from the alphabetic form of numeric information, and the remaining digits are condensed. 9192 becomes 12 when the nine's are removed, and the remaining characters condensed

If there is an alphabetic character at the end of the Airway Identifier, the ten's position is dropped Figure 8 shows examples of the airway identifier as the airway appears in the computer memory before and after being converted to the form in which it will be stored in the processing table

A maximum of five characters are set because it permitted the storing of two airway identifiers in each word of the Airway - RAMAC Address Table.

The airway identifier, as modified, is stored in the high order portions of the first unused odd word in the processing table

Fix identifiers need not be modified in any way for storing in the processing table Figure 8 shows how a representative flight plan route looks in the processing table Note that the fix is in the high order positions of the computer word, followed by zeros. The figure shows both the alphabetic and the numeric forms of the word, the numeric form representing the actual ten digit computer word A fix is stored in the processing table in the first unused even location

If the first two characters of an item of routing are numeric, the fix may be longitude-latitude or relative direction Longitude-latitude or relative direction is determined by checking the fourth character of an item of routing for alphabetic or numeric character. This character is checked because it is the first alphabetic character for a relative direction fix point

Relative direction is stored in the input band as two separate items (1) the mileage and relative direction from the fix, (2) the fix identifier. Mileage from the fix is punched as three characters. Thus, 17 miles northest of Indianapolis is punched as 017NE space IND It is stored in the input band as 9091977565 0069756400

The Input Routine converts the numeric characters of relative direction from alphabetic form to numeric form It also codes the relative direction so that it requires one digit instead of either two or four digits The code is a non-zero digit from one to eight inclusive The digit chosen will be dependent upon the direction from the fix, with north being assigned the digit representation one, east being assigned the digit representation three, and northwest being assigned the digit representation eight (See Figure 10). Thus, for relative direction, the identification of the fix, the code indicating direction, and the mileage are combined into one word and stored in a fix position in the processing table This word is so organized that the mileage will be the three high order positions, the fix and the representation of the direction in the low order position (Figure 9).

Latitude-longitude is all numeric but requires more than one computer word in the read-in band due to being read into the computer in alphabetic form. When stored, latitude-longitude is converted to numeric form and combined into one word. For example, 34 degrees 18 minutes, 85 degrees 25 minutes will be punched 341808525 It will appear as 93949198909889592 95 in the input band, and as 3418085250 in the processing table The zero indicates to the Direct Routine that the word is longitude-latitude

Fixes are stored in even locations between 1900 and 1920, and the airways are stored in the odd locations between 1901 and 1919 The routing information is modified as necessary for the use of the Direct Routine or Airway Routine. For instance, the airways filed in a flight plan are modified to the five digit form of the Airway-RAMAC Address Table. For fixes filed as relative direction, the fix identification with the mileage converted to numeric form, and the relative direction coded, are combined into one word All designations of fix points other than three character fix identifiers are stored as negative words.

The storage location in the processing table of the next item of information, fix or airway, is determined by a computer word which is changed every time any information is stored in the processing table The manner in which it is updated depends upon whether the last item of information and the new one are of the same type The computer thus remembers whether, (1) it has two consecutive fixes and should add a two to this word to store the second fix in the first blank even location, (2) it has two consecutive airways and should add a two to the word to store the new airway in the first odd location, (3) it has a fix followed by an airway, or an airway followed by a fix in which case it should add only one to the word to store in the next consecutive location. This is simply a device to keep airways in odd locations of the processing table, and fixes in the even locations of the processing table

After the Input Routine has stored the first item of routing in the processing table, it determines whether the first segment of the flight plan was direct or airway. Having determined this, it seeks the RAMAC address of the airway table or the middle track of the Radial Table

In the print area, the routing is stored with one space separating the items, the first character of the departure point appearing in the high order positions of word 1313 This is the first word of routing to be printed on line one of the flight progress strip (see Figure 11A). This method of storing route makes the routing on the printed strip easy to read, and does not waste space on the strip or in the computer memory A maximum of 24 characters of routing may be printed on each line of the flight progress strip

If the entry fix and time has not been encountered, when the first 30 characters of information have been processed, the card is read a second time and the next 30 characters are read in and processed Then, if the entry fix and time has not been reached, the card is read for the third time

When the program finds an "E" or a "P" as an item of routing, the program recognizes that it has reached the end of the routing information The "E" indicates an estimate on an aircraft in flight The "P" indicates a proposed flight, and will be followed by the proposed departure time The program then processes the entry fix and entry time or the proposed departure time.

For an enroute flight, the entry fix is processed like any other fix, except that it is stored in a specific drum location for the direct route and airway routines The time is converted to numeric form and is stored in a drum location It is also stored in the print bands with hours in drum location 1369 and minutes in drum location 1321

After storing the time, the Input Routine causes a transfer to either the Direct Routine or the Airway Routine.

General and semi-detailed flow charts of the Input Routine are provided in Figures 13 and 14

DIRECT ROUTINE

The Direct Route Routine processes and prints flight progress strips for all the fix postings required on direct flight plans and also on direct segments of combination direct and airway flight plans Any type of fix designation, fix identifier, longitude-latitude, relative direction, or rho theta, is accepted by the direct processing routine Flight progress strips for either enroute or proposed flight plans are printed in the appropriate format (as used in the IND ARTCC) Winds aloft are taken into consideration in the computation of ETA and of plus time. The Direct Routine is compatible with the Airway Routine, as is necessary for the processing of combination flight plans All information required for strip printing not provided by input is computed by the Direct Routine Figures 15 and

16A - 16M provides general and semi-detailed flow charts of Direct Routine.

The Direct Routine does not require that a fix in the ARTCC area be filed in a flight plan, as the routine is capable of determining where the flight will cross the area Also, there is no limit to the number of fixes outside the ARTCC area which are filed in a flight plan There is also no limit imposed by the computer program on the distance between filed fixes.

A new approach was taken to the problem of determining for direct route segments at what fixes flight progress strips should be printed It is based upon the fact that there is a defined geographical area of responsibility around each fix posting point (Figure 17) A method of determining whether a flight enters the area of responsibility of a particular fix would also determine whether a flight progress strip should be prepared for that point The procedure chosen for this determination is dependent upon being able to numerically express the location of each fix in the ARTCC area and to mathematically define the area of operational responsibility around each fix

There are several co-ordinate systems which could be used to obtain a numerical expression for the location of a fix A rectangular co-ordinate system was chosen because,

1 The mathematics involved is less complicated for this system

2 A smaller number of tables and drum storage locations are required, since all fixes in the IND ARTCC area can be designated by fewer digits.

The rectangular co-ordinate system was used in the basic 650 program A square grid with a grid side of one nautical mile was superimposed on the IND ARTCC area The y-axis is parallel to the 84 degree meridian The x axis is perpendicular to the y axis starting at the point where the 39° north line of latitude crosses the 84^{o} west meridian. This point in the grid system is designated as Y=500 X=500. The origin of the co-ordinate system is southwest of the center's area, and all of the center area is in the first quadrant, where the sine and cosine functions are positive (See Figure 18)

Each radio fix within the Indianapolis area was assigned a three-digit x value based on its distance in nautical miles from the y-axis of the co-ordinate system, and a three-digit y value based on its distance from x axis These two co-ordinate values are sufficient to locate any point in the center area

Fixes outside the IND Center area, but within 300 miles of it, are assigned x and y values on the co-ordinate grid The x and y values of these points are positive.

The fix identifiers filed in a flight plan to designate a direct route of flight are used in the first step in the direct routine. These identifications are used for table look up in the inside fix table

INSIDE FIX TABLE The Inside Fix Table is a Table in the 1150 - 1200 bands which contains the identification of all the fixes in the IND ARTCC area (Figure 19A) The primary fixes are at the beginning of the table followed by the secondary fixes. The fix indentification is in the high order positions of the word The adjacent two positions on the right contain characters of the RAMAC address where information relating to flights over the fix will be stored The two low-order digits are 99 in the case of primary fixes. For secondary fixes, they are the two right-hand digits of the drum location of the associated primary fix. This table is used to obtain the address within the inside fix x-y table

INSIDE FIX X-Y TABLE This table is in drum bands 1000 - 1050 The three high order positions of each word are y value The three low order positions are x value. The middle four digits in this table are unused and are zero (Figure 19B).

The inside fix table and the inside fix x-y table are in identical order, 150 locations apart. Hence, if the identification of a fix is known, its address in the inside fix table is used to locate the co-ordinate values of the fix in the fix x-y table. The co-ordinate values are used to compute the slope of the line of flight. Also, when one of the end points of the line of flight is a secondary fix, the co-ordinate values from this table are used to rotate the end points of the line of flight into the co-ordinate system which will be used to obtain the reporting fixes

If one or both of the fixes is outside the area (as, for instance, a flight from Pittsburgh, Pa), the identification, PIT, is squared and the middle four digits of the lower accumulator are temporarily stored These four digits comprise the identification code which is stored in the outside fix table. The first of the five RAMAC tracks of the outside fix tables is read to high speed storage. A table look-up-equal function is performed on the middle four digits of the word. If no equal is found, the process is repeated with the second track. When an identical four digits is found (on the first track for PIT), the x and y of the fix are stored in temporary locations

OUTSIDE FIX TABLE· All fixes within 300 miles of the ARTCC Area are stored in the outside fix table (Figure 20A). In each word are stored the co-ordinate values of a fix and a four-digit code for the identification of that fix. The y value of the fix is stored in the three high order digits of each word. The corresponding x value is stored in the three low order digits

The code for the fix identification is stored in the middle four digits of the word. It is developed in the following manner. The fix identifier is squared, and the digit positions 4, 5, 6 and 7 stored in the outside fix identifier

Below is an illustration of this for STL

$(828373)^2$ =
68620/1827/129

1827 is stored in the outside fix table as the identification code for STL.

Approximately 300 outside fixes are stored in the outside fix table. They are stored on RAMAC tracks. The fixes are so ordered that the most frequently used outside fixes are on the first RAMAC track

The outside fix table is the source of x and y values for the Direct Routine when it is processing a flight segment having one or both end points outside the IND ARTCC Area. If the fix is designated by something other than a three-digit identifier, some computing is required.

RELATIVE DIRECTION. The x and y of the fix are obtained from the outside fix table The x and y values are then modified by the distance and direction from the fix. The table below summarizes the modification

Direction	Code	X	Y
N	1	Unchanged	Add Mileage
NE	2	Add 707 Times Mileage	Add .707 Times Mileage
E	3	Add Mileage	Unchanged
SE	4	Add .707 Times Mileage	Subtract .707 Times Mileage
S	5	Unchanged	Subtract Mileage
SW	6	Subtract .707 Mileage	Subtract 707 Times Mileage
W	7	Subtract Mileage	Unchanged
NW	8	Subtract .707 Mileage	Add 707 Times Mileage

Mileage = Miles from fix filed in flight plan.

Thus, for a fix filed 25SIND (025 6975645 is in the processing table), the x and y will be x equal 392, y equal 550 minus 25 or 525

RHO-THETA Rho-theta filing is handled very much like relative direction The direction from the fix is converted to an angle of 90 degrees or less Whether it was between 0 and 90, 91 and 180, 181 and 270, or 271 and 360 is remembered by the computer program The sine and cosine of the angle is obtained from the slope table. The change in the x is equal to the distance times the cosine of the angle The y is altered by an amount equal to the distance times the sine of the angle Whether this correction is added or subtracted depends upon the original angle, and is identical to the change made on relative direction.

Thus, for a fix filed IND V 15090 (90 miles from IND VOR on 150 degree radial) zero x is 392 and zero y is 550 By conversion these values become 466 for x and 489 for y.

LONGITUDE-LATITUDE TABLE Latitude-longitude is converted to x and y in the following manner. There are presumed to be 60 nautical miles per degree latitude The number of miles from the latitude nearest the zero x axis is computed by multiplying the degrees latitude by 60 and adding the minutes of latitude This value is then corrected by subtracting the number of miles between the axis and 32 degrees north latitude The zero degree x axis is assumed to lie on 32 degrees north latitude

The x value is computed, using miles per degree longitude, stored in the latitude-mileage table The minutes are also corrected by a factor stored in this table Then it is corrected by subtracting the number of miles from the zero y axis at this latitude

The latitude-mileage table (Figure 20B) contains the number of miles per degree longitude for each degree latitude in the IND ARTCC area The latitude is in the high order positions of the table word. In the next five digits are the number of miles per degree longitude In the low order positons, is a correction factor for the position of the zero degree y axis in relation to the longitude This information is tabulated at one degree intervals from 35 degrees N to 42 degrees north.

The latitude-mileage table is used by the Direct Routine to obtain information needed to convert to x and y co-ordinates a point filed in longitude-latitude.

When the x and y values of the two end points have been obtained the slope of the line of flight is computed from the relation $\frac{y2 - y1}{x2 - x1} = m$ where m is the slope, y2 and x2 are the co-ordinates of the second point, y1 and x1 are the co-ordinates of the first point.

The sin-cos-RAMAC Address table is designed so that when the slope of the line of flight is known, the RAMAC Address of the Radial Table to be used for processing the flight segment may be obtained. Also, the slope will be used to obtain the value sine, cosine functions for computing the x and y values of the line of flight in the new co-ordinate system.

SLOPE TABLE· This table contains three items of information slope, sine function values, and cosine function values (Figure 21). It is stored in drum locations 0850 - 0870. The slope is stored in the four high order digits of the computer word. The sine is stored in the three digits next to the slope The cosine is stored in the three low order digits of the word.

The sine and cosine are stored at five degree intervals in the table from zero degrees to 90 degrees. The slope stored in the table is that of 2.5 degrees, 7.5 degrees, etc., halfway between the angles for which the sine, cosine are stored.

This is to make sure that the sine and cosine obtained from a TLU by slope will be those for the co-ordinate system most nearly parallel to the line of flight.

If the axes of the co-ordinate system are rotated in either a clockwise or counterclockwise direction around the point of origin of the co-ordinate system, the x and y values of the fix points in the Center's area will change in relation to the new position of the axis (Figure 22). Note in the drawing that the distance from the x axis to the point is 550 miles, thus, y equals 550, and the distance from the y axis is 392 miles, thus, x equals 392 in the co-ordinate system described. If the axes are rotated 30 degrees in a counterclockwise direction, as shown in Figure 22, the distance of this same point from the x axis is 280, and from the y axis is 614, thus, the new y value equals 280, the new x value equals 614. This new x-y value (in the rotated co-ordinate system) is called the rotated x-y value.

On Figure 23, it will be noted that some of the points are below the rotated axis. These points would have negative distances from the axis. From a programming standpoint, this is undesirable, as it would necessitate additional program steps to properly process such points. Therefore, a constant is added to all of the y values in the rotated system to make all of them positive. If the axes are rotated in a negative (clockwise) direction, the x values of some points will become negative, so a constant is added to these values to keep them positive. It was determined that a constant of 200 was adequate to make all the x and y values positive under all rotations of the axes to plus 45 degrees and to minus 45 degrees (45 degrees in a counterclockwise and in also a clockwise direction).

Determination of whether to report a flight at a specified fix is based upon the fact that any flight entering the predefined area surrounding a fix must be posted at that fix. This geographical area of responsibility surrounding a fix is irregular in shape, so cannot be simple defined mathematically. However, such an area can be defined by drawing lines of variable length through a fix, like spokes through the hub of a wheel, if there are a sufficient number of the lines to make the angle between them small. Figure 24 shows the IND fix posting area defined in this manner. The length of each of the "spoke" lines is measured in nautical miles from the fix to each end of the line segment through the fix. These lines are called radials. Each radial and its reciprocal is described as the radial mileages at a certain angle around the fix. Referring to Figure 17, 36 and 16 are the radial mileages at zero degrees by x 52 and 25 are the radial mileages at minus 30 degrees by x.

The radial perpendicular (plus or minus 2.5 degrees) to the line of flight is used to determine whether the flight enters the fix area. Figures 24A and 24B show a flight from LOU (Louisville, Kentucky) to FFO (Wright-Patterson Air Force Base Ohio). The perpendicular radials for the fixes along this flight are shown. Note that the perpendicular radials to the line of flight do not touch it for SHB, FLM, RID. The radials were drawn of such a length that they would meet any line of flight which would go through the fix posting areas. See Figure 17, where the radials perpendicular to the flight line are extended beyond the fix area so that they will intercept any flight which goes through the area.

It is very important that these radials be carefully drawn and carefully measured, as the accuracy of the fix postings by the Direct Route Routine is dependent upon them. If greater accuracy is desired, the number of radials may be increased, but would increase the number of radial tables. There is a range of plus or minus 2.5 degrees from a parallel between the fixes of the co-ordinate system and the line of flight. The computed co-ordinate value for the end points of the line parallel to the axis may vary as much as four miles per 100. Because the average of this value for the end points is the "co-ordinate value of the line of flight", it can vary by as much as two miles at the end points. This is presently considered negligible.

The radial mileages are used in combination with the x and y values of the fix points to form Radial Tables which will be used by the Direct Routine to determine at what fix points a flight should be posted.

RADIAL TABLE. Each radial table (Figure 25) contains the co-ordinate x and y values of every fix posting point in the center area. For each fix the y value is stored in the three high order digits of the computer word, and the x value is stored in the three low order digits of the word. The middle four digits consist of two two-digit mileages, each of which represents the maximum distance in a definite direction from the fix at which a flight should be posted.

The y value is in the three high order position of the word, the distance in nautical miles from the fix in the positive direction along with the axis, in the next two positions (7 and 6), the distance toward the zero degree axis, in positions (5 and 4), and the x value, in the low order three positions.

There are 40 radial tables. Each table contains the x and y values of every fix posting in the co-ordinate system. The original co-ordinate system is rotated in five degree intervals from zero degrees to 90 degrees. There are two tables resulting from each five degree rotation. One contains the mileages parallel to the x axis of the co-ordinate system. The other contains the mileages perpendicular to the x axis of the particular co-ordinate system.

Each table is ordered with respect to one of the co-ordinates. Those with mileages perpendicular to the x axis are ordered in ascending x value. Those with mileages parallel to the x axis are ordered in ascending y value.

The former will be referred to as "ordered by x", and the latter, as "ordered by y"

The radial table is used in the processing of direct flights to determine for which fixes flight progress strips should be prepared For each strip printed, the fix identifier is obtained from the radial fix table.

RADIAL FIX TABLE· There are 40 additional tables of fix identifications corresponding to the 40 radial tables. The six high order digits of the word contains the fix identification the four low order digits are zeros. The identification corresponds to the x, y and radial mileage word in the radial table.

This identification is obtained after the x, y and radial mileage word is used to process this flight.

The distance between fix posting points of the flight segment is determined by subtracting the two y values if the table is ordered by Y, or subtracting the two x values if the table is ordered by x. Using this distance and the aircraft speed, the time for this aircraft's flight between these two points is computed This computed time is added to the aircraft's estimated time of arrival at the last processed fix. This is the flight estimated time of arrival at this fix Then the next fix is processed. When the second end point of this route segment is processed, the next segment is processed If it is not direct, the program proceeds to the airway routine

AIRWAY ROUTINE

The Airway Routine processes the prints flight progress strips for all airway route segments of a flight plan It has the capability of determining the direction of flight and if the flight junctions with another airway without the junction fix being filed in the route of flight The airway tables furnish the airway routine the information from which fix postings flight progress strips will be prepared. The General and Semi-detailed flow charts for Airway Routine are provided in Figures 26 and 27

Processing of a flight plan is performed one route segment at a time The airway routine is started by either the Input Routine or the Direct Routine. The Input Routine sends the program to the Airway Routine as soon as it has stored the last item of information in the flight plan, if the first route segment is airway. This is determined when input organizes and stores route.

The Direct Routine sends the program to the Airway Routine when it recognizes an airway segment following a direct segment. This would occur in the case of a combined direct and airway flight plan.

After being initiated, the airway routine first changes the estimated or proposed time from hours and minutes to all minutes. This is done for simplification in computations of time. The minutes are converted back to hours and minutes prior to printing each strip

It then transfers the proper airway table to high speed storage from RAMAC disc storage. The location of the airway table was previously sought by the input routine, if this is the first segment, or by either the airway or direct routine, if it is not the first segment The airway table is located by the use of Airway-RAMAC address table

AIRWAY-RAMAC ADDRESS TABLE The Airway-RAMAC Address Table is a table stored on the drum which contains two coded airway identifications per computer word (Figure 28). The identifications are coded in the following manner: the first digit of the alphabetic character is dropped, hence "V" (85 in digit form) will be coded as "5" and J (71), as "1". If there is an alphabetic character at the end of the identification, as the "S" in V12S, it will be similarly coded. Thus, five is the maximum number of characters for an airway identification. V12 is coded as 50120. V1516 as 51516. The identification of every airway in the IND ARTCC area is stored in this table.

The drum location of an airway identification is modified by a constant to develop the RAMAC address of the corresponding airway table. The constant is determined by whether the identification is in the high or in the low order positions of the computer word.

The Airway-RAMAC Address Table is used by the airway, the direct route and the input routine. A group of instructions common to the three routines cause the RAMAC address of the airway in the next segment of the flight plan to be developed.

AIRWAY TABLE: There is an airway table (Figures 29) for each airway in the Indianapolis ARTCC area. The airway table is divided into two parts information in the first part relates to the IND ARTCC area, and the second part to areas outside the IND ARTCC.

In each airway table the first part, in addition to having all of the fixes for the airway in the IND ARTCC area, has the airports from which a flight may take off or land. If any of these airports are not on the airway two zeros are used to indicate that the fix will not have a flight progress strip prepared for it. All airways which junction with the airway for which the table was designed are also listed in the table.

The first 15 words of each airway table are used to improve the estimate of elapsed time between fixes. These words are obtained by arbitrarily dividing the airway into three sections, with each section split into five altitude layers Each word has the altitude in the three high order positions. The next three digits to which 50.0 is added is a correction factor for an estimate of a flight in a north or easterly direction and the three low order digits are a correction factor for a flight in a southerly or westerly direction.

In word 16 will be the easterly or northerly entry fix followed in descending order by the fixes on the airway sequenced as a flight would pass over them ending with the westerly or southerly entry fix. For a flight in an easterly or northerly direction the airway routine works down the table and for a flight in the opposite direction it works up the table. Each word is constructed as follows: the high order digits are the fix identification, the next two digits are 99 for an entry fix. For fixes inside the IND ARTCC area the first digit indicates which correction factor to use and the second digit tells if the fix is a print or non-print fix. The two low order digits are number of minutes required for a flight making a ground speed of 250 knots to fly to the next fix. The second entry fix in the table has two zeros in the low order position of the word.

If there are airways that junction at the fix, the identification of the airways are stored 20 locations away. Since two identifications per word are maximum, it is necessary to store the fix once for each two airways that junction at the fix. If there is an odd number of airways that junction, the last odd airway identification is placed in the high order position of the word, the remaining digits being zeros.

The word located in 9059 in the table gives the address of the last fix on the airway that is located inside the IND ARTCC area. When the table look up is performed, and the address found is greater than that stored in the word in 9059 it means the fix is located outside the IND ARTCC area.

The fixes outside of the IND ARTCC area are the second part of the table and are located on a different track in RAMAC. Fix and junction airways are listed and the ten digit word is given a sign. A fix or airway with a minus sign is west of the area and, conversely, plus is east.

Next, the airway routine checks to see if another airway segment follows the one it is about to process. This is done to determine how to set certain programming switches, which must be set at this time. These switches will subsequently divert the program to: (1) The end of the program, (2) The direct routine, or (3) Another airway segment.

If no airway segment follows, it is an indication of either the end of the flight plan, or that the next segment is direct. If the check reveals the end of the flight plan, a switch is set to terminate the program as soon as it is through processing and printing strips for this segment. If a direct segment follows, a switch is now set to divert the program to the direct routine, when it is through processing and printing strips for this segment.

If an airway segment follows an airway setment, the routine obtains the RAMAC address for the second airway table. This will enable it to begin working on the second segment when the current one has been processed

The routine now sets a switch that will refer it later to a constant location for printing altitude. Printing of altitude on strips is a repetitive operation, since it does not change.

A check is then made to see if the flight plan is proposed or enroute. If the flight plan is proposed, switches are set that will by-pass printing of current fix estimate information relative only to enroute.

This completes the checking and setting of switches relative to the airway segment The computations and printing of strips will be accomplished as the routine moves from fix to fix within the segment. When this segment is complete, the program will move on to another segment within this or the direct routine, or to the end of the program.

In processing from fix-to-fix, the first operation is a table look up in the airway table to find the "minutes" from the first fix of the segment to the next fix This information is stored in a temporary location and will be used during computation of plus times A determination is made to see which direction, up or down the table, it is going. This is accomplished by doing a TLU on the end fix in the segment. Track two, which contains the airway table for outside fixes, is transferred to high-speed storage and the TLU is done, if the end fix is not found in the table on the drum When the 'up' or "down direction has been determined, it is checked against a control digit at the end of the table to tell which color to print this strip.

A check is made to see if a junction has been filed If not, and there is a junction in this segment, the junction fix must be determined and temporarily stored. It is necessary to know where to leave or enter this airway when looking for fixes.

The next fix in the segment is now checked to see if it is an exit fix. If so, certain switches are set to terminate the program.

A check is made to see if this fix is adjacent to, but not on a jet track. If it is, a strip will be printed in a relative direction from the fix. Since identification and direction of such a fix are stored in a different section of the table area, a switch is set to index the program when printing

A check is made to see if this is a dummy fix. A dummy fix is one that is not actually on the airway. It will be printed only if it is the departure point, or the destination. The switch must now be set to cause printing, if this is found to be a dummy fix.

A check is made to see if this is the junction fix If so, the routine knows it must pick up the next airway when looking for the next fix. Print switches are set and processing of the fix is ready to begin.

The routine now goes to drum location 1832 and gets the speed factor from the speed factor table

SPEED-FACTOR TABLE: This table is used by the airway routine to convert the time stored in the airway tables if the flight is making a speed other than the standard 250 knots If the aircraft's speed is less than 250 the factor is greater than one, and if the speed is greater than 250 the factor is less than one The time stored in the airway table is multiplied by the correction factor.

The correction factor is stored in the four low order positions of the word and the speed is the three high order positions of the word.

A decision was made to start the table with a speed correction factor word for 100 knots. Each succeeding word in the table is for a speed, which for a distance of 100 nautical miles would make a time difference of three minutes over the previously listed speed This idea was used to minimize the size of the table.

The minutes of this fix, which were previously stored, and speed are used with the speed factor to develop a plus time for this fix. This is stored in a temporary location. Plus time is also added to total time and stored. A determination is made to see which of the previous fix estimates should be carried on this strip as a previous fix estimate. This is done because only certain fixes, such as compulsory reporting points, are desired to be carried as previous fix estimates. A certain digit in the fourth low order positions of each fix in the airway table is used to indicate which fix is to be used as previous fix estimate.

After storing the previous fix estimate, its fix ident and the current fix estimate, the routine, by switches previously set, will go to the next fix in the segment and perform the same operation Also, line one of this fix will be printed at this time, if this is a print fix. (Lines two and three of a print fix are printed during processing of a subsequent fix or fixes. The reason for this is that the printer is relatively slow in operation, and the computer may as well go on with the processing, since some fixes will not be printed.) The printer is given opportunity to print succeeding lines of a fix at certain states of processing subsequent fixes.

When all the fixes in a segment have been processed and printed, the routine will go on to the next segment, or end of flight plan, as described before

CONCLUSIONS

1. The machine produced strips are neater and more readable than handwritten strips as shown in Figure 30. The following are some of the errors which occurred in handwritten strips which have been eliminated by the machine:

   a. Ten-minute errors.

   b. Hour errors.

   c. Insufficient postings.

   d. Incomplete information.

2. If the flight plan contains a large amount of alpha information, it cannot be processed. A modification to the equipment is expected in June 1959 that will correct this problem.

3. Considerable time is required to enter a single card of flight plan information into the Type-407 equipment. For the machine to accept it, it must be associated with blank cards inserted before the information card. The modification scheduled for June 1959 will eliminate the cards.

4 There was not enough time allotted to programming before the system was placed in operation When the system went into operation in July 1958, the program was sufficiently complete to allow 68 per cent of the flight plans to be machine-processed. Through improvements in the program, the system in operation in April 1959 was processing 94 per cent of the flight plans.

5. It takes an average time of ten seconds to process a flight plan The 650 RAMAC system would be easier to program and faster in operation if the amount of fast access storage were increased. Only 2000 words may be stored on the present storage drum for quick access at any one time. The programming must bring data as required from RAMAC storage to the drum storage for use. This condition will reduce the number of flights that may be handled per unit time if any program routine is added that requires more data to flow between the RAMAC storage and the drum storage The modification planned for June 1959 will increase fast access storage to 6000 drum words and 120 core words

6. The preparation of the program was started in March of 1958 and "Direct Route" processing was started on November 20, 1958. Between March and November, approximately 4000 man-hours were spent in the preparation of the computer programming. From November 1958 to April 1959, over 1000 man-hours were spent on computer programming improvements.

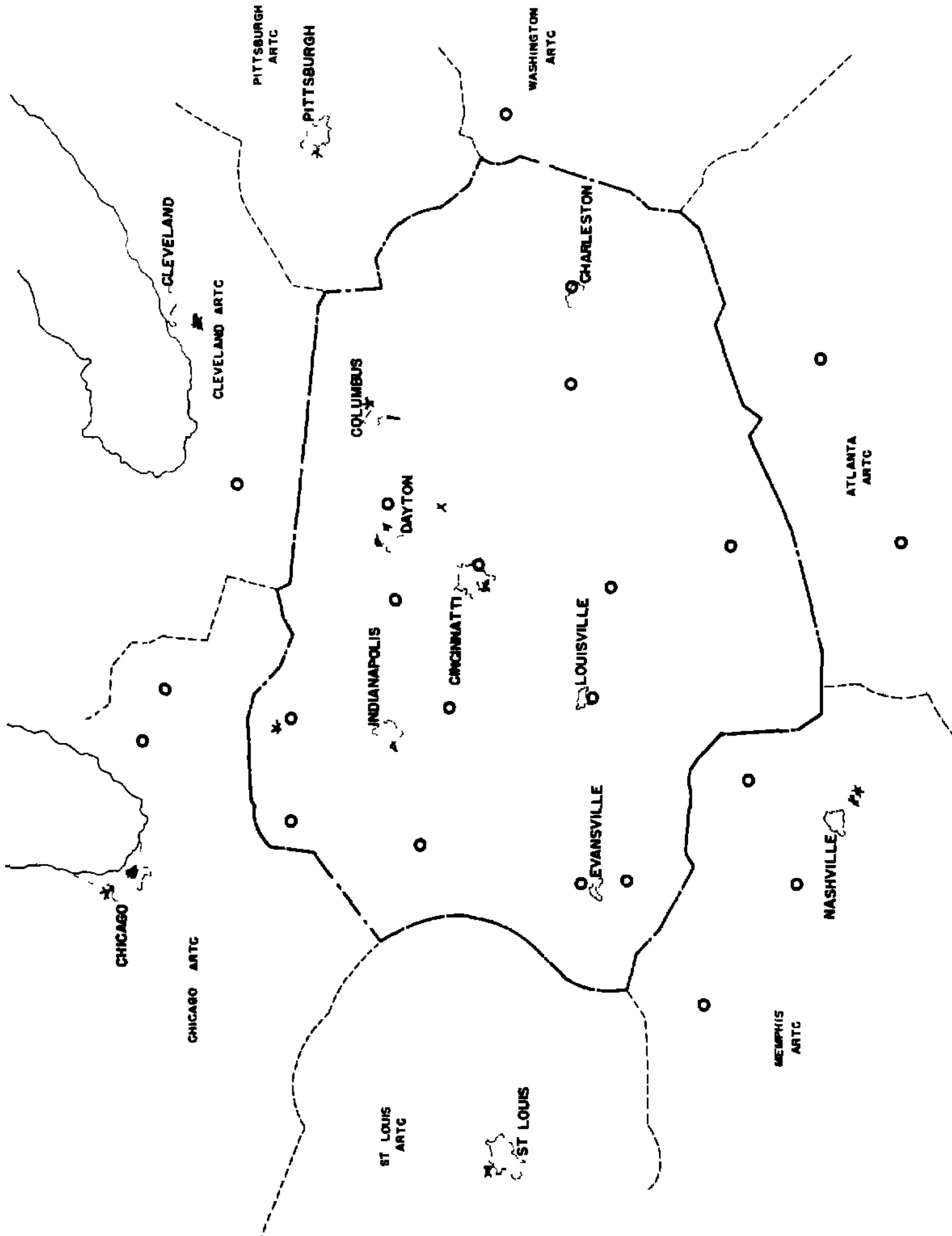

FIG. 1 INDIANAPOLIS CONTROL AREA

FIG. 2 - TYPE 838 INQUIRY STATION

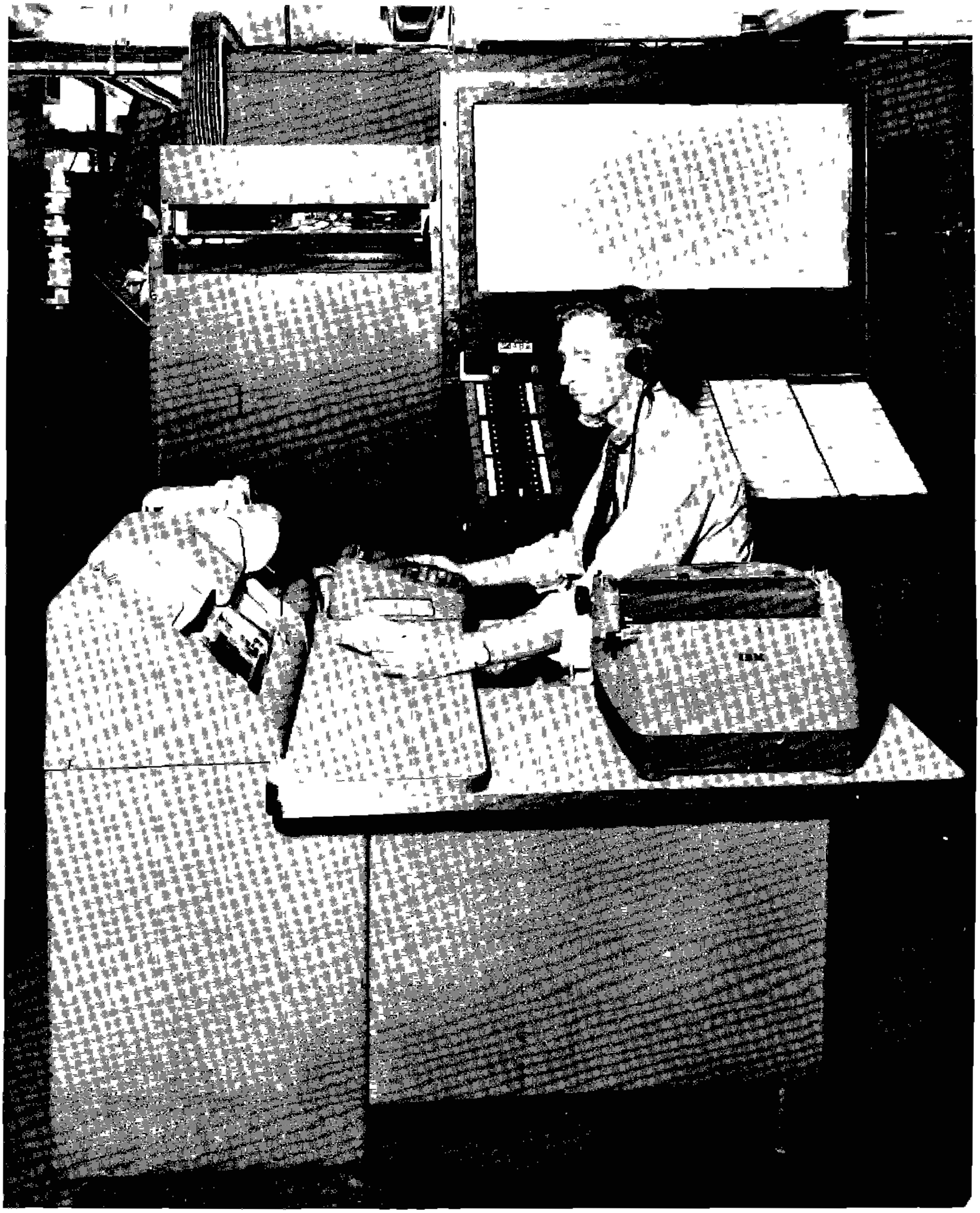

FIG. 3 - TYPE 826 CARD PUNCH UNIT

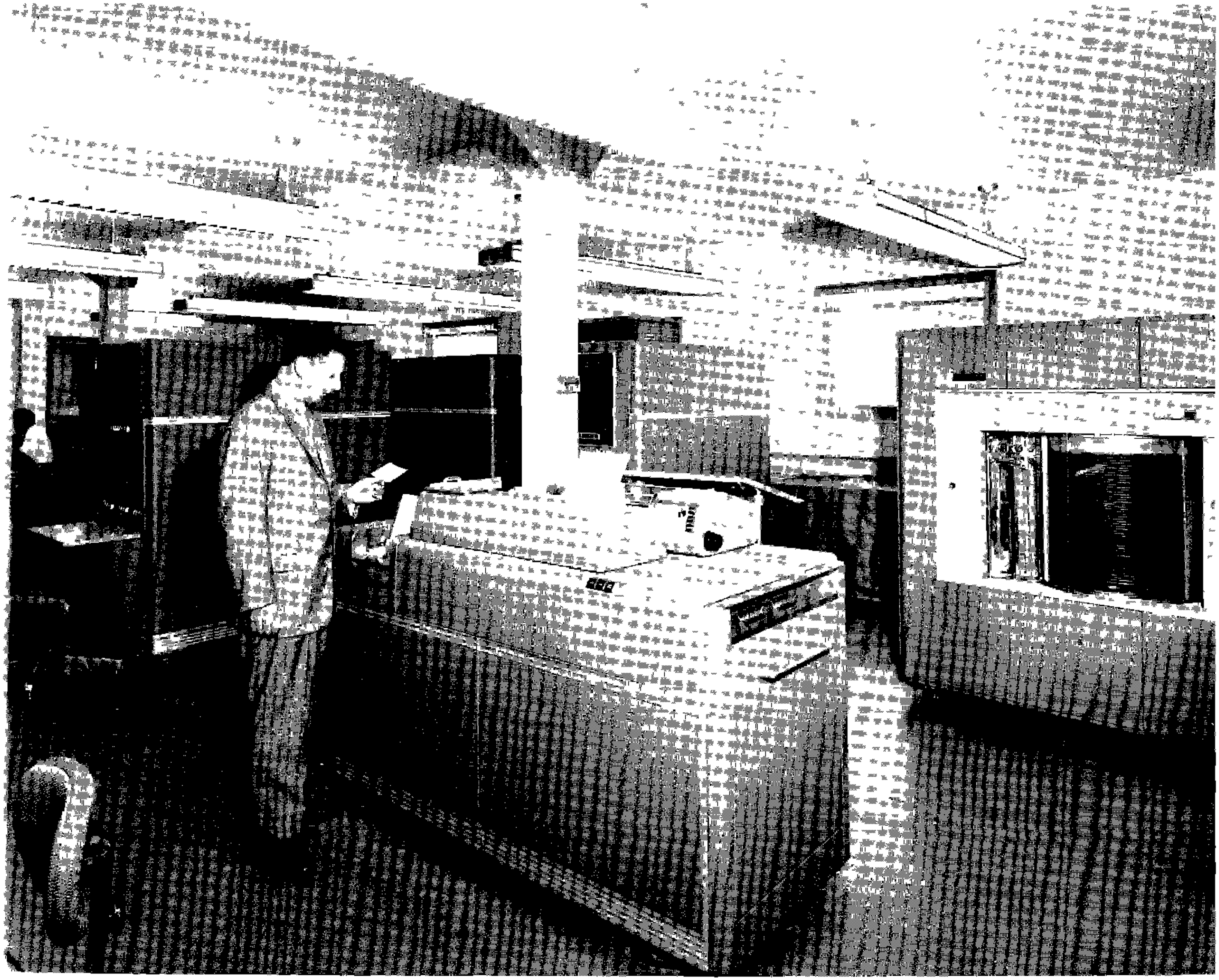

FIG. 4 - TYPE 355 DISC STORAGE UNIT (RIGHT) AND TYPE 407 ACCOUNTING MACHINE (CENTER)

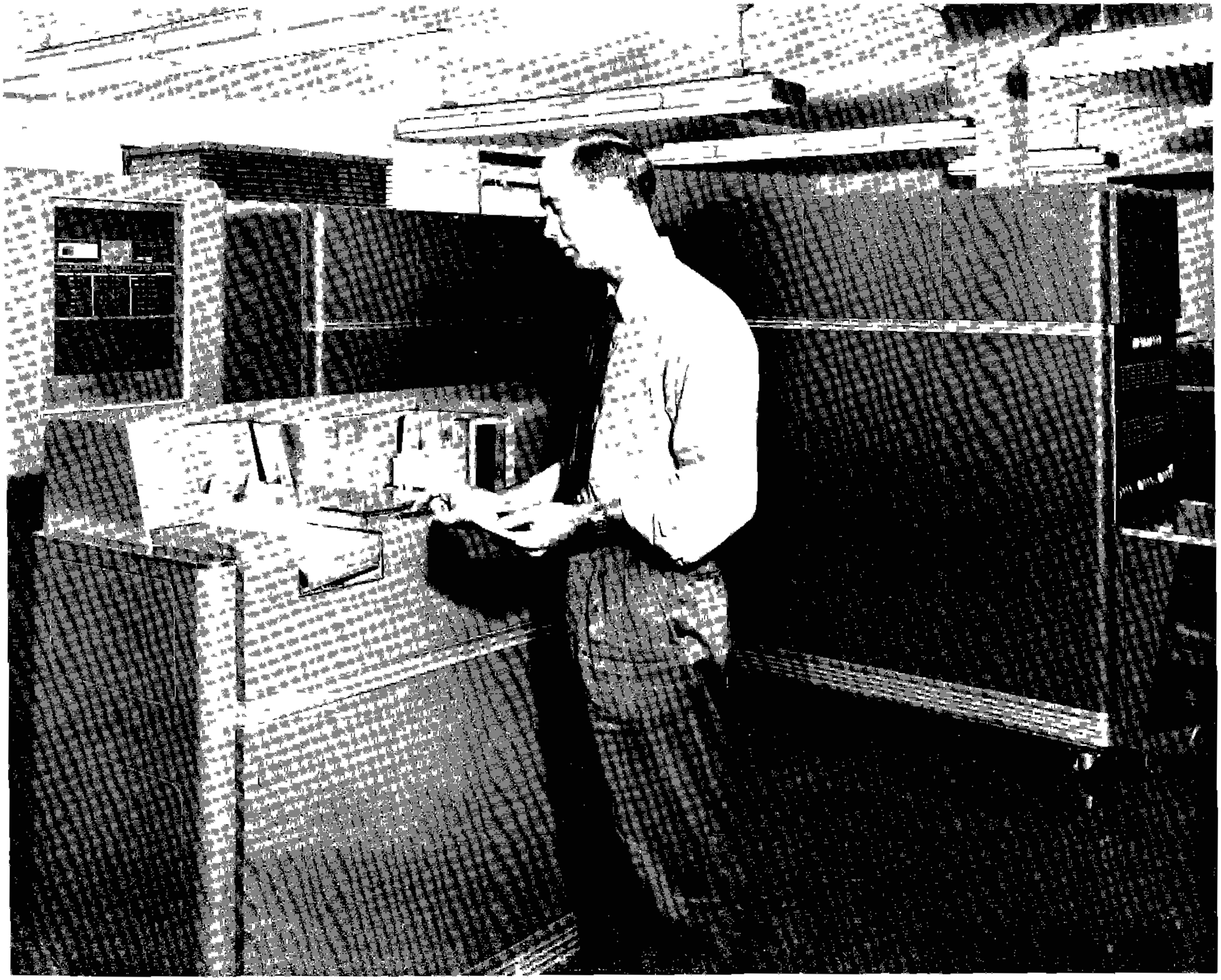

FIG. 5 - TYPE 533 CARD READ-PUNCH UNIT

FIG. 6 - TYPE 650 CONSOLE UNIT

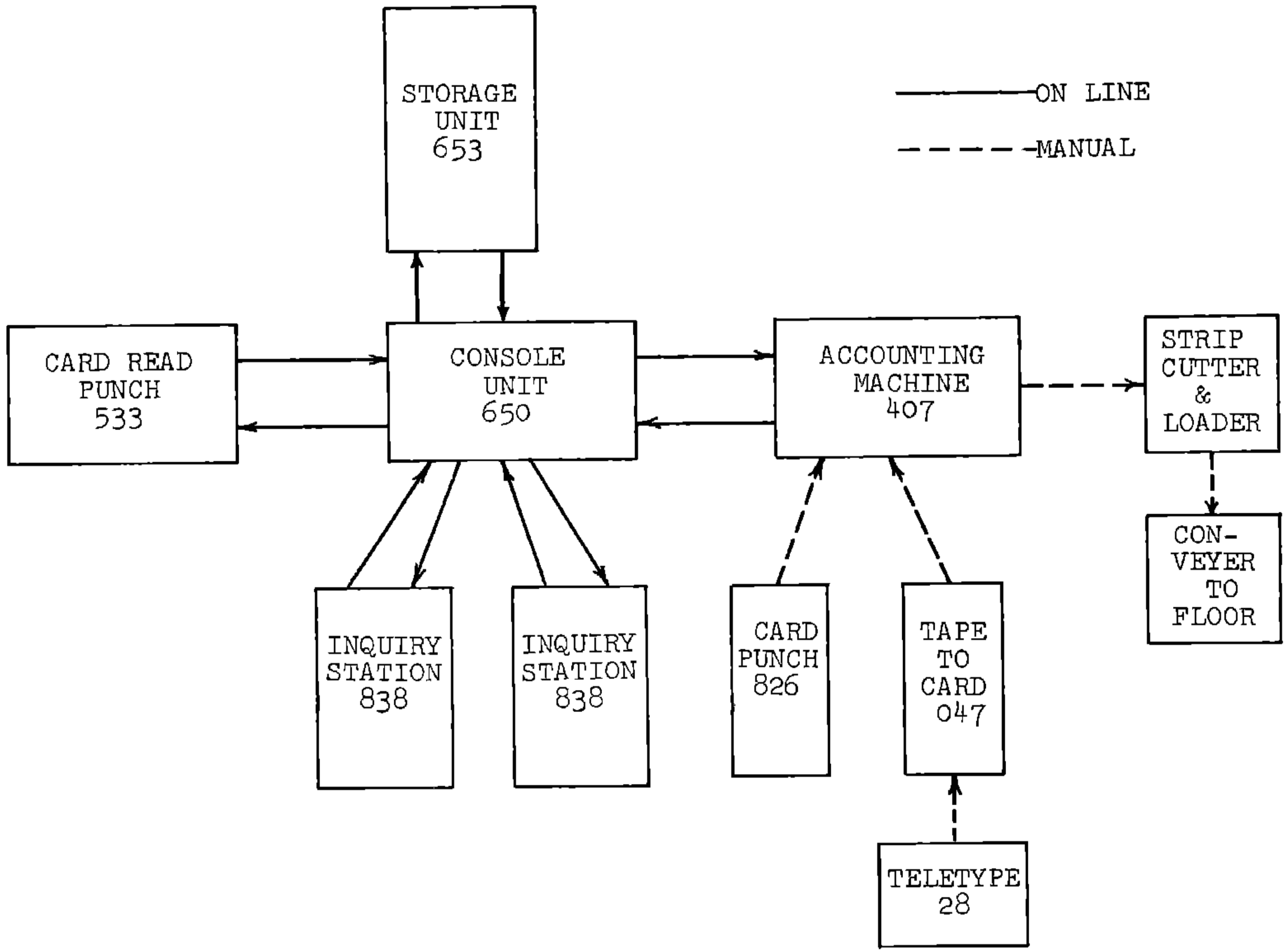

FIG. 7 FLOW DIAGRAM IBM 650/RAMAC SYSTEM

IDENTIFICATION	TYPE	SPEED	DEPARTURE POINT	ALTITUDE	ROUTING	ESTIMATE OR PROPOSED	ENTRY FIX	ENTRY TIME
T19	CN	180	LGA	100	V12 V50 HUF V14 STL	E	HLG	1853

FORMAT FOR ENTERING FLIGHT PLAN INTO THE COMPUTER

DRUM LOCATION	INPUT BAND
1339	T19ΔC
1340	NΔ180
1341	ΔLGAΔ
1342	100ΔV
1343	12ΔV5
1344	0ΔHUF

INPUT BAND

DRUM LOCATION			COMPUTER REPRESENTATION
1900	LGA00		7367610000
1901	V1200		5120000000
1902	00000		0000000000
1903	V5000		5500000000
1904	HUF00		6884660000
1905	V1400		5140000000
1906	STL00		7982730000

PROCESSING TABLE

FIG. 8 FORMAT FOR ENTERING AND STORING INFORMATION

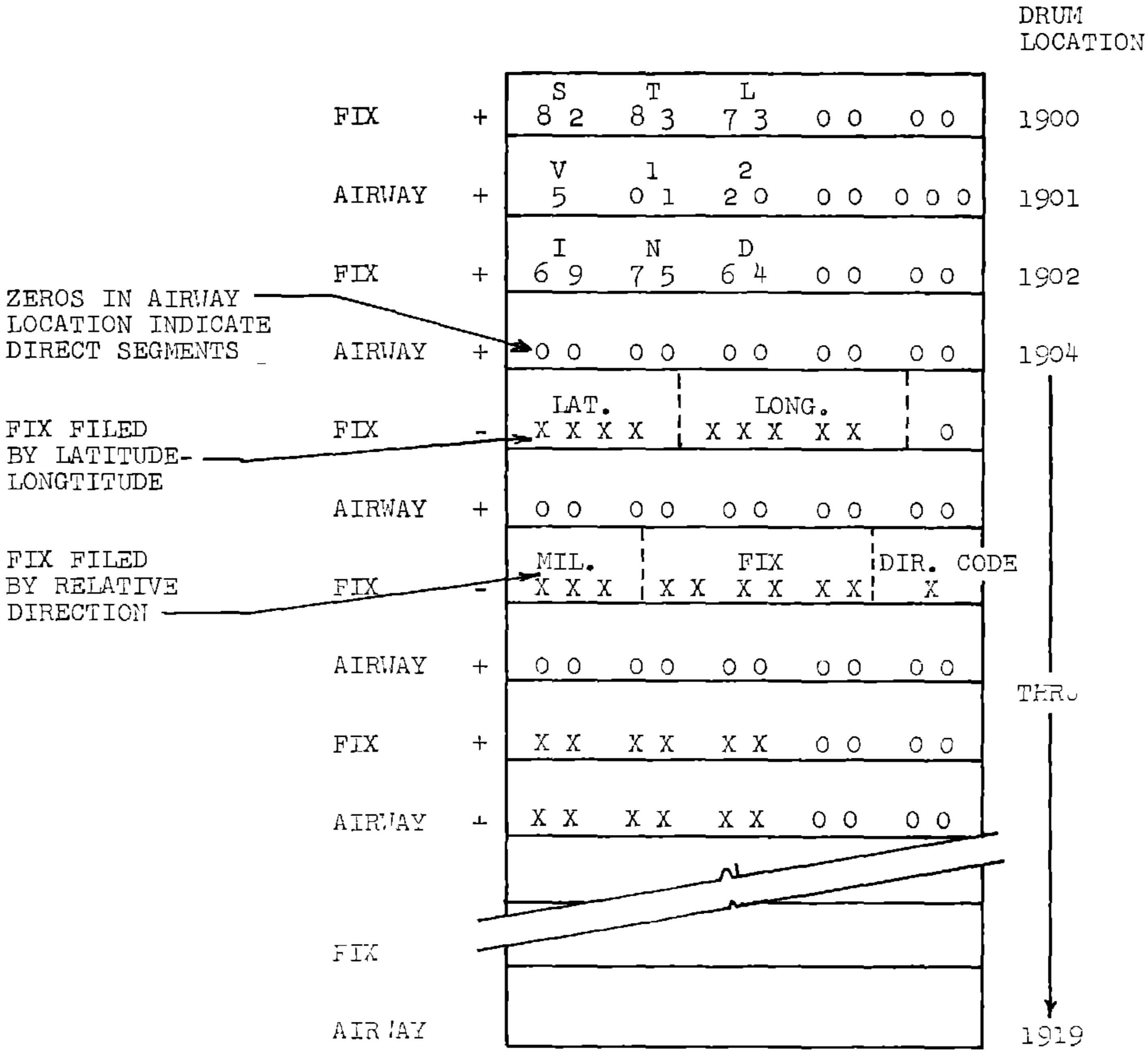

FIG. 9 PROCESSING TABLE

DRUM LOCATION	DIRECTION CODE			
030	1	N X X	0 0	0 0 0 0 0 0
030	2	N X X	E X X	0 0 0 0 0 0
030	3	E X X	0 0	0 0 0 0 0 0
030	4	S X X	E X X	0 0 0 0 0 0
030	5	S X X	0 0	0 0 0 0 0 0
030	6	S X X	W X X	0 0 0 0 0 0
030	7	W X X	0 0	0 0 0 0 0 0
030	8	N X X	W X X	0 0 0 0 0 0
030	9	TLE ARGUMENT		

FIG. 10 RELATIVE DIRECTION TABLE

		DRUM LOCATION
ROUTE	X X X X X X X X X X	1313
ROUTE	X X X X X X X X X X	1314
ROUTE	X X X X X X X X X X	1315
ROUTE	X X X X X X X X X X	1316
PREV. FIX ¦ ACTUAL	X X X X X X ¦ X X X X	1317
FIX ¦ DPTR. PT. ¦	X X ¦ X X X X X X ¦ O O	1318
¦ ETA PREV. FIX	O O O O O O ¦ X X X X	1319
¦ ALT	O O O O O O O ¦ X X X	1320
¦ ETA	O O O O O O O O ¦ X X	1321
¦ SEL. CODE ¦ DIR. CODE	O O O O O O O O ¦ X ¦ X	1322

FIG. 11A TYPE 407 THREE LINE PRINT - LINE 1

	DRUM LOCATION
ROUTE X X X X X X X X X X	1363
ROUTE X X X X X X X X X X	1364
ROUTE X X X X X X X X X X	1365
ROUTE X X X X X X X X X X	1366
ROUTE X X X X X X X X X X	1367
TYPE: X X X X X X ¦ O O O O	1368
O O O O O O O O ¦ ETA HOUR: X X	1369
O O O O O O O O O O	1370
O O O O O O O O O O	1371
O O O O O O O ¦ SEL. CODE: X ¦ SEL. CODE: X ¦ DIR. CODE: X	1372

FIG. 11B TYPE 407 THREE LINE PRINT - LINE 2

	DRUM LOCATION
TRAFFIC INFORMATION X X X X X X X X X X	1413
TRAFFIC INFORMATION X X X X X X X X X X	1414
TRAFFIC INFORMATION X X X X X X X X X X	1415
TRAFFIC INFORMATION X X X X X X X X X X	1416
TRAFFIC INFORMATION X X X X X X X X X X	1417
TRAFFIC INFORMATION X X X X X X X X X X	1418
MACHINE NUMBER 0 0 0 0 0 0 0 | X X X	1419
SPEED 0 0 0 0 0 0 0 | X X X	1420
0 0 0 0 0 0 0 0 0 0	1421
SEL. CODE DIR. CODE 0 0 0 0 0 0 | X X X | X	1422

FIG. 11C TYPE 407 THREE LINE PRINT - LINE 3

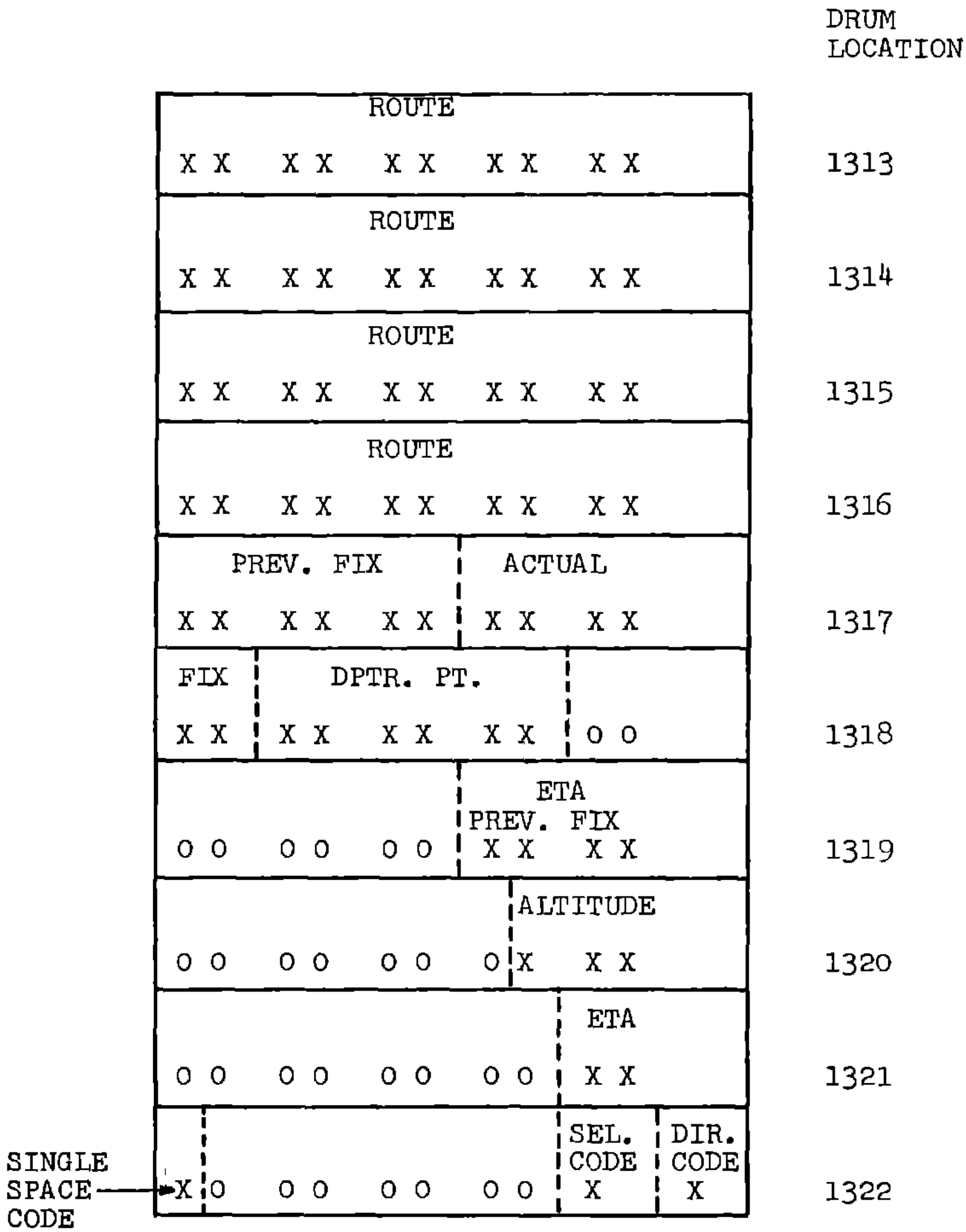

FIG. 12A TYPE 407 FIVE LINE PRINT - LINE 1

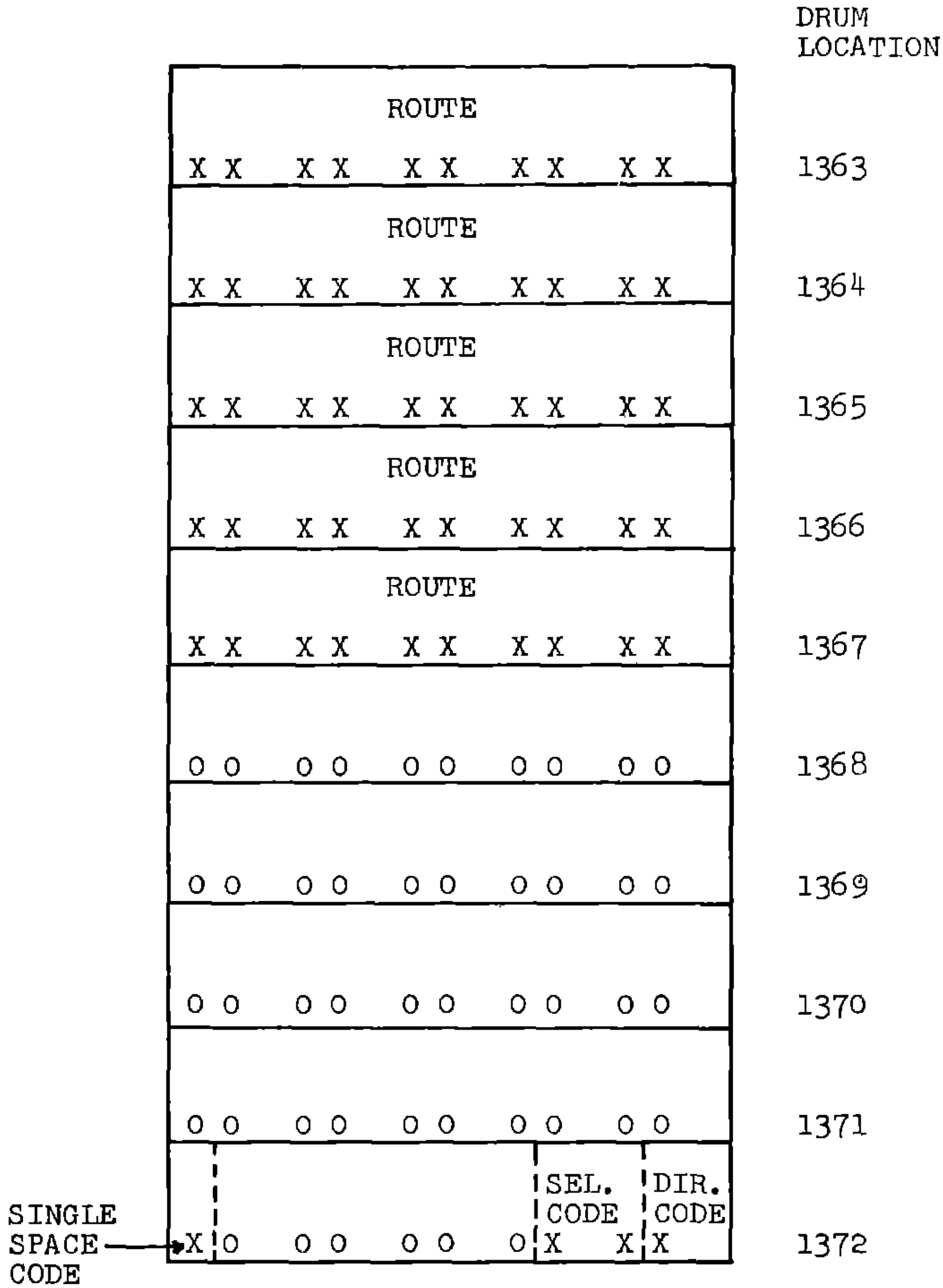

FIG. 12B TYPE 407 FIVE LINE PRINT - LINE 2

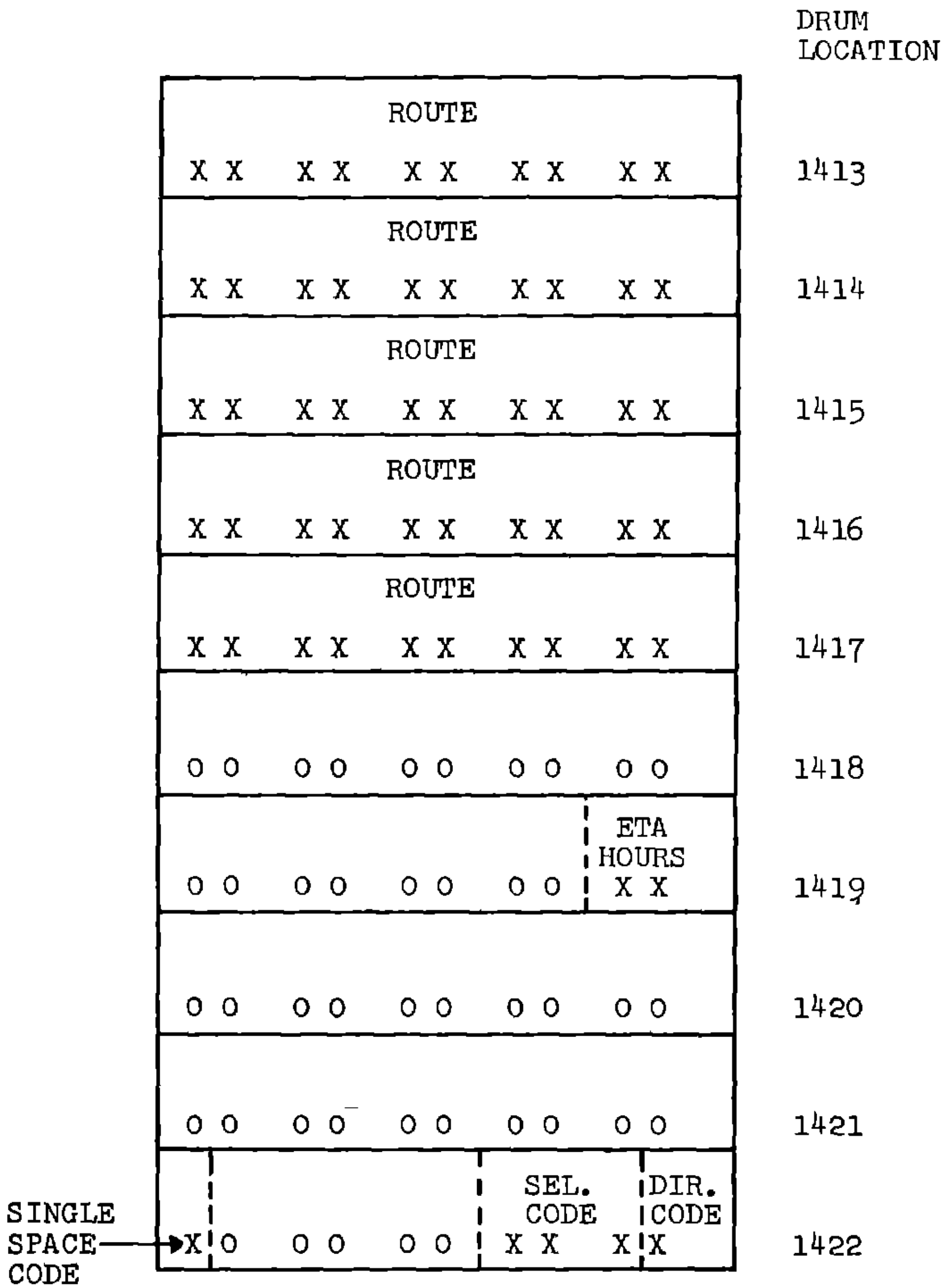

FIG. 12C TYPE 407 FIVE LINE PRINT - LINE 3

Contents	DRUM LOCATION
ROUTE X X X X X X X X X X	1463
ROUTE X X X X X X X X X X	1464
ROUTE X X X X X X X X X X	1465
ROUTE X X X X X X X X X X	1466
ROUTE X X X X X X X X X X	1467
O O O O O O O O O O	1468
O O O O O O O O O O	1469
O O O O O O O O O O	1470
O O O O O O O O O O	1471
SINGLE SPACE CODE → X | SEL. CODE: O O O O X X X X | DIR. CODE: X	1472

FIG. 12D TYPE 407 FIVE LINE PRINT - LINE 4

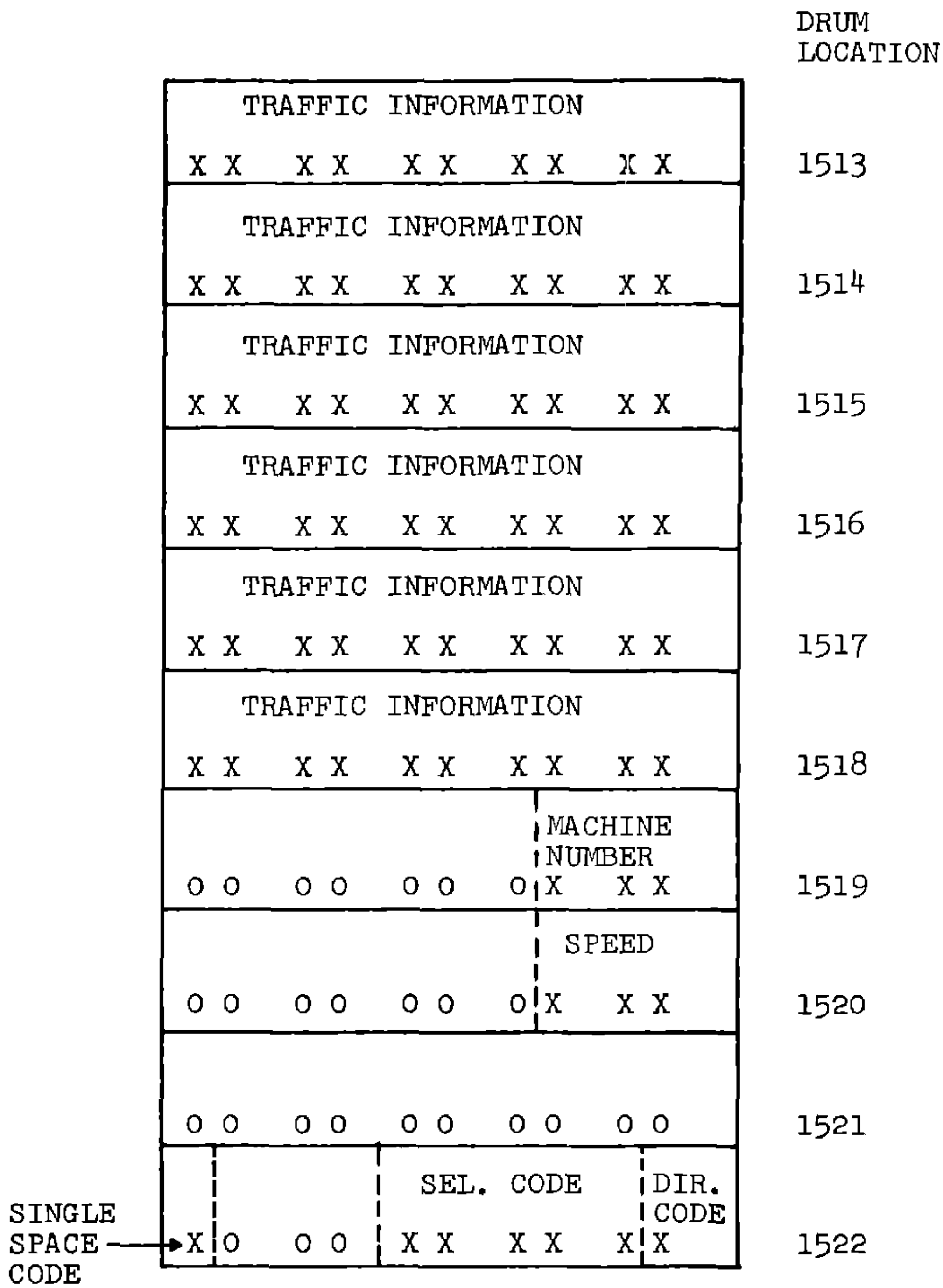

FIG. 12E TYPE 407 FIVE LINE PRINT - LINE 5

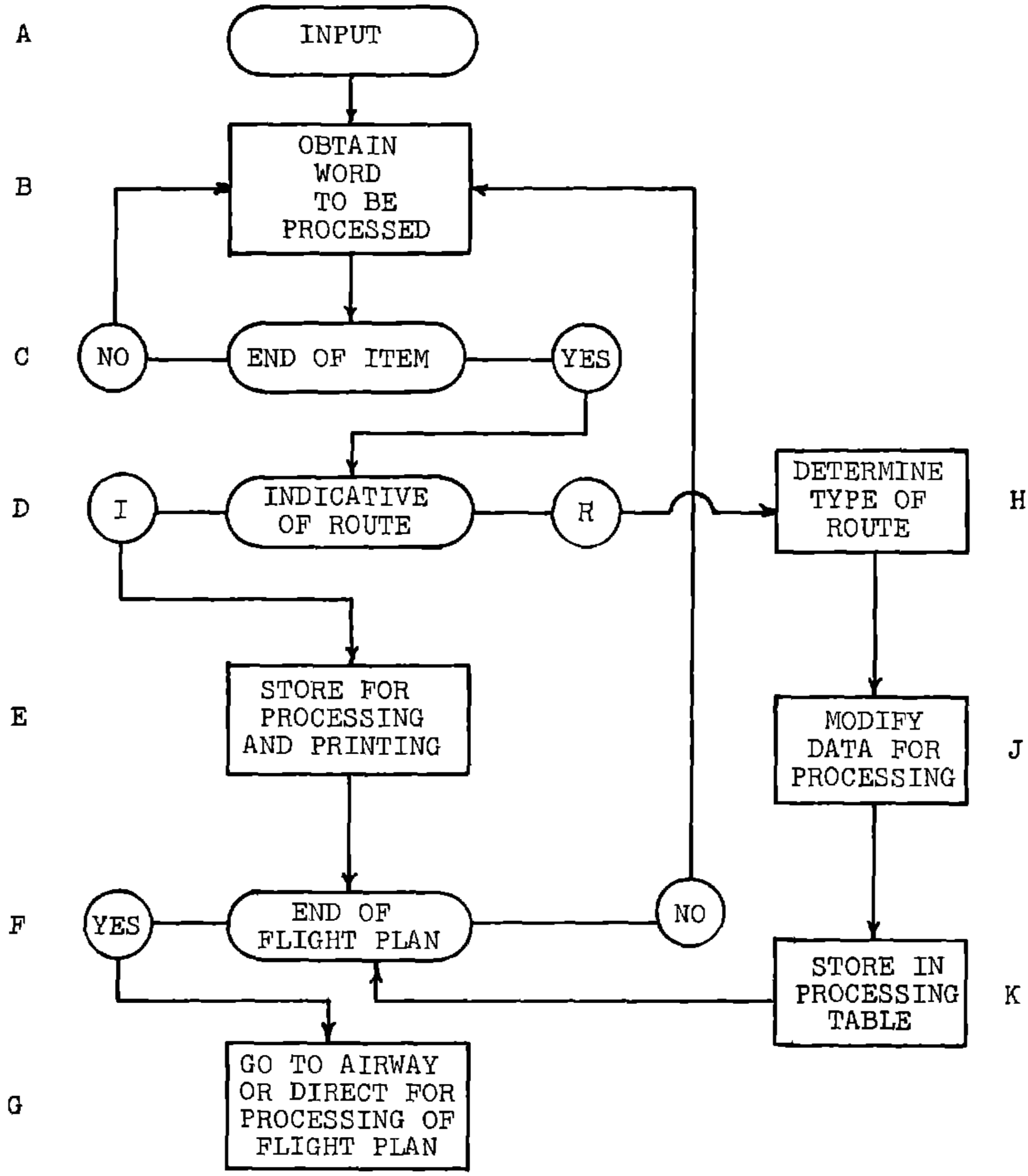

FIG. 13 GENERAL FLOW CHART OF INPUT ROUTINE

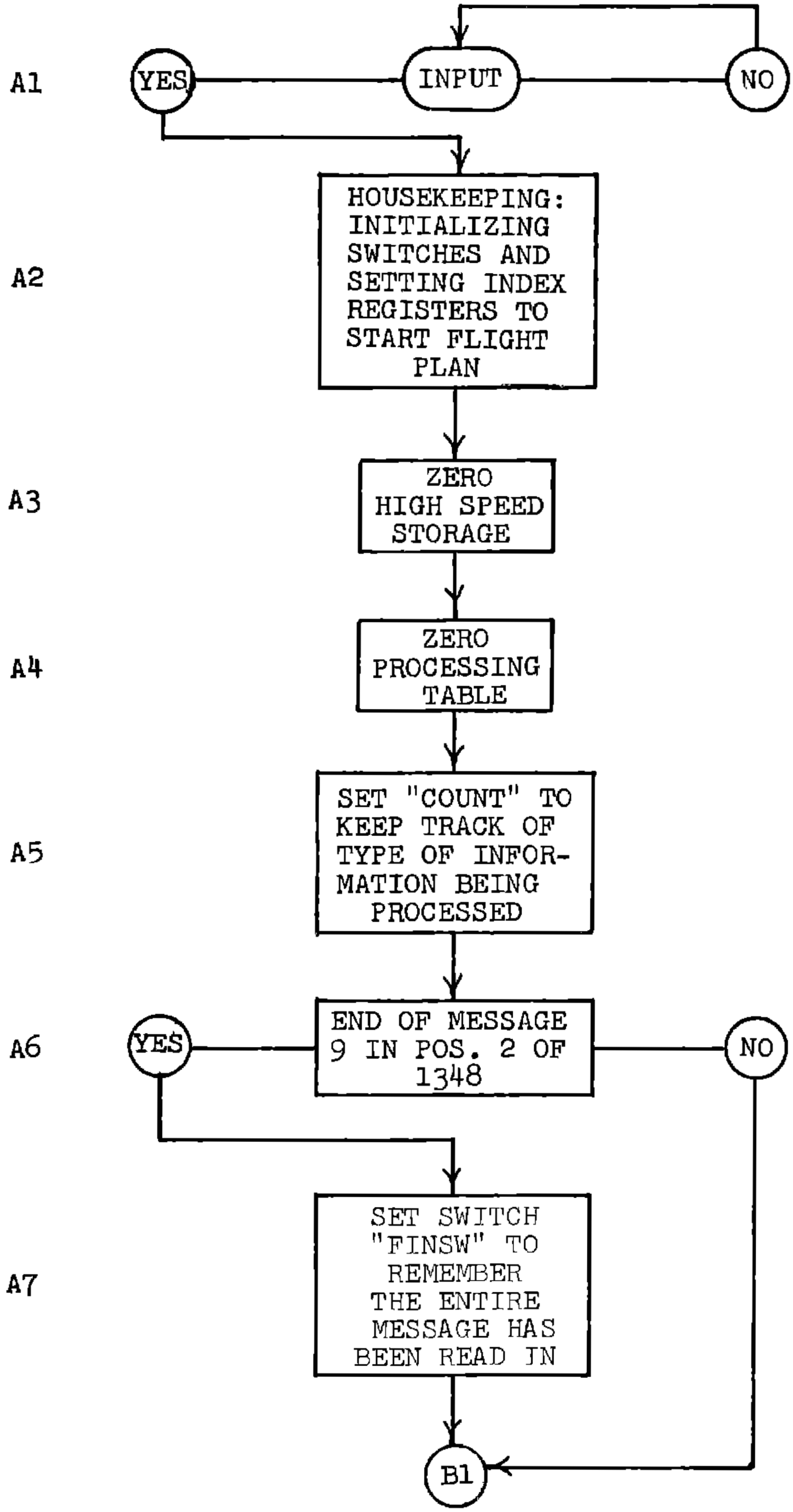

FIG. 14A - SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

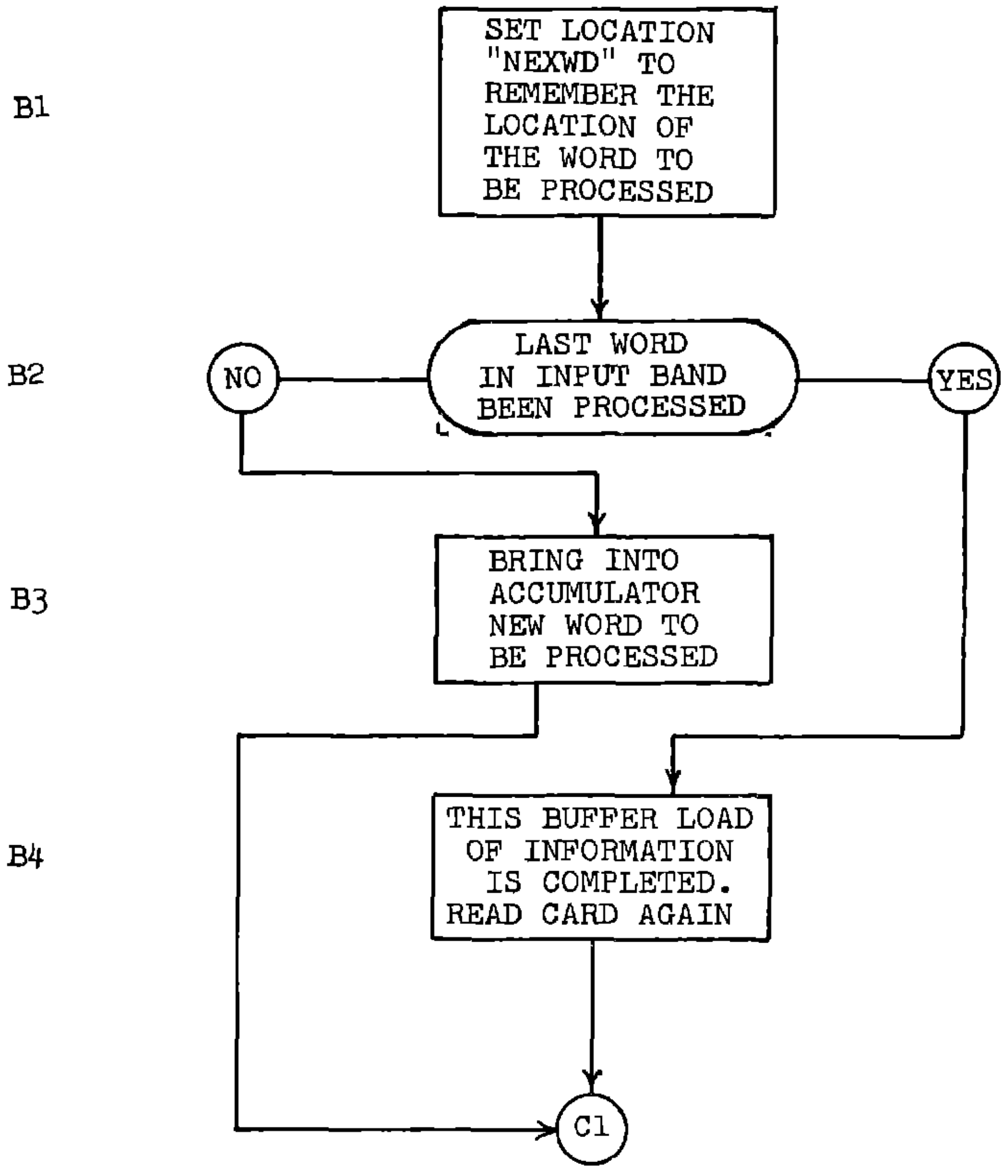

FIG.14B SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

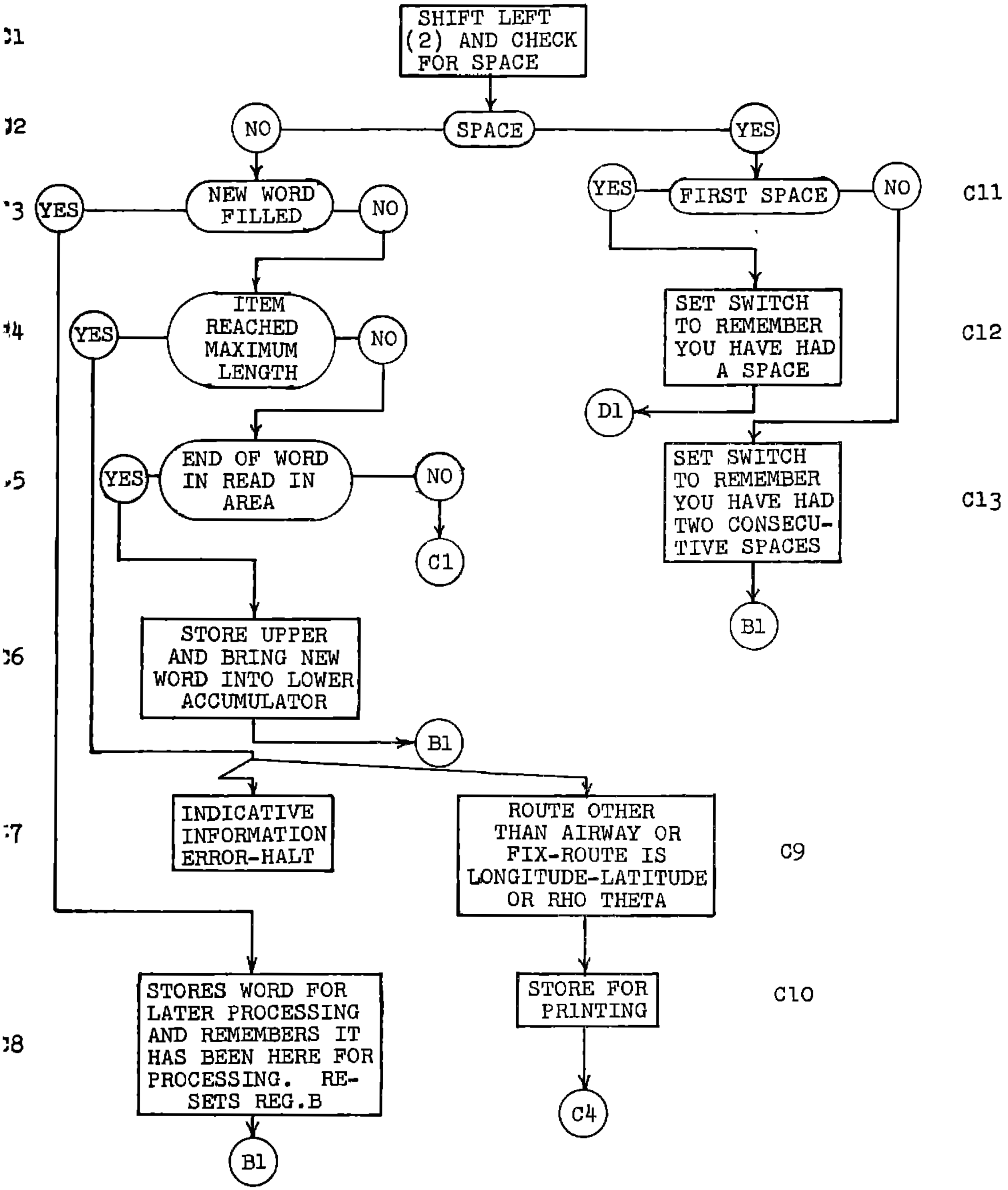

FIG. 14C - SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

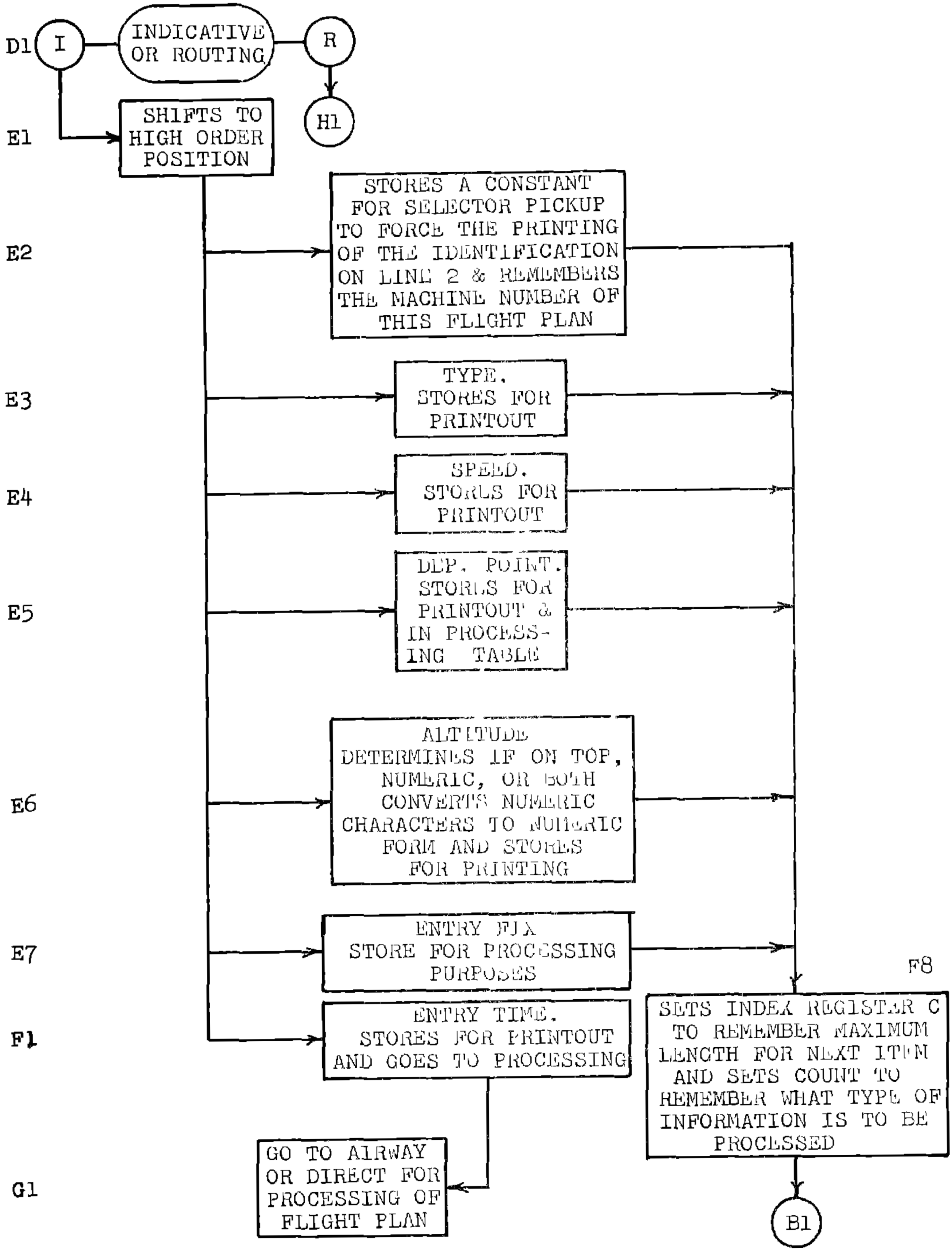

FIG. 14D SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

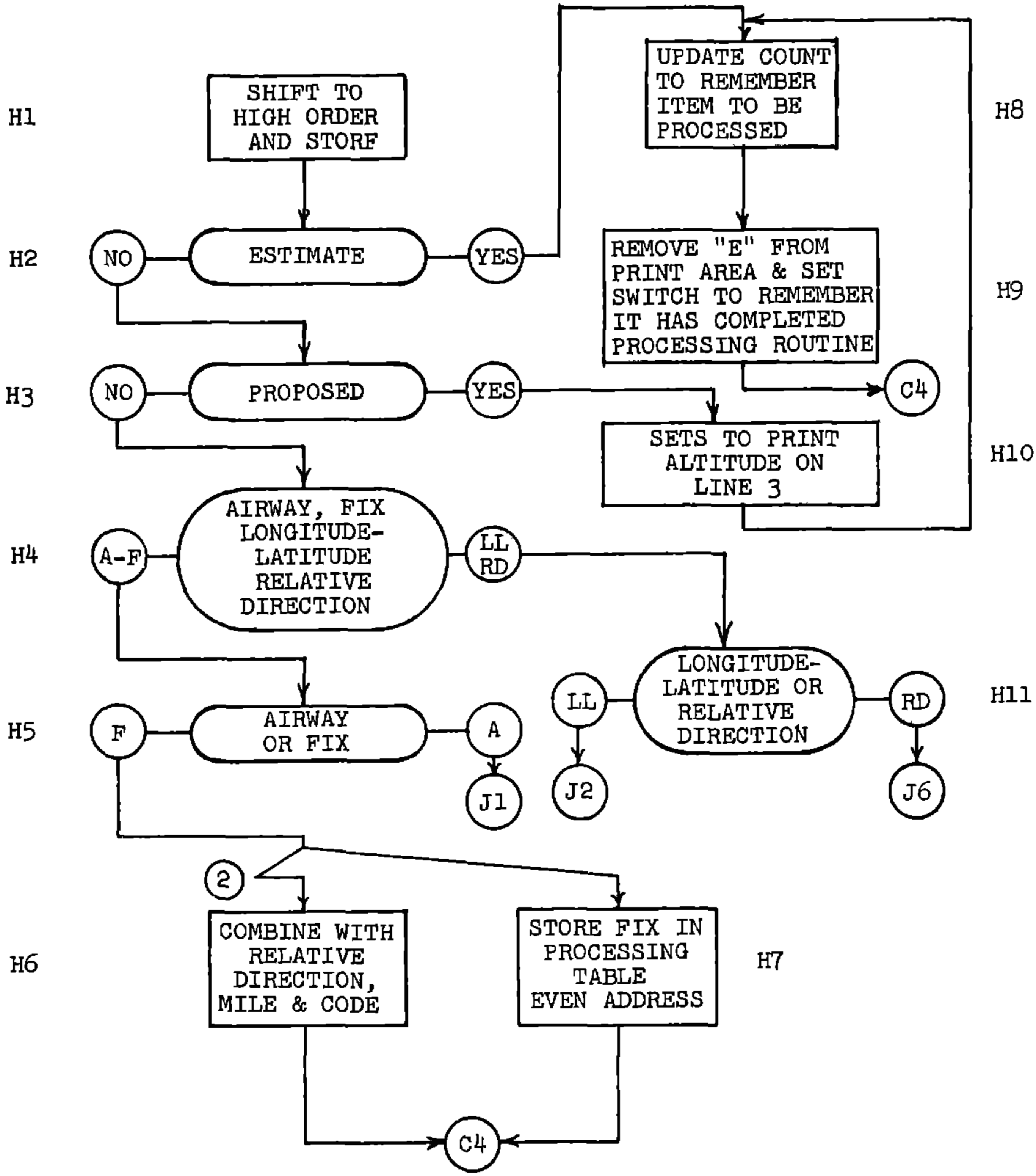

FIG. 14E SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

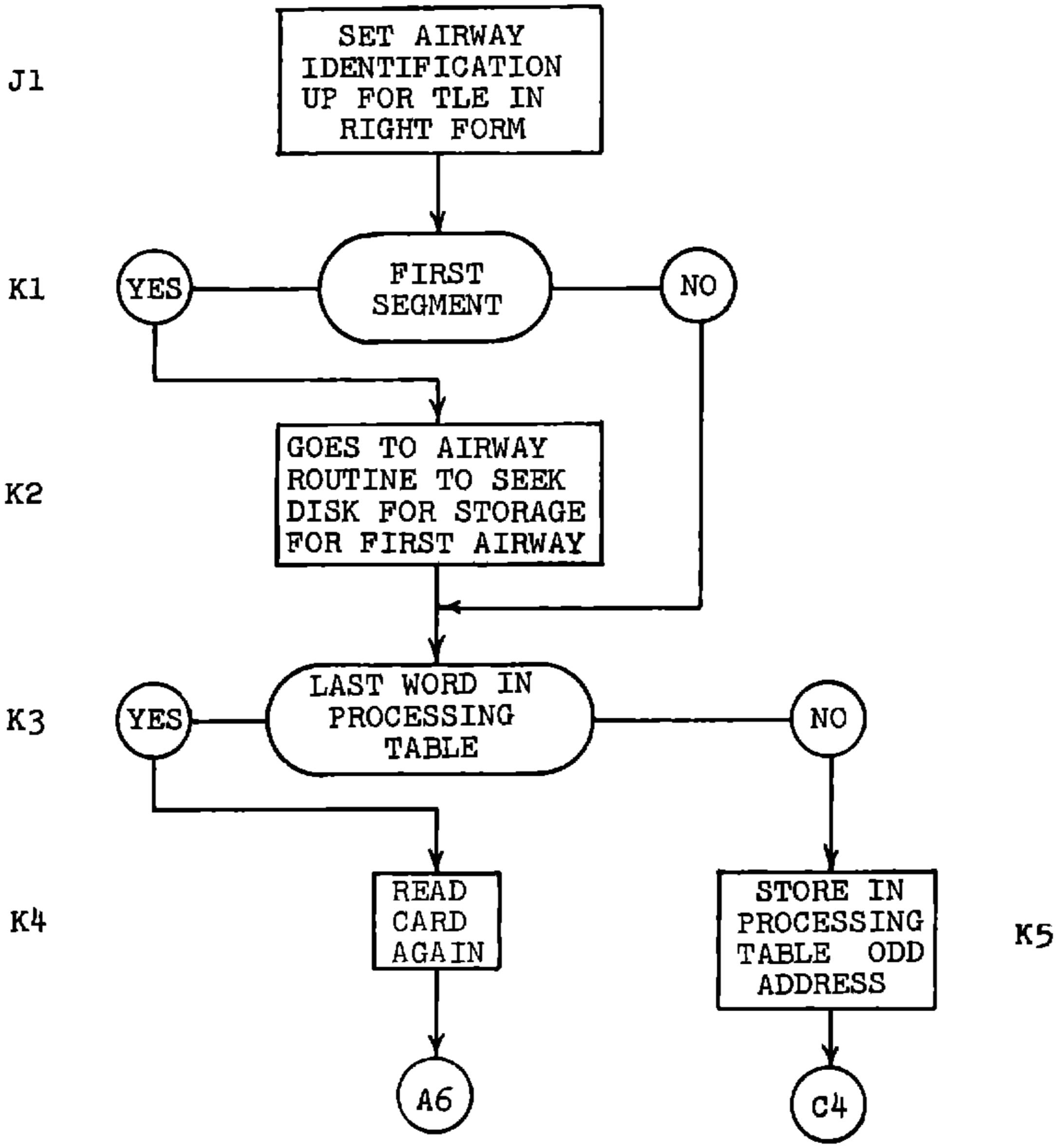

FIG.14F SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

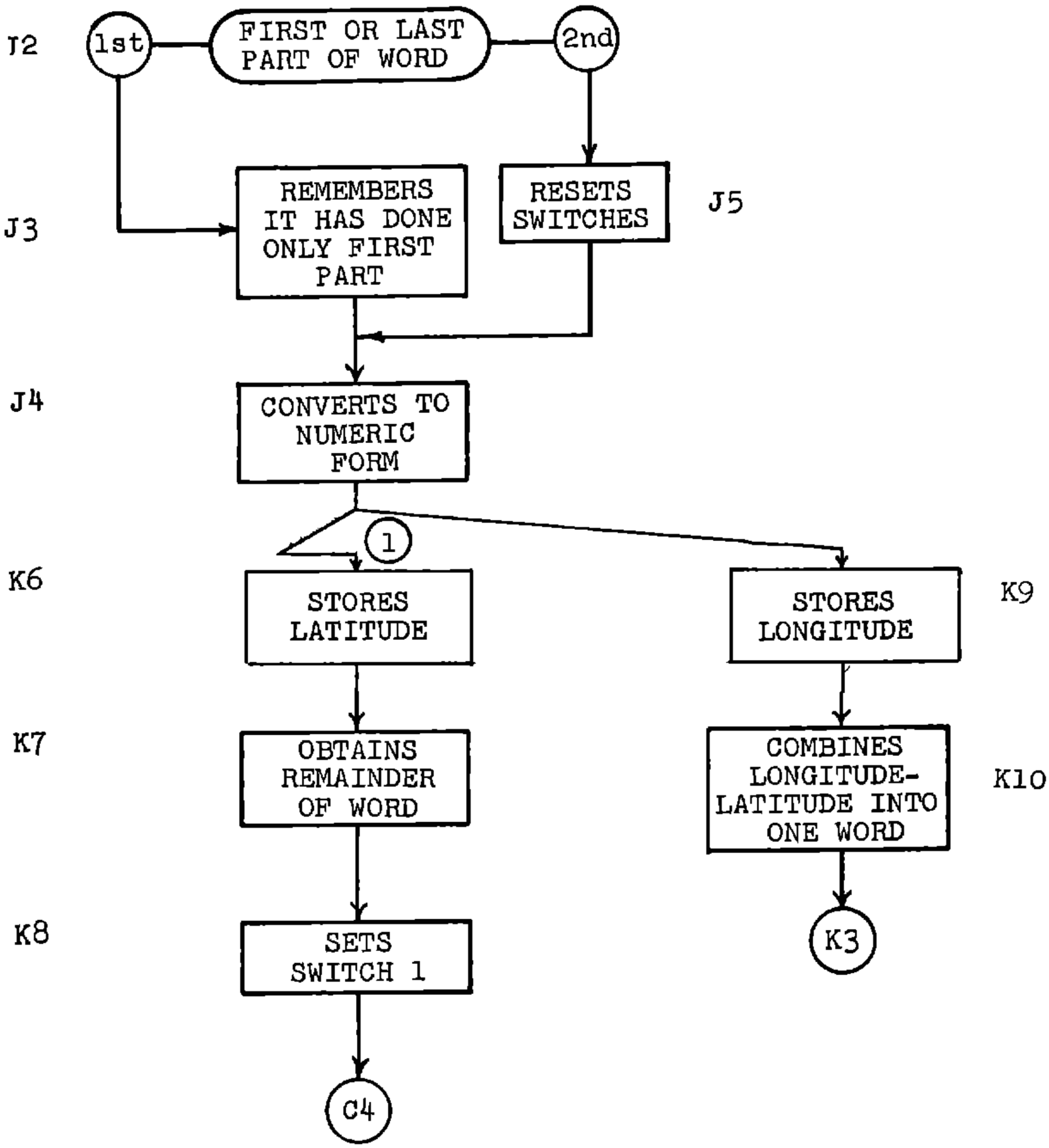

FIG. 14G SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

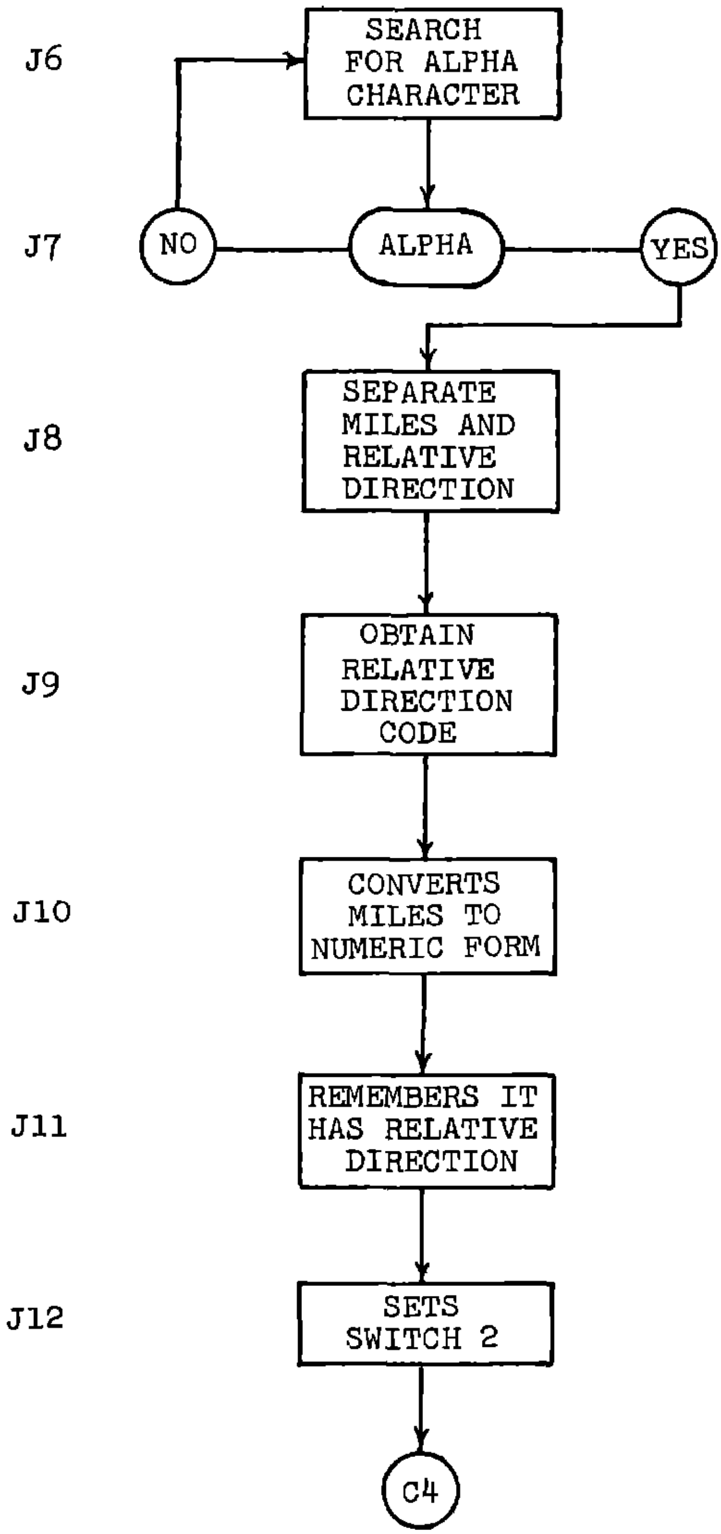

FIG. 14H SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

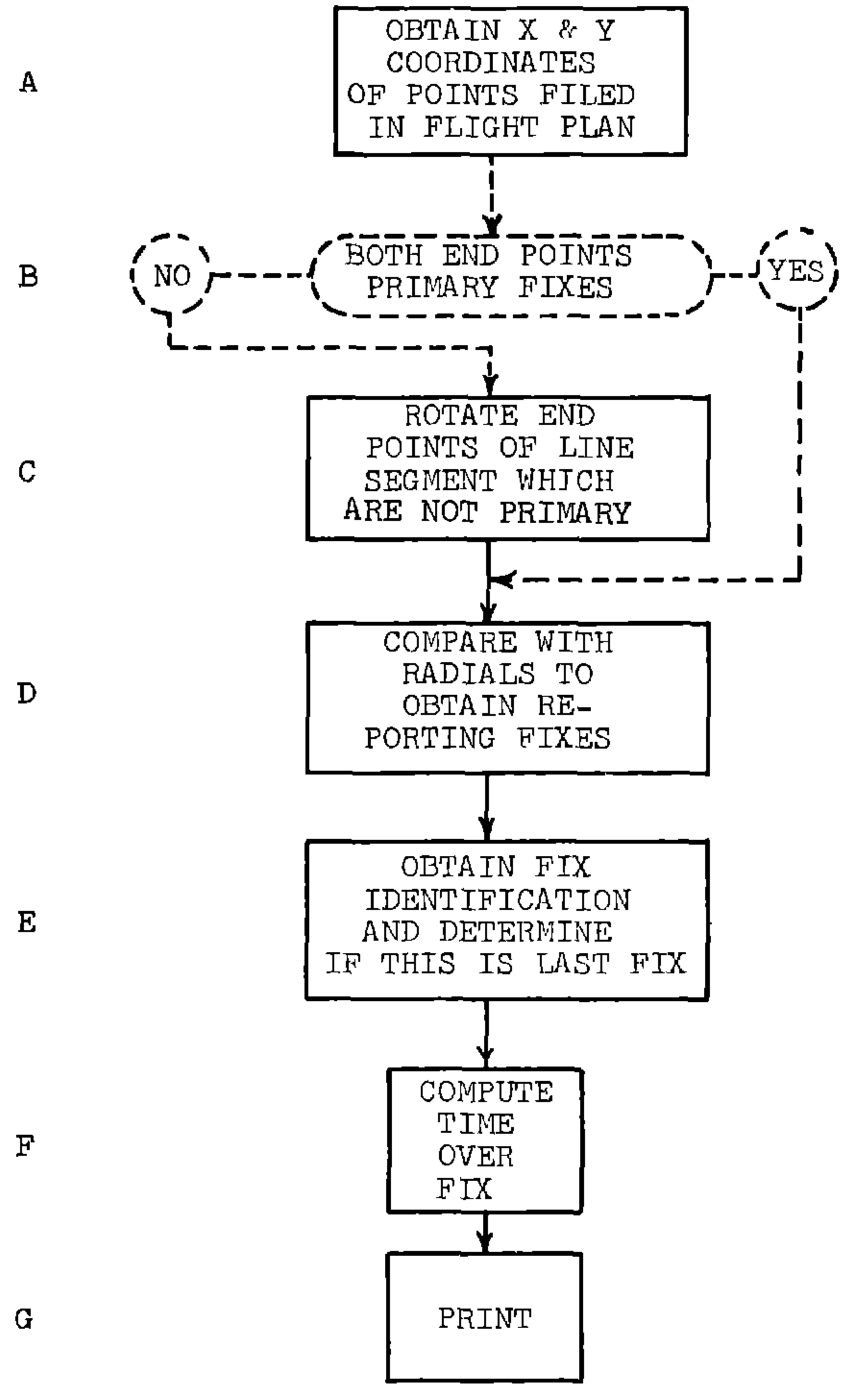

FIG. 15 GENERAL FLOW CHART OF DIRECT ROUTINE

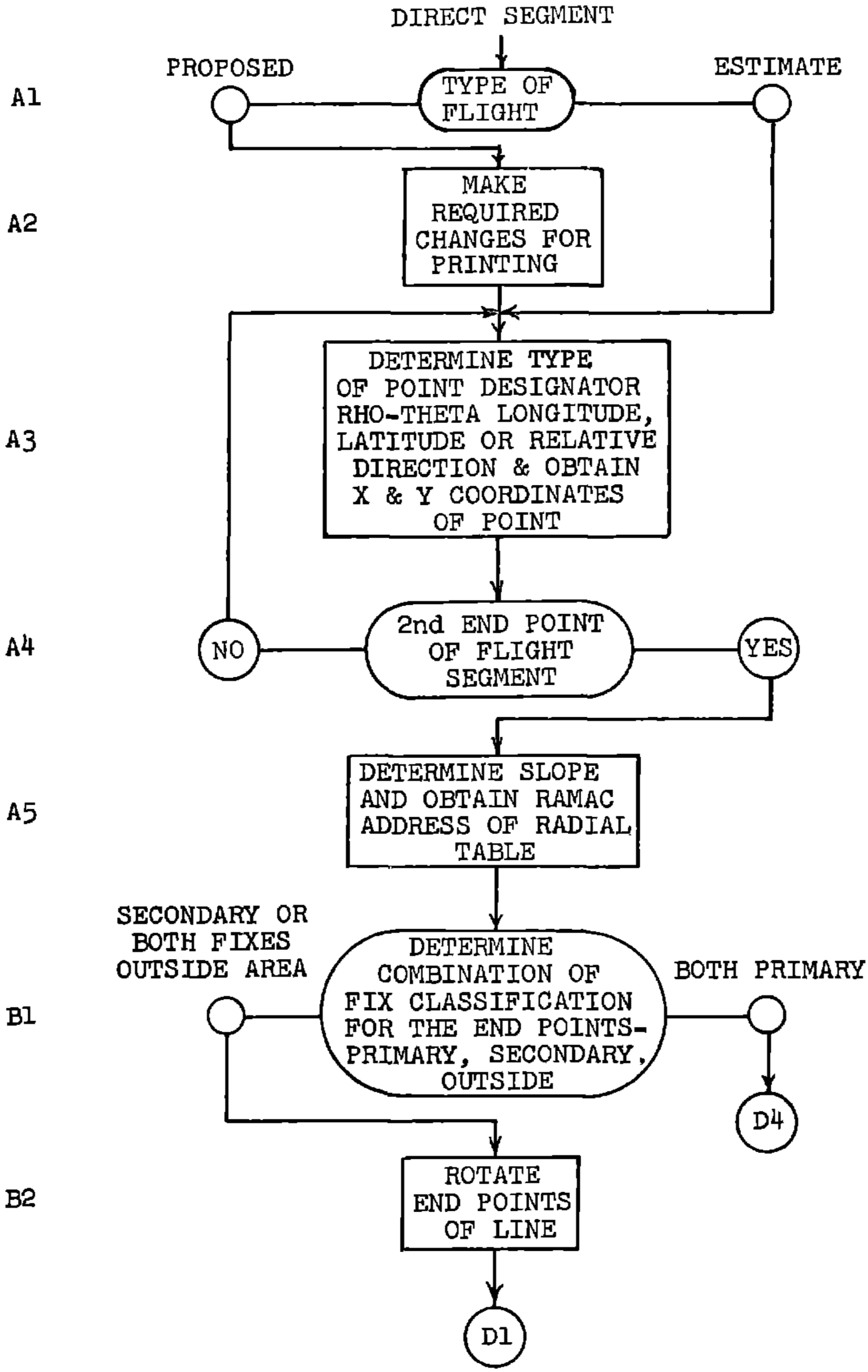

FIG.16A SEMI-DETAILED FLOW CHART OF DIRECT ROUTINE

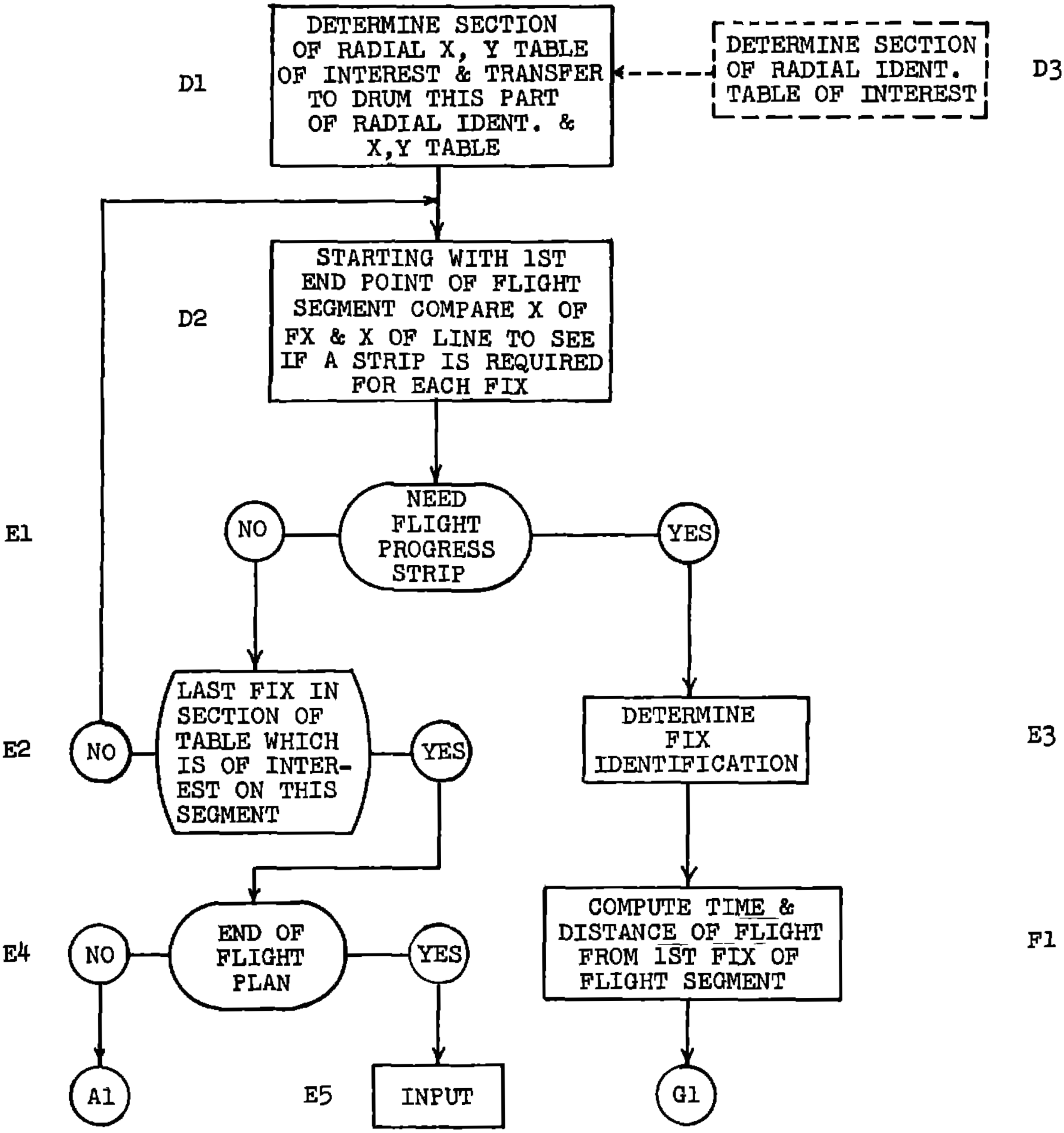

FIG.16B SEMI-DETAILED FLOW CHART OF DIRECT ROUTINE

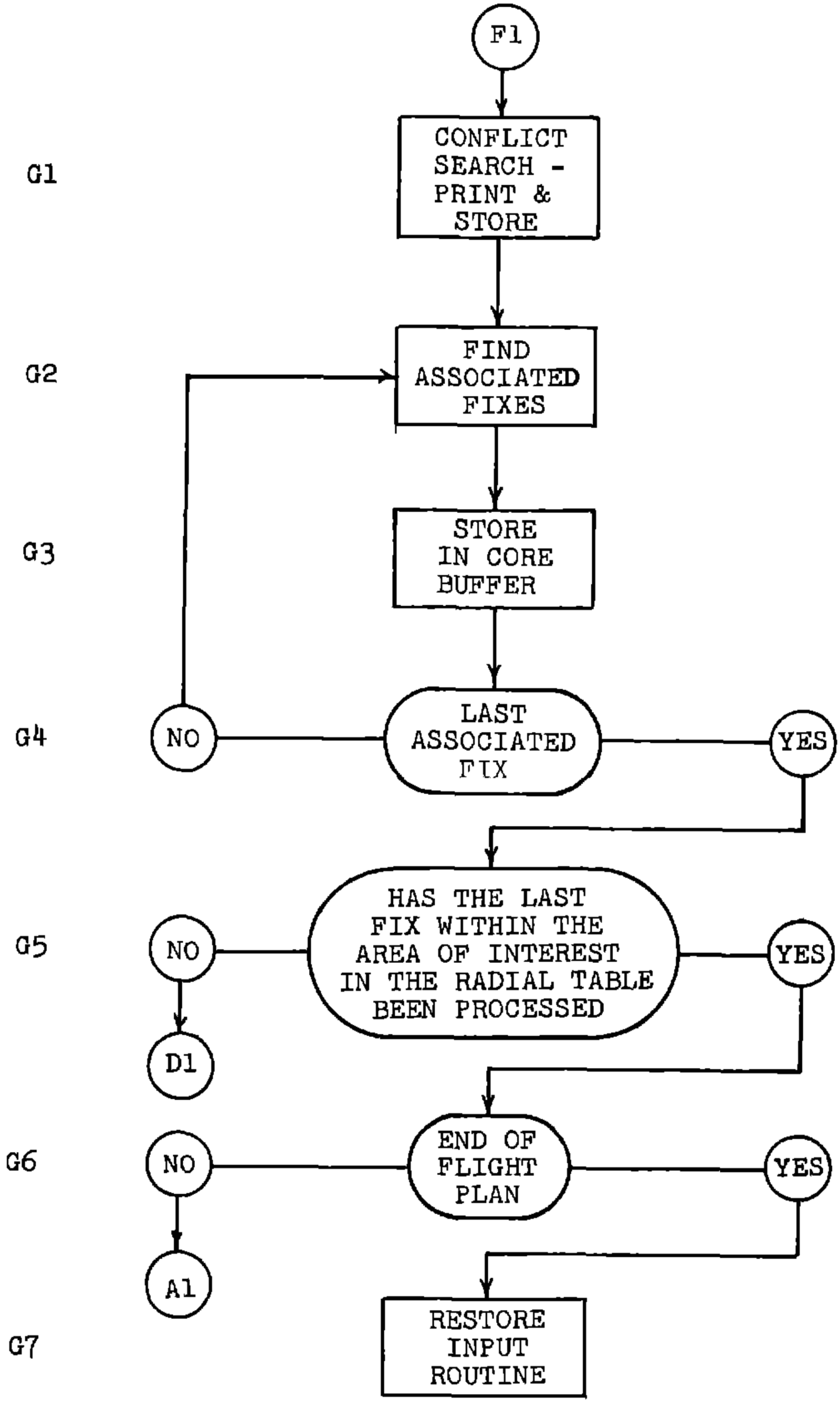

FIG. 16C SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

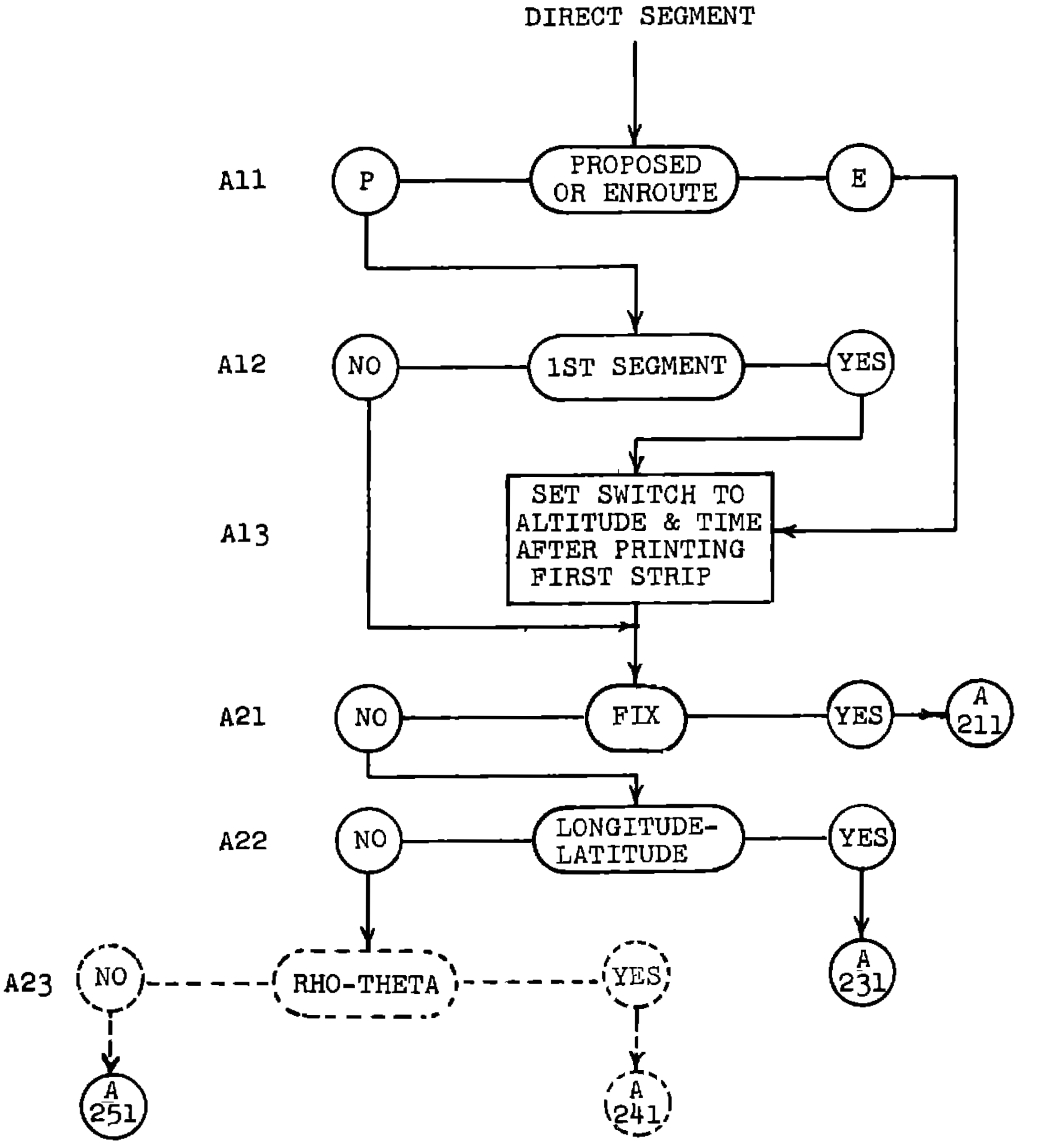

FIG. 16D SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

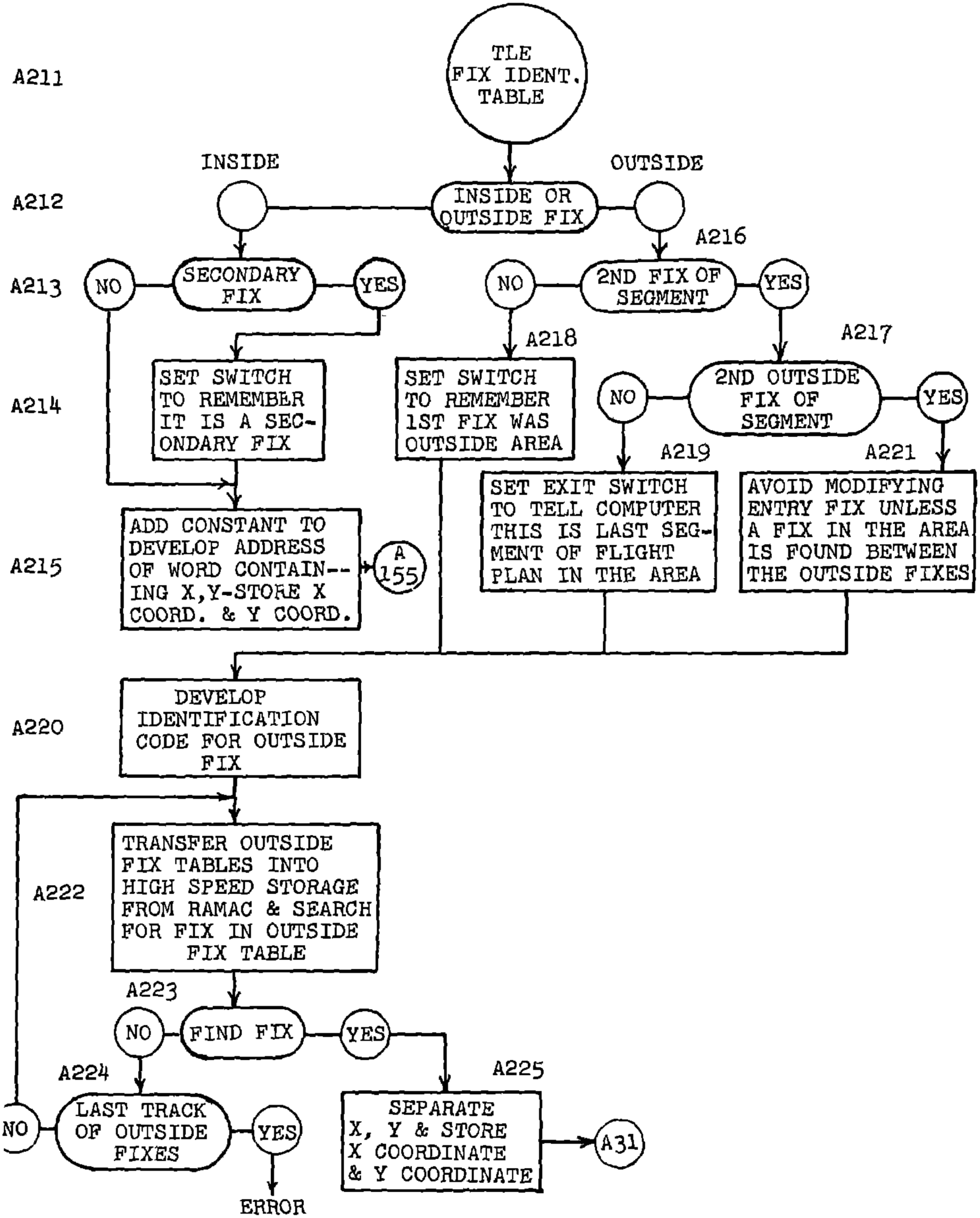

FIG. 16E SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

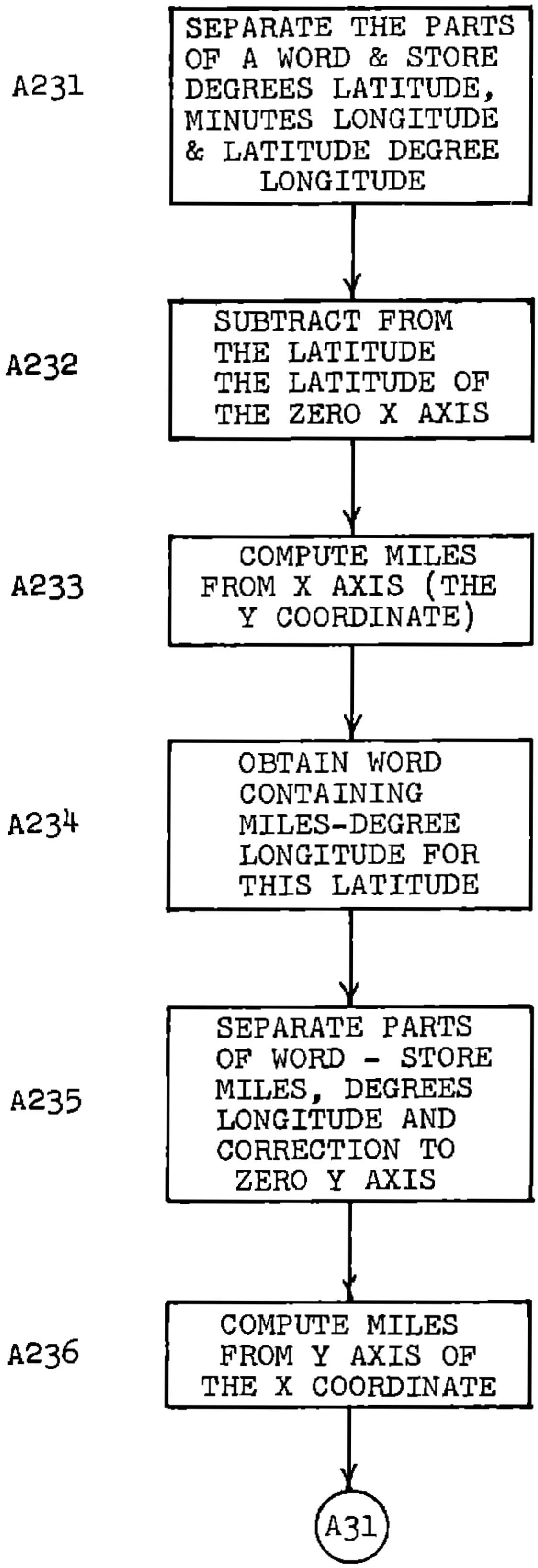

FIG. 16F SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

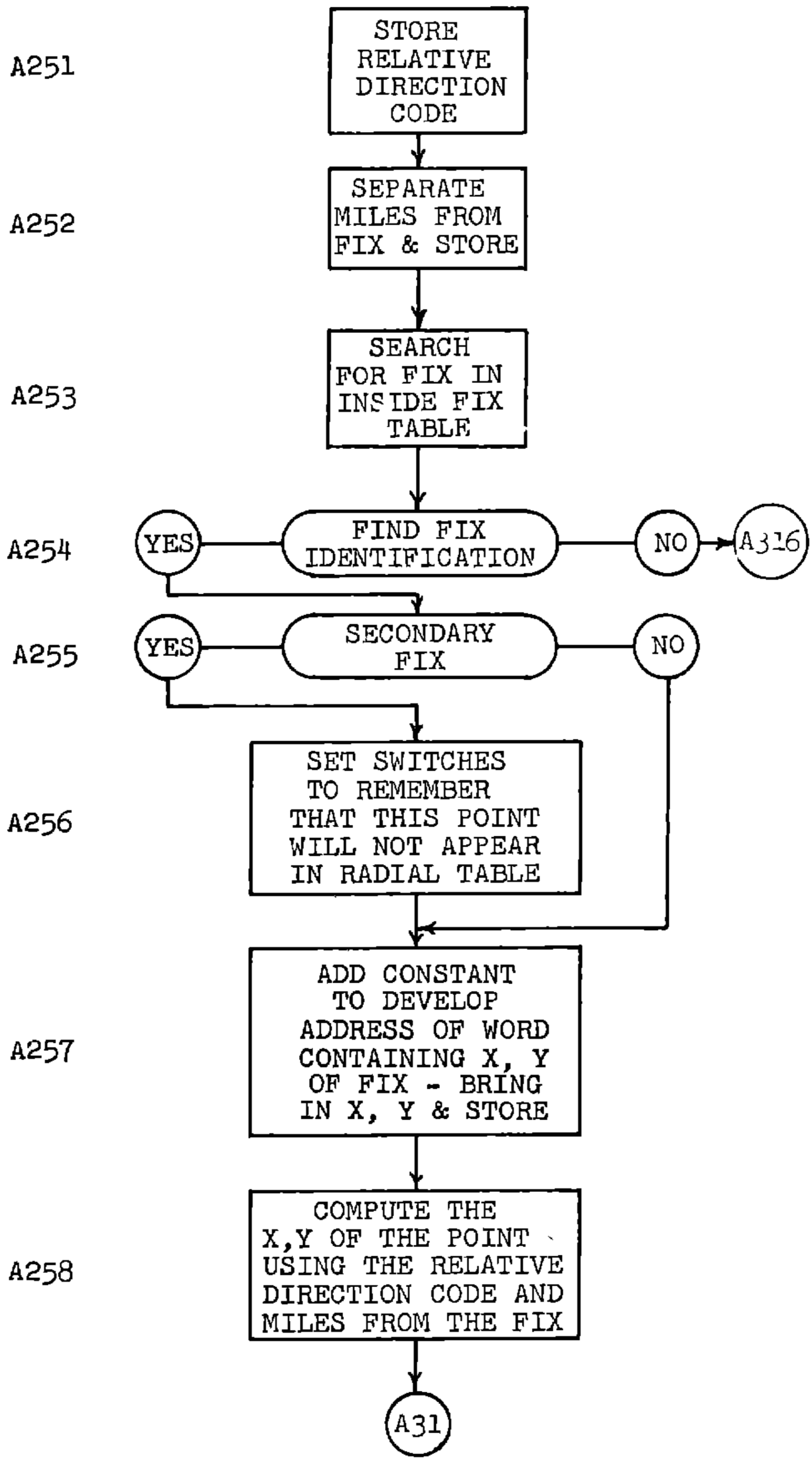

FIG. 16G SEMI-DETAILED FLOW CHART OF DIRECT ROUTINE

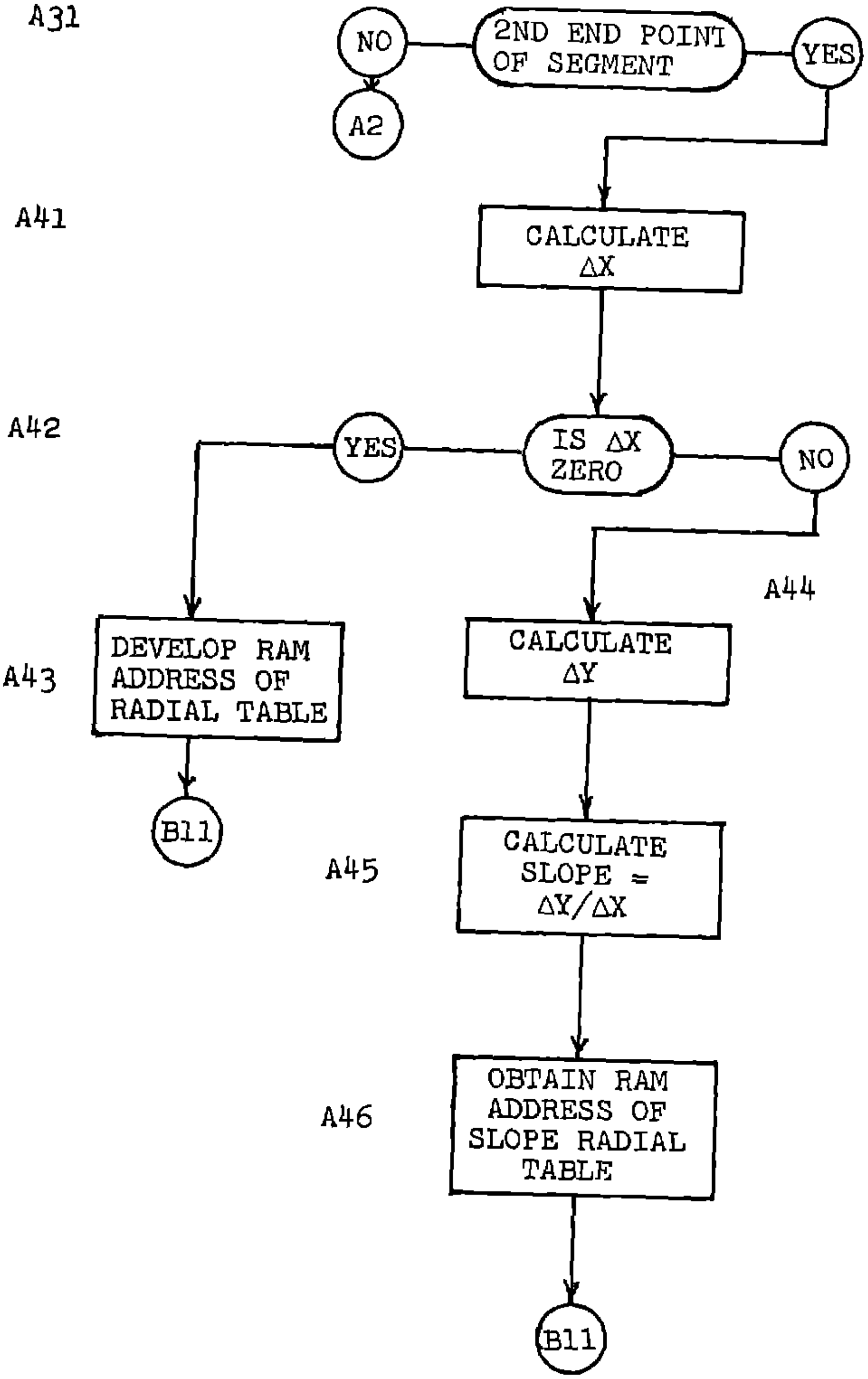

FIG. 16H SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

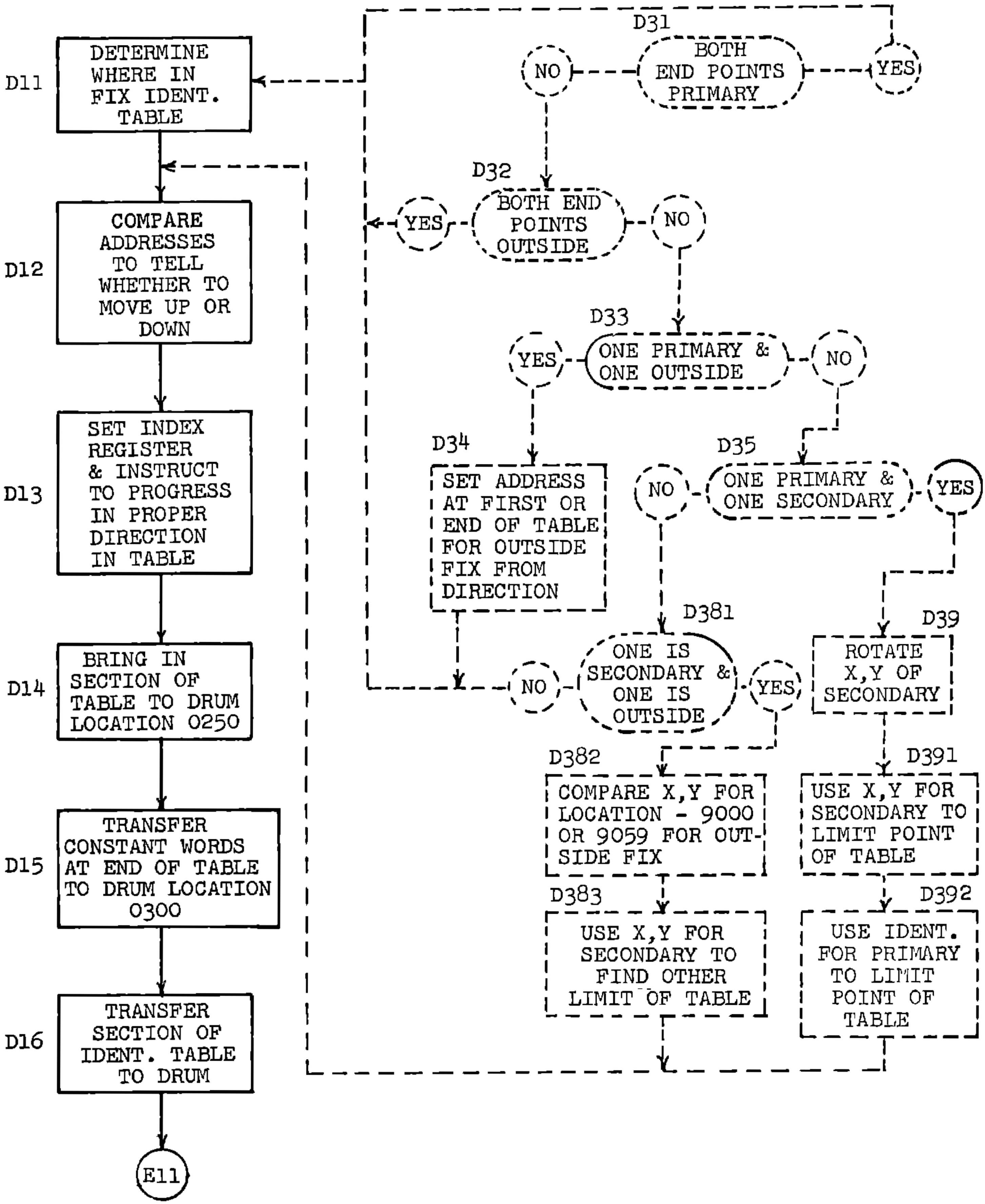

FIG. 16I SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

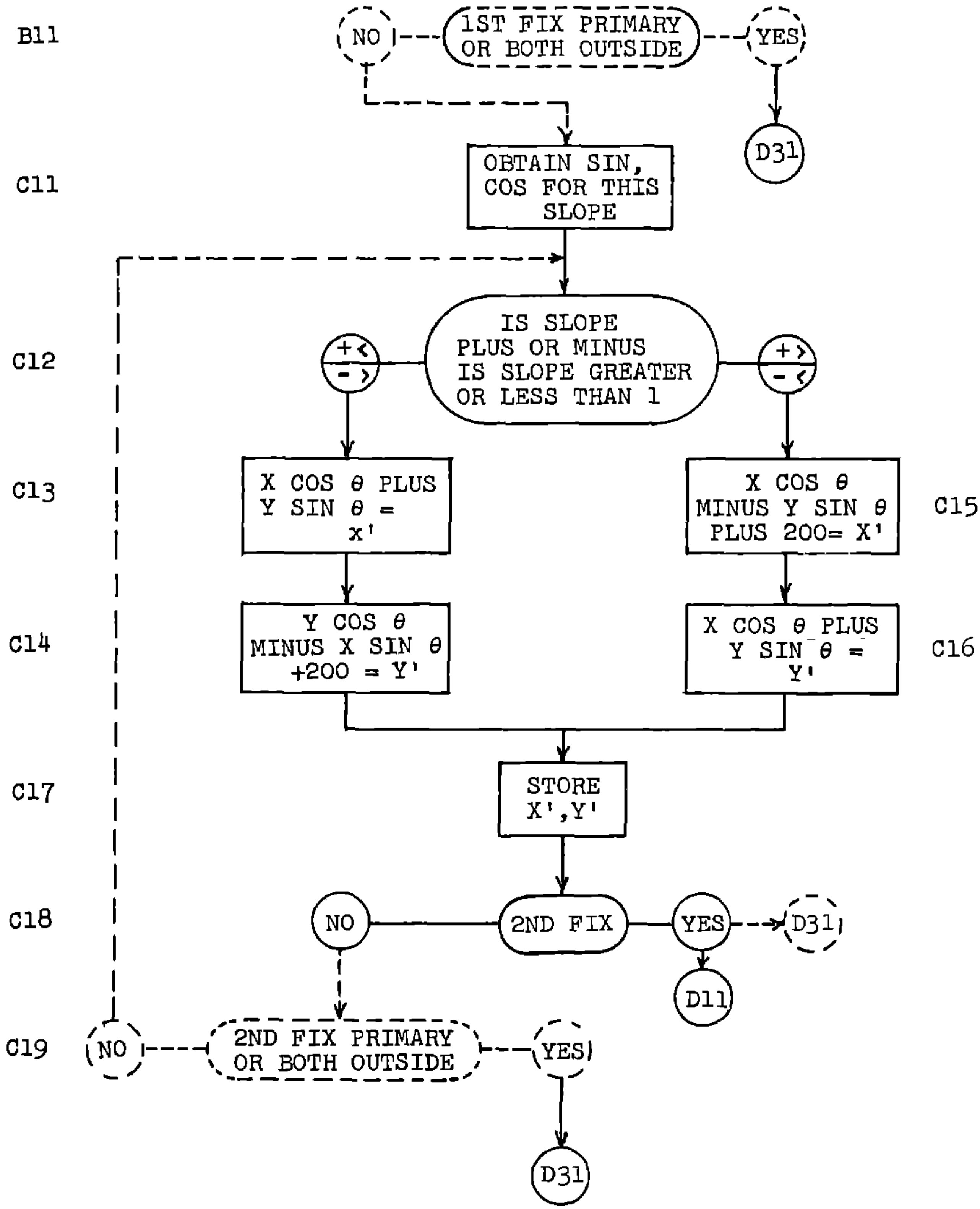

FIG. 16J SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

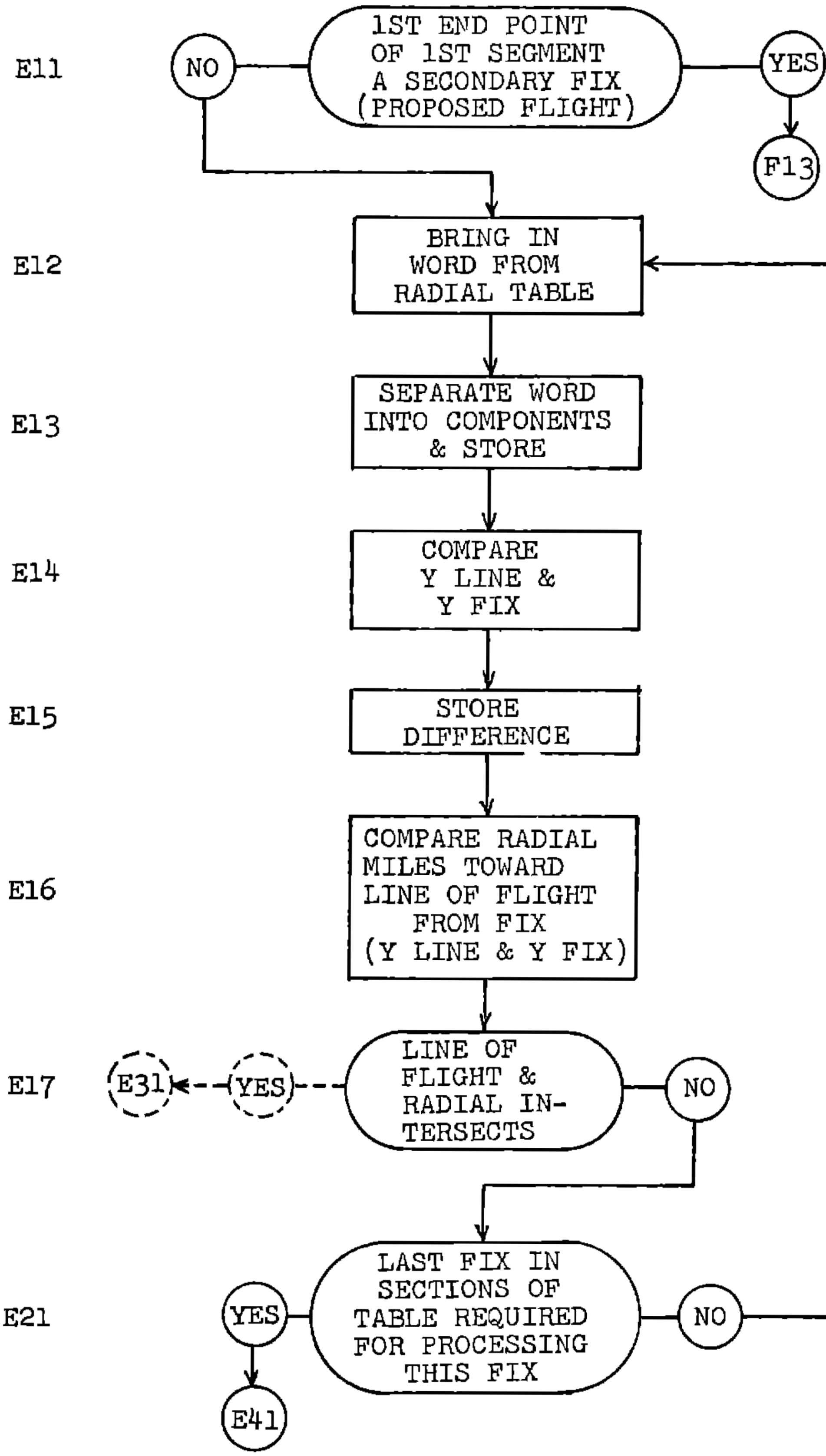

FIG. 16K SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

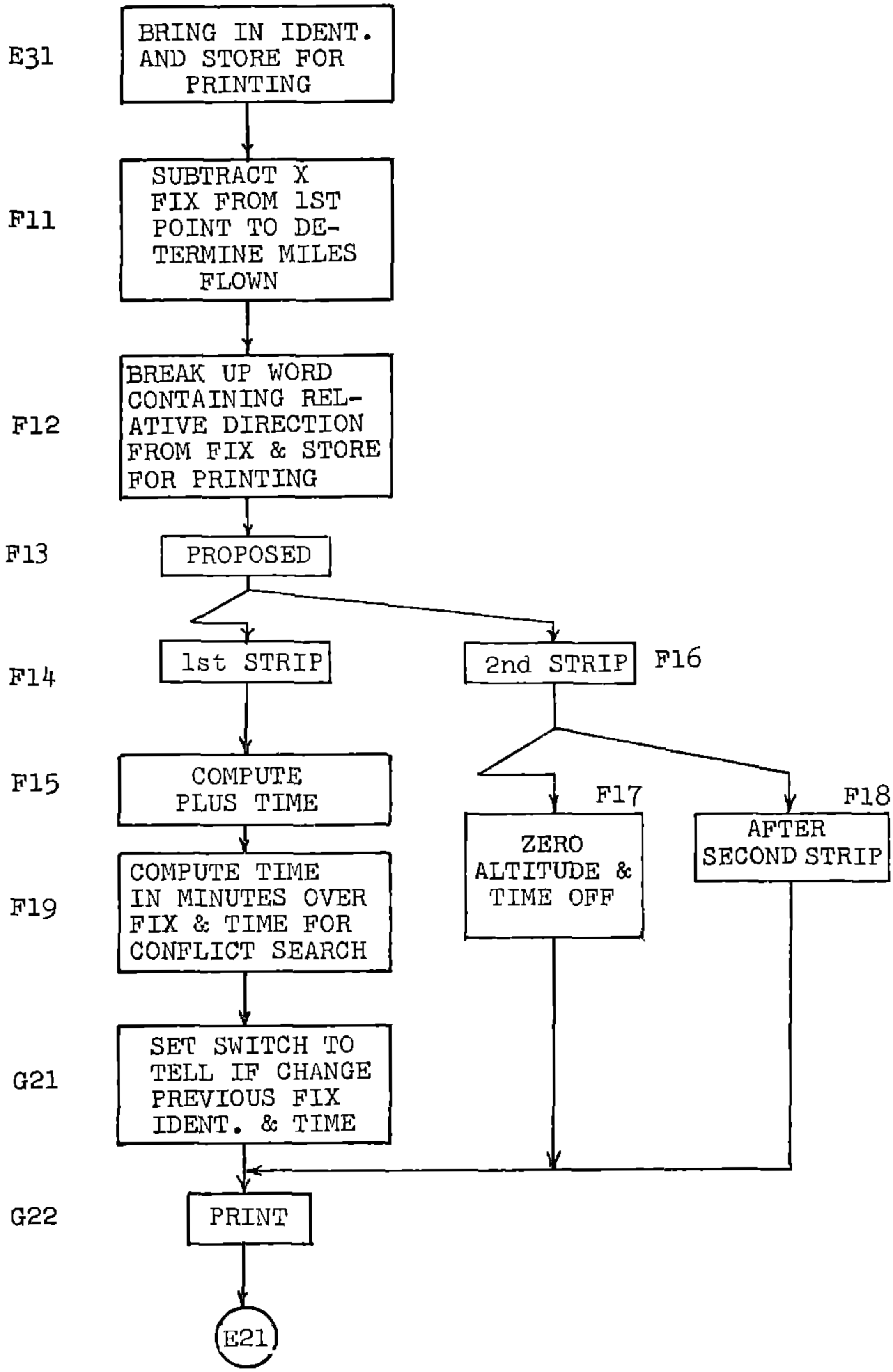

FIG. 16L SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

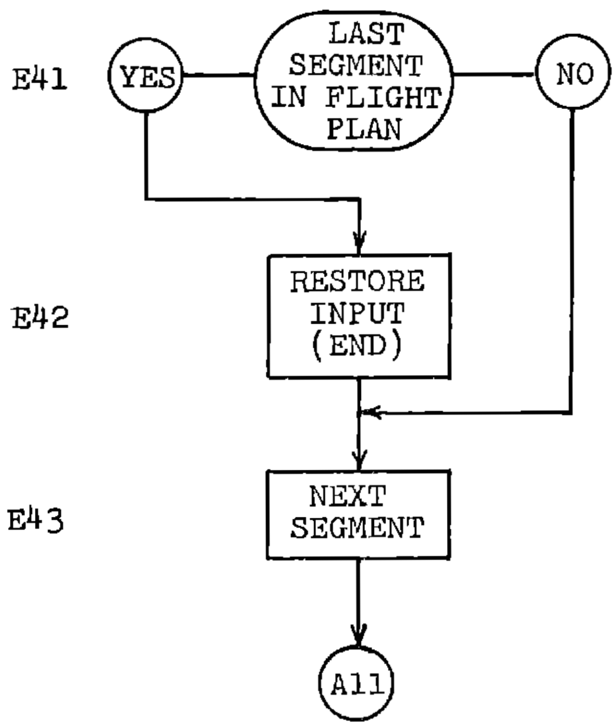

FIG. 16M - SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

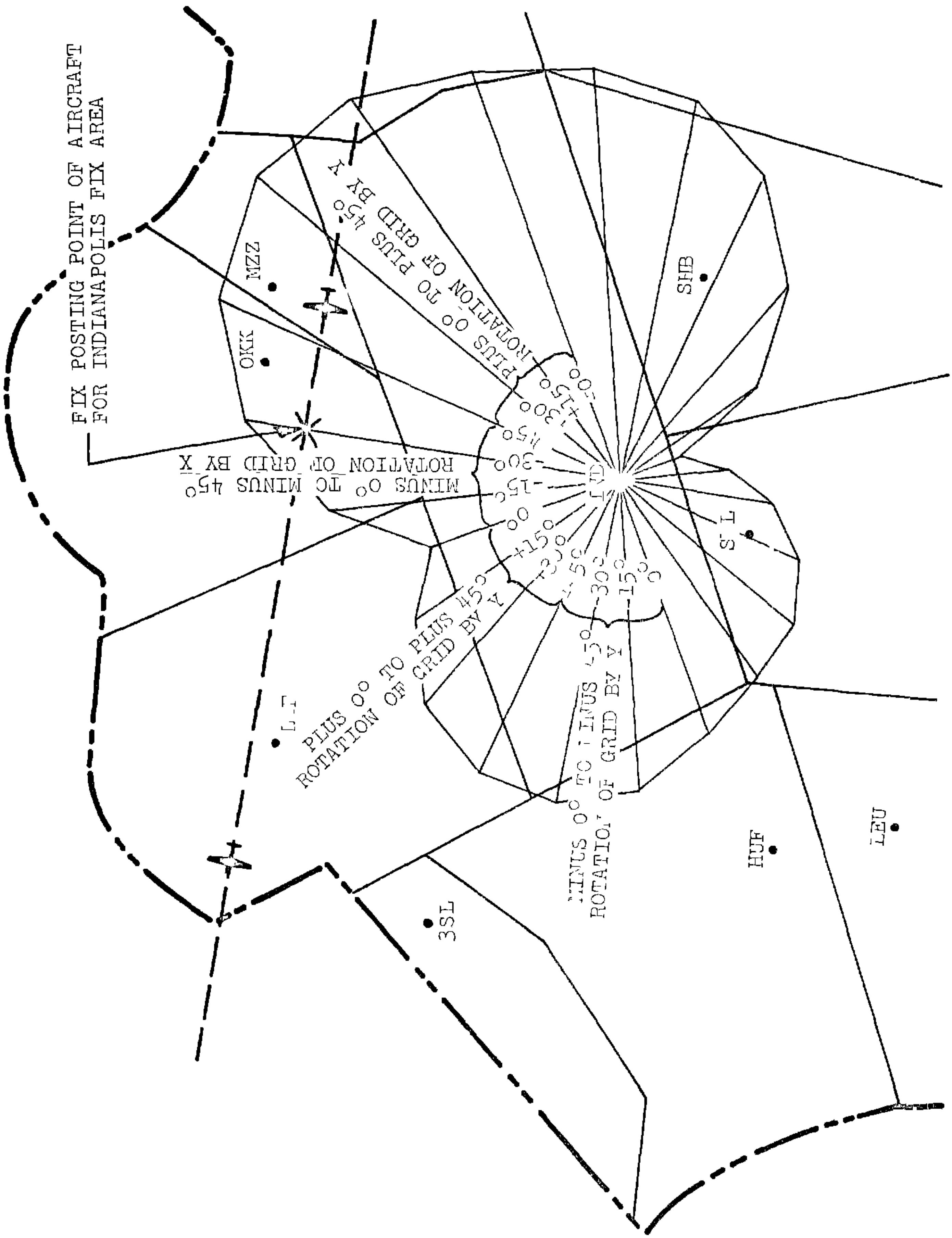

FIG. 17 NORTHWEST SECTOR OF INDIANAPOLIS CONTROL AREA
SHOWING FIX AREAS AND INDIANAPOLIS SPIDER WEB

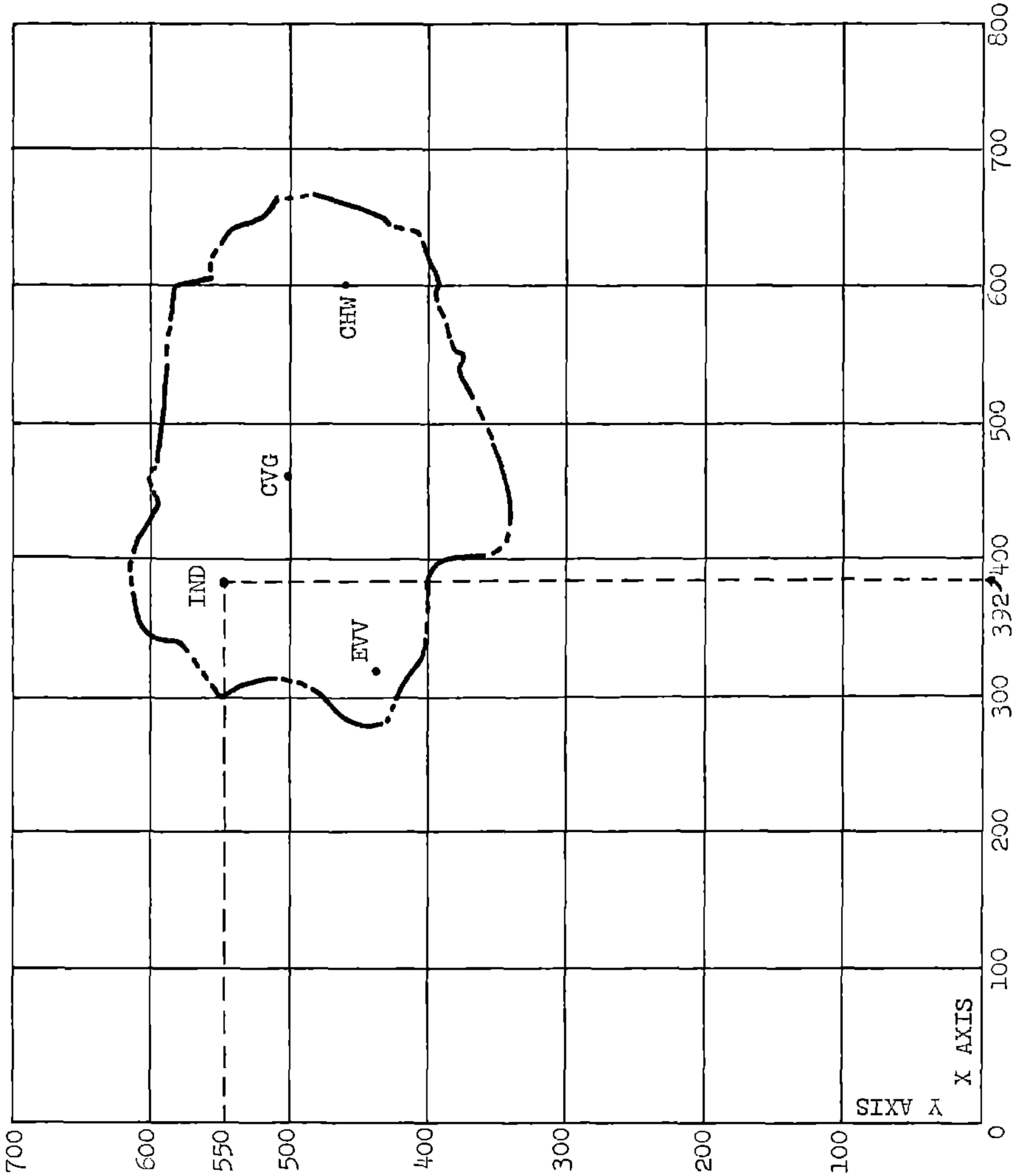

FIG. 18 CONTROL AREA AND COORDINATE SYSTEM

IDENT. OF AIRPORT	3 DIGITS OF X VALUE	3 DIGITS OF Y VALUE	DRUM LOCATION
X X X X	X X X	Y Y Y	1900
X X X X	X X X	Y Y Y	1901
X X X X	X X X		
X X X X		Y Y Y	
	X X X	Y Y Y	THRU
X X X X	X X X	Y Y Y	
X X X X	X X X	Y Y Y	
X X X X	X X X	Y Y Y	1927

4 CHARACTER IDENTIFICATION DEVELOPED BY IDENT.^{2} AND EXTRACTING DIGITS 3, 4, 5, AND 6 FROM THE PRODUCT.

FIG. 19A INSIDE-FIX TABLE

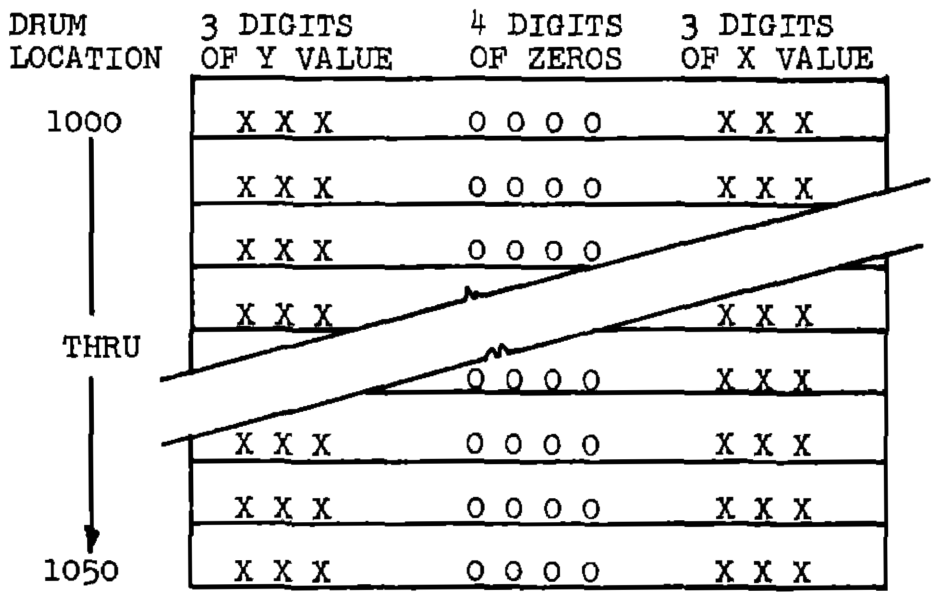

FIG. 19B INSIDE FIX X, Y TABLE

	3 DIGITS OF Y VALUE	4 CHARACTER IDENTIFICATION DEVELOPED BY SQUARING AND EXTRACTING DIGITS 3, 4, 5, 6, FROM THE PRODUCT	3 DIGITS OF X VALUE
9000	Y Y Y	X X X X	X X X
	Y Y Y	X X X X	X X X
	Y Y Y	X X X X	
	Y Y Y		X X X
THRU		X X X X	X X X
	Y Y Y	X X X X	X X X
	Y Y Y	X X X X	X X X
9058	Y Y Y	X X X X	X X X
9059	TLE ARGUMENT		

FIG. 20A OUTSIDE FIX TABLE

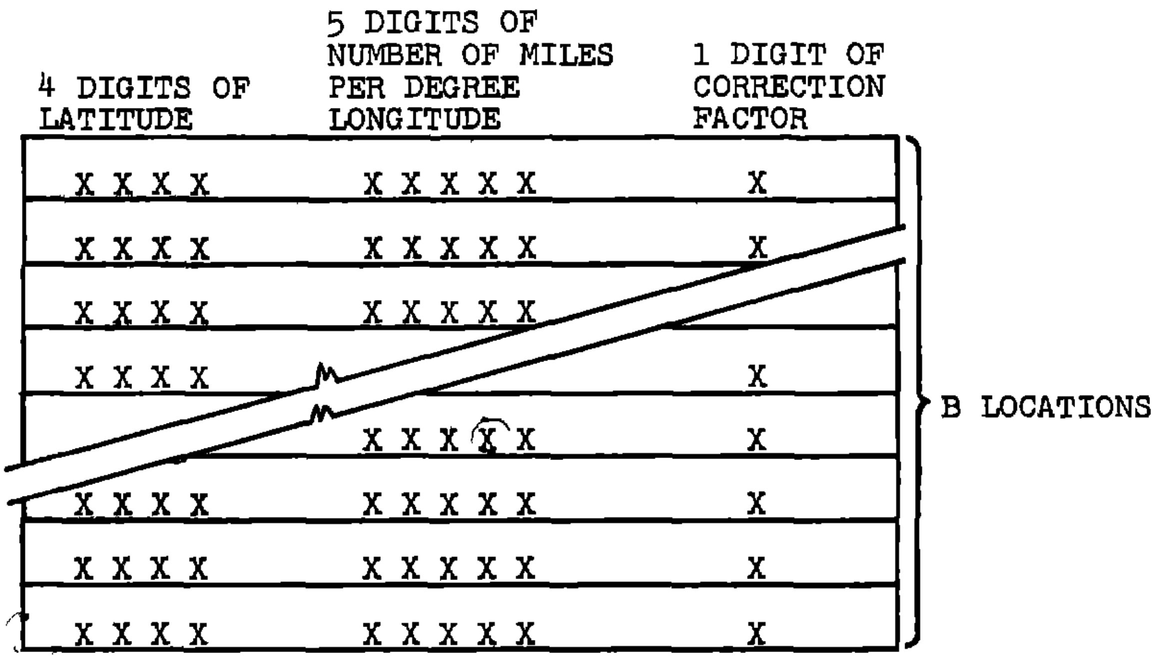

FIG. 20B LATITUDE-MILEAGE TABLE

SLOPE	SIN	COS	DRUM LOCATION
0002	017	999	0850
0009	087	996	0851
0018	174	985	0852
0027	259	966	0853
0036	342	940	0854
0047	423	906	0855
0058	500	866	0856
0070	574	819	0857
0084	643	766	0858
0100	707	707	0859
0119	766	643	0860
0143	819	574	0861
0173	866	500	0862
0214	906	423	0863
0275	940	342	0864
0373	966	259	0865
0567	985	174	0866
1143	996	087	0867
9999	999	017	0868

FIG. 21 SLOPE TABLE

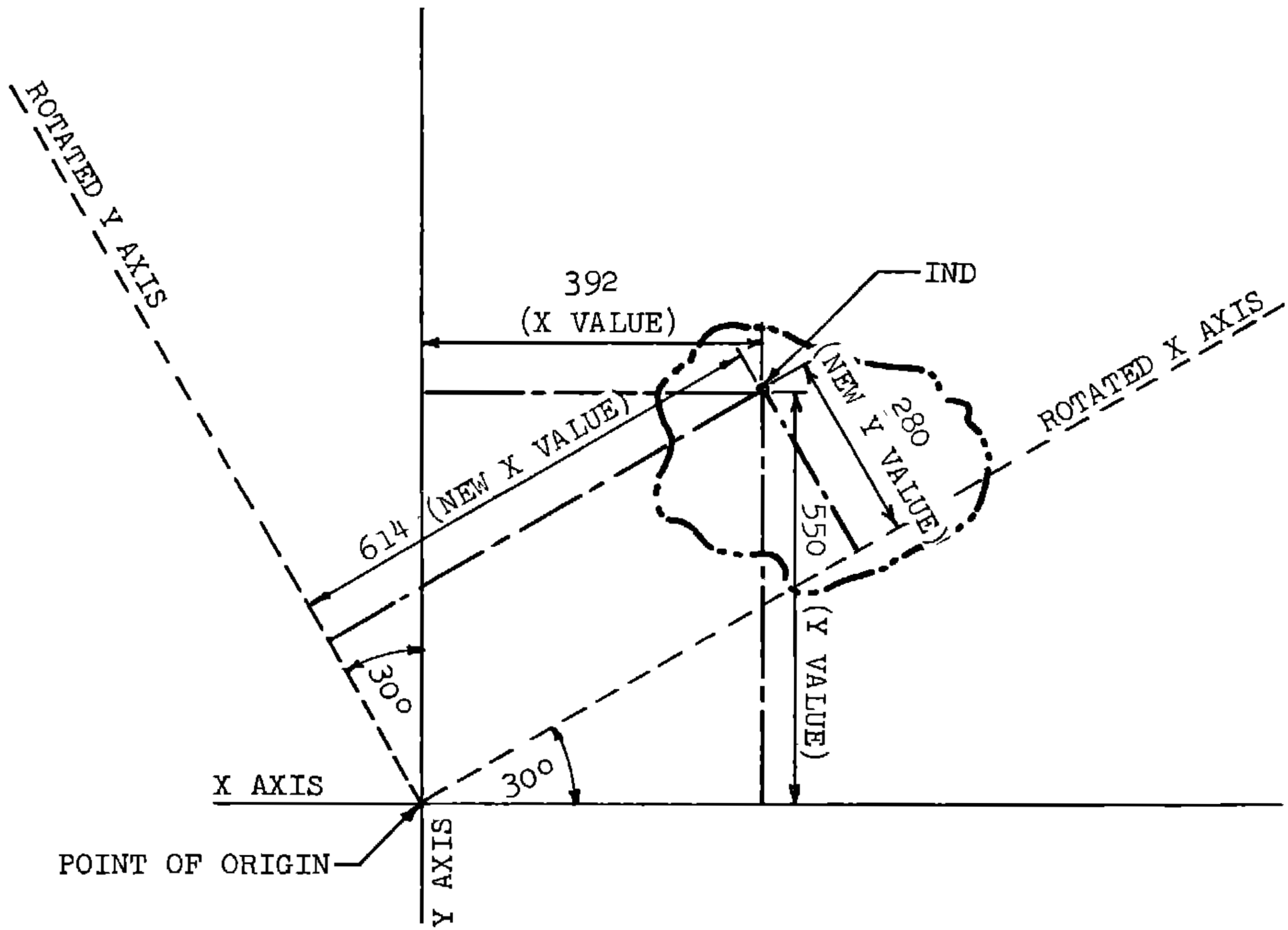

FIG. 22 THE CHANGING OF THE COORDINATE VALUES OF A FIX BY ROTATION OF THE GRID

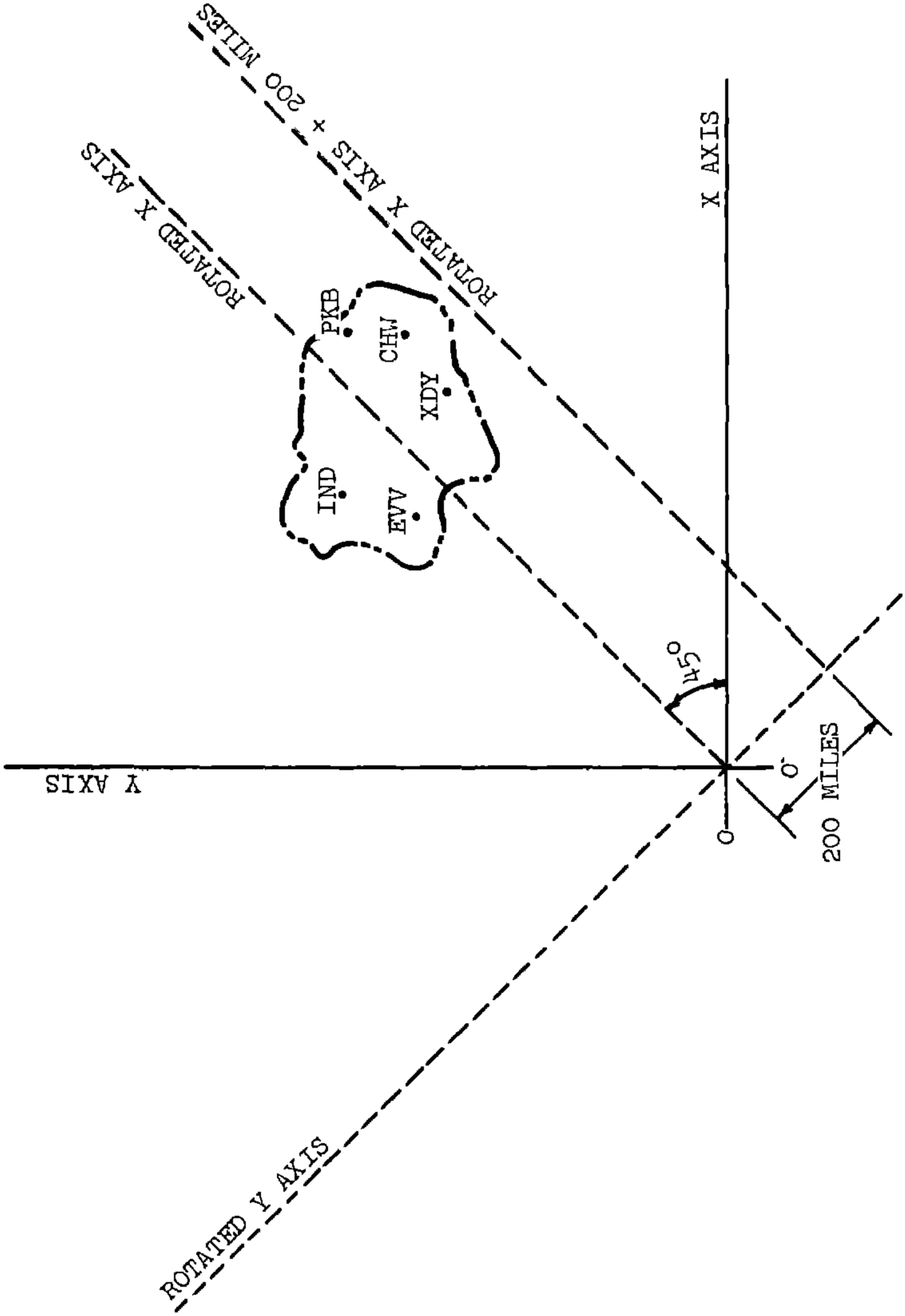

FIG. 23 ROTATION OF THE X AXIS SHOWING HOW THE ADDITION OF A CONSTANT KEEPS MILEAGE POSTIVE

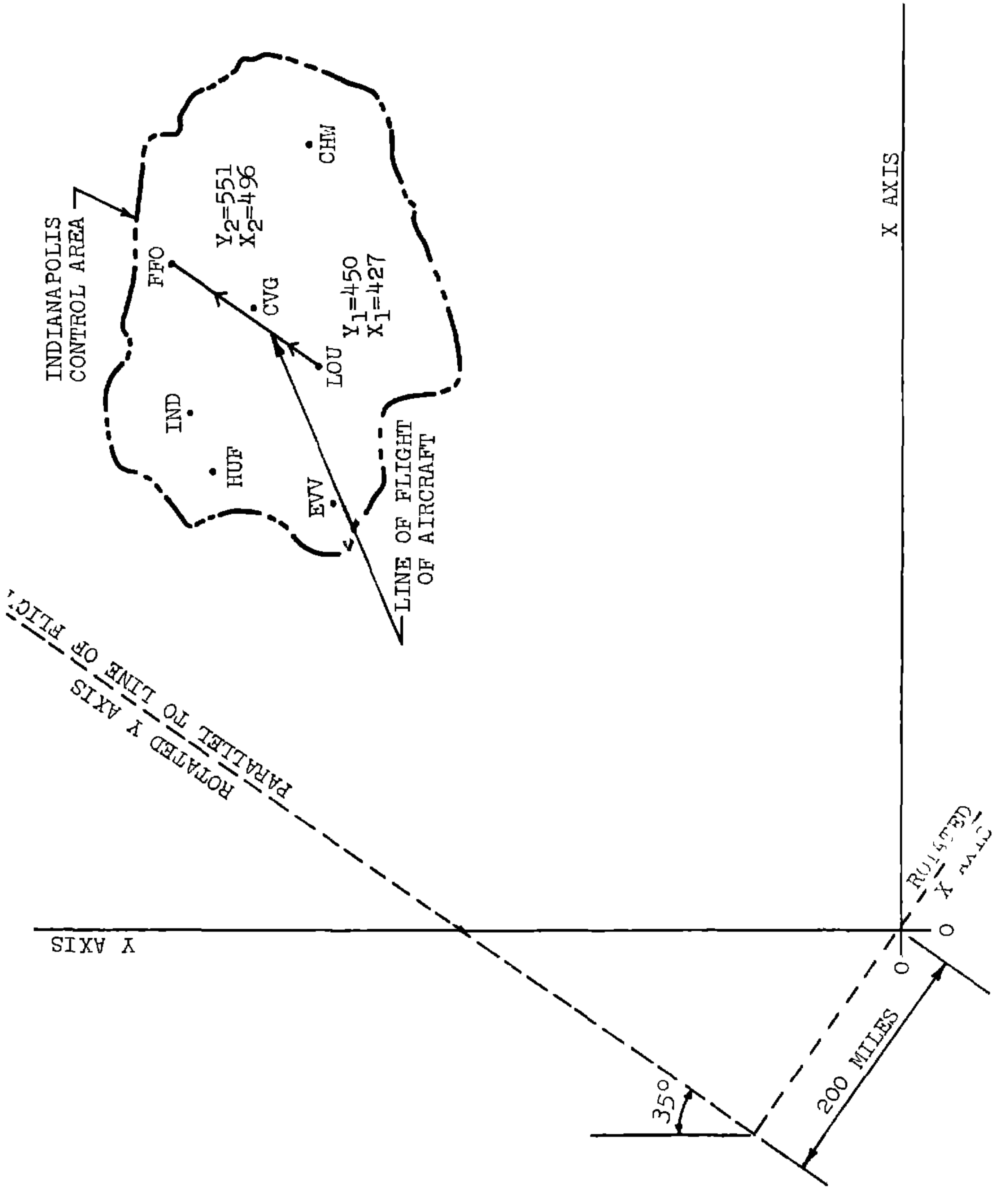

FIG. 24A FLIGHT PATH OF AIRCRAFT AND ROTATION OF GRID PARALLEL TO LINE OF FLIGHT

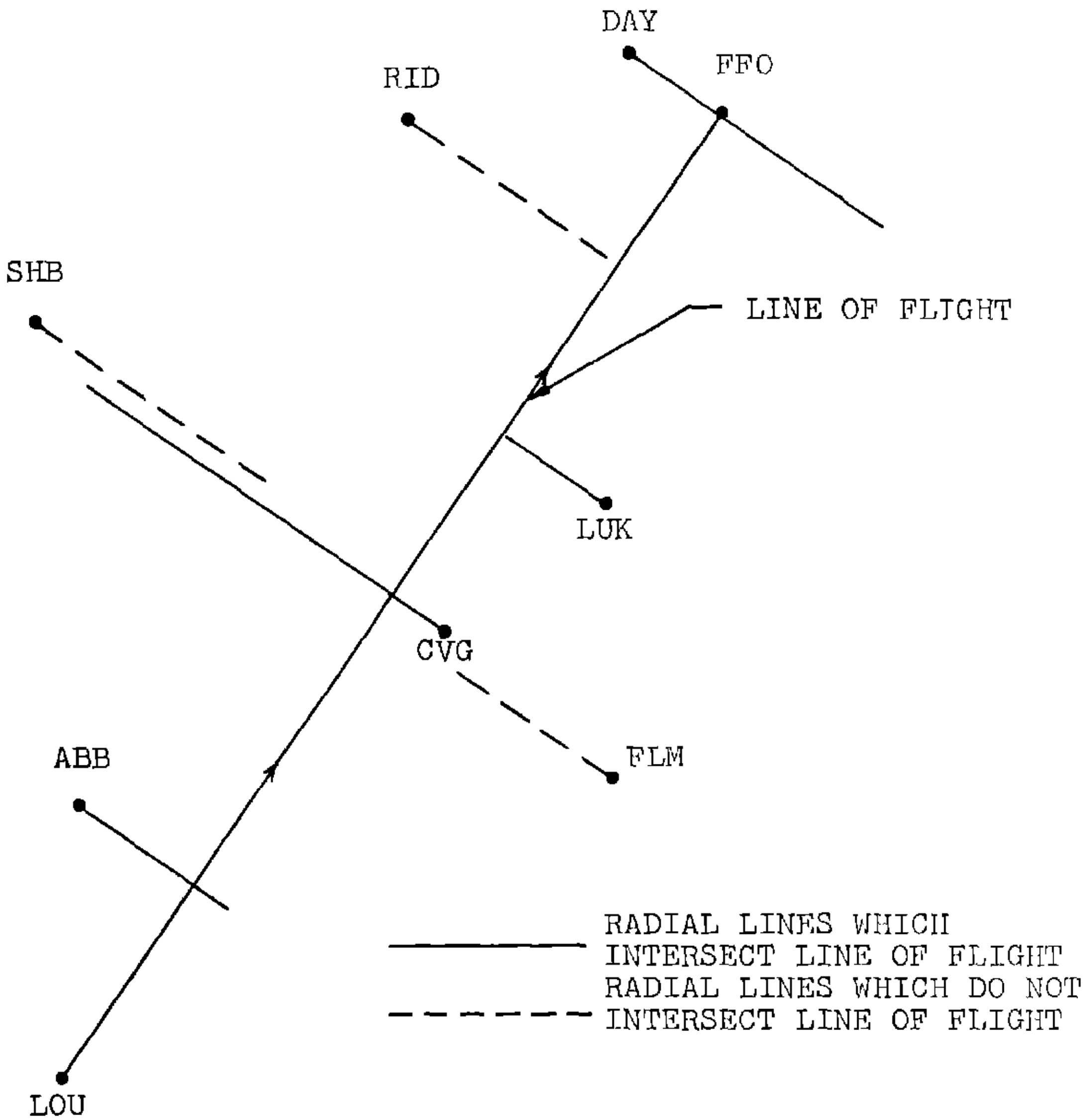

FIG. 24B RADIAL INTERCEPTS FOR DETERMINATION OF FIX POSTINGS

DRUM LOCATION	3 DIGITS OF Y VALUE	2 DIGITS OF UP MILEAGE	2 DIGITS OF DOWN MILEAGE	3 DIGITS OF X VALUE	
9000	Y Y Y	X X	X X	X X X	
	Y Y Y	X X			
THRU			X X	X X X	
9047	Y Y Y	X X	X X	X X X	
9048	0 0 0	0 0	0 0	0 0 0	6 WORDS OF ZEROS
	0 0 0	0 0			
THRU			0 0	0 0 0	
9053	0 0 0	0 0	0 0	0 0 0	
9054	X X X	X X	X X	X X X	5 WORDS OF HISTORY
	X X X	X X			
THRU			X X	X X X	
9058	X X X	X X	X X	X X X	
9059	X X X X	0 0		X X X X	1 WORD OF DIRECTION

FIG. 25 RADIAL TABLE

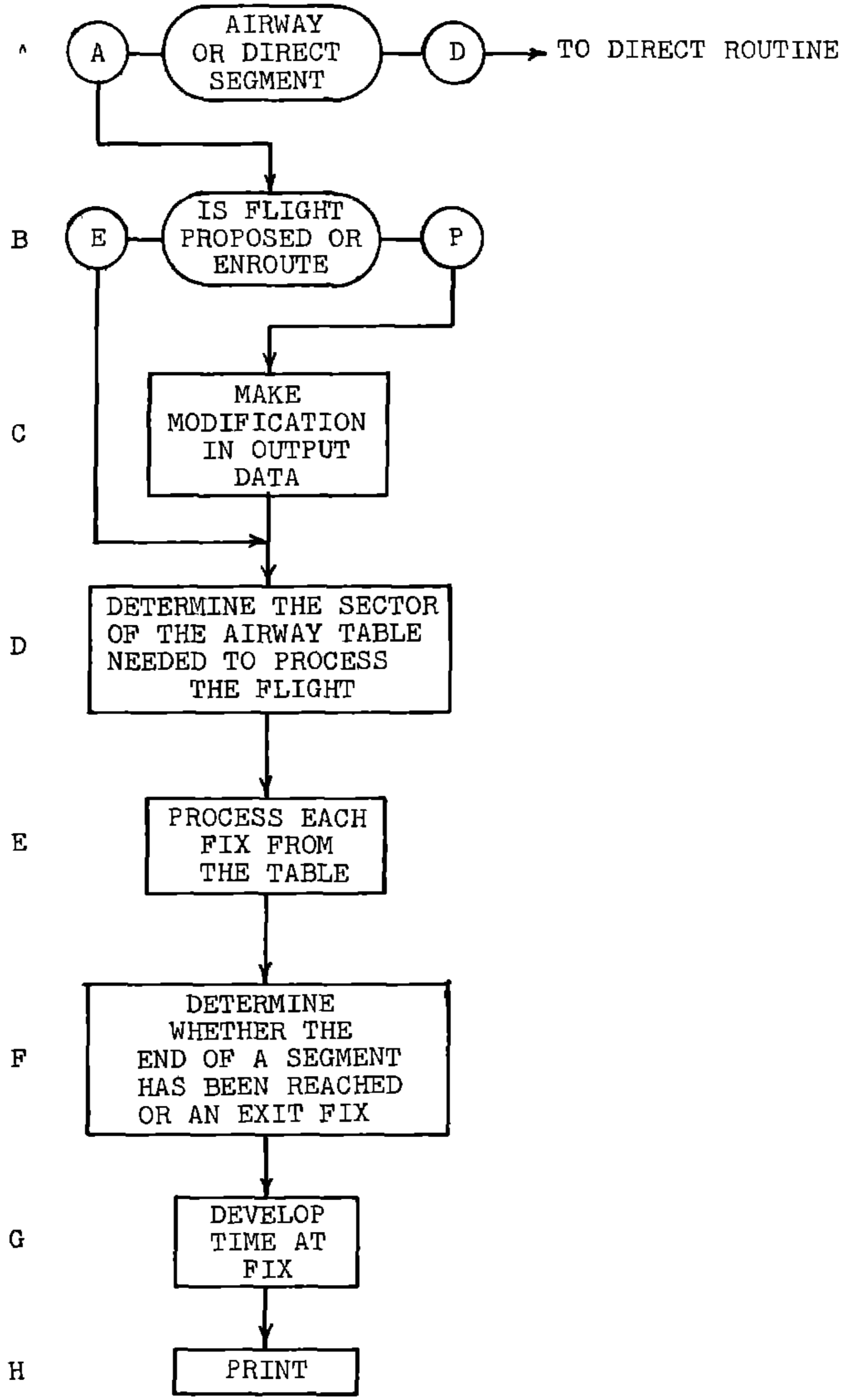

FIG. 26 GENERAL FLOW CHART OF AIRWAY ROUTINE

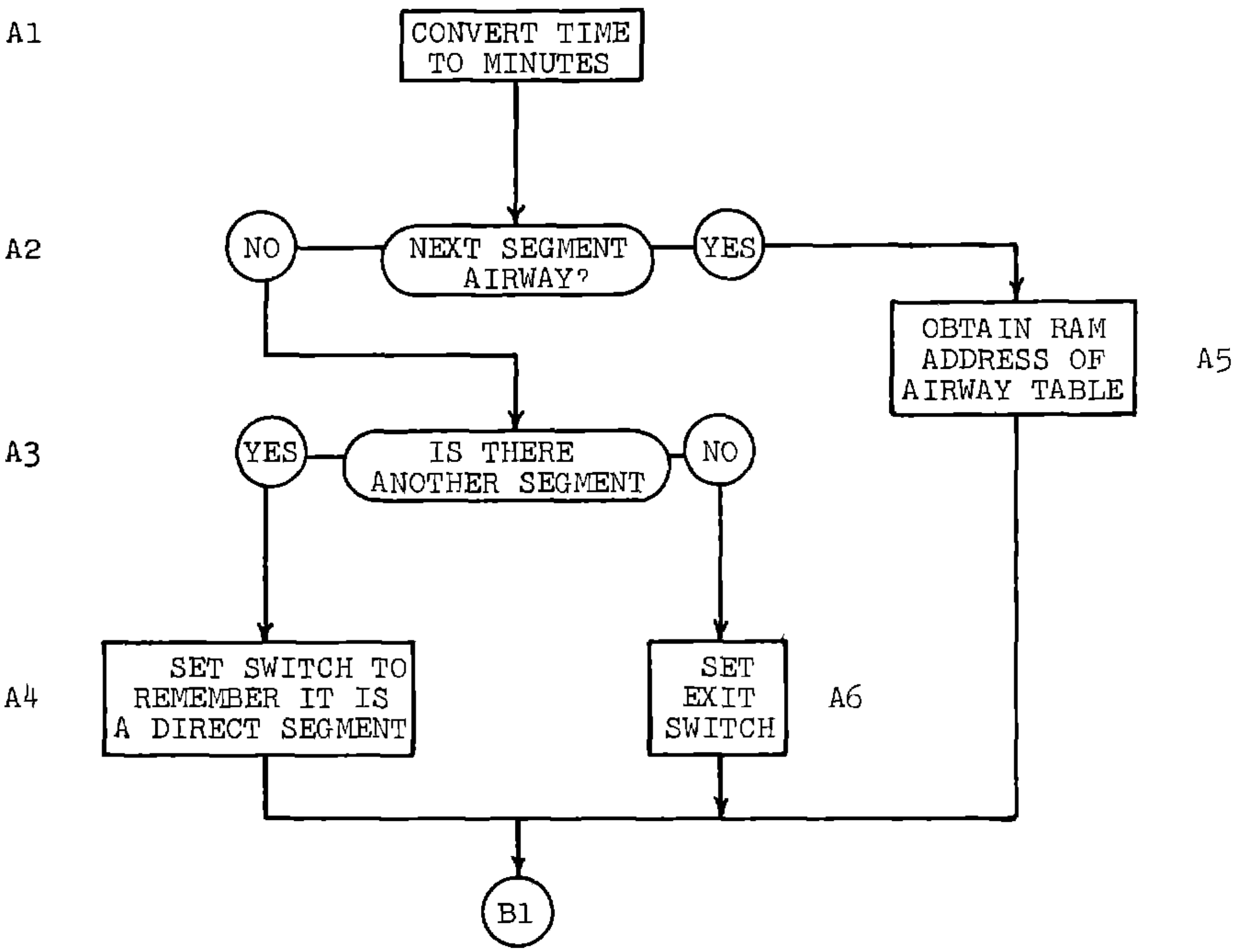

FIG. 27A SEMI-DETAILED FLOW CHART OF AIRWAY ROUTINE

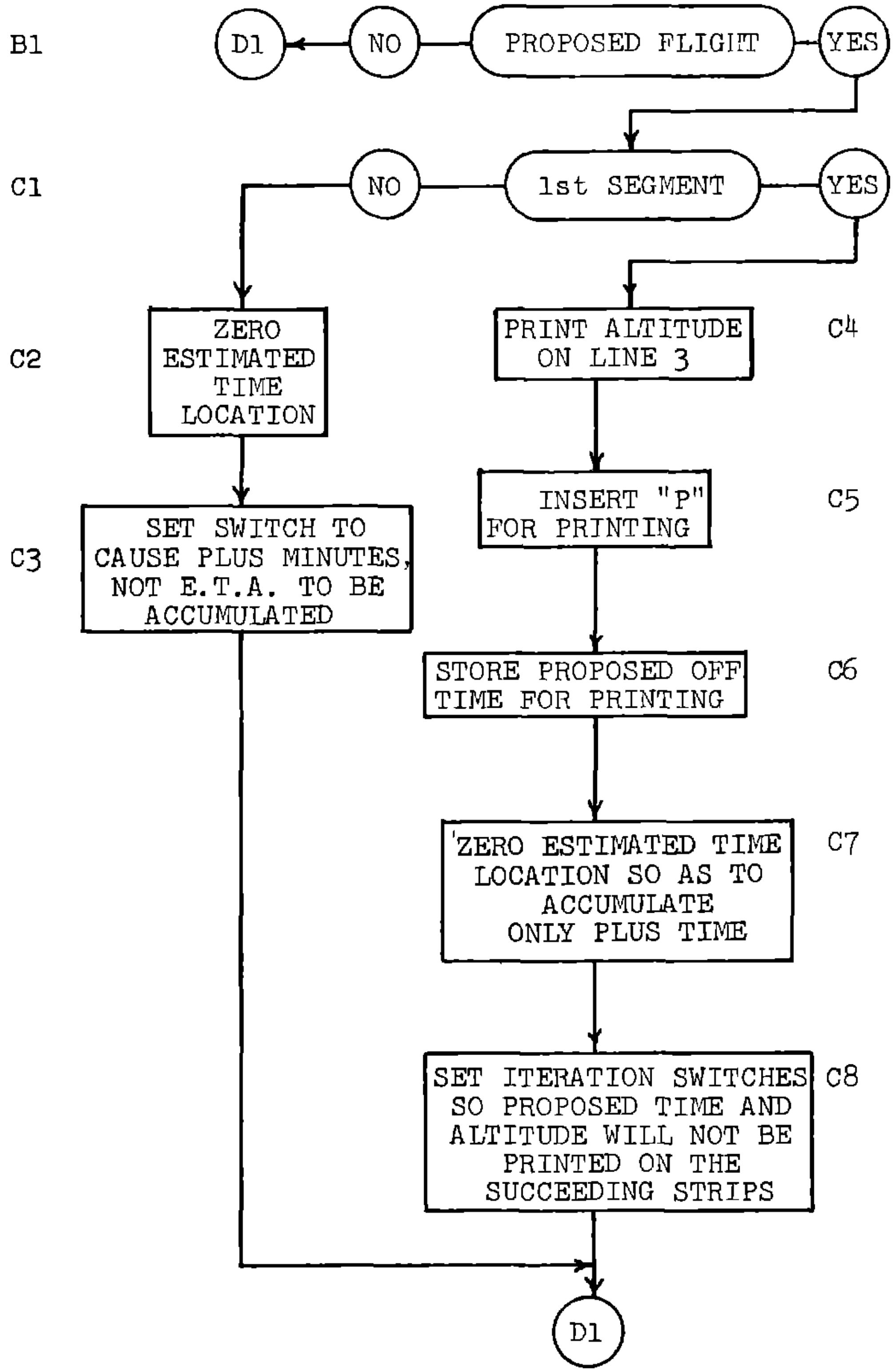

FIG. 27B SEMI-DETAILED FLOW CHART OF AIRWAY ROUTINE

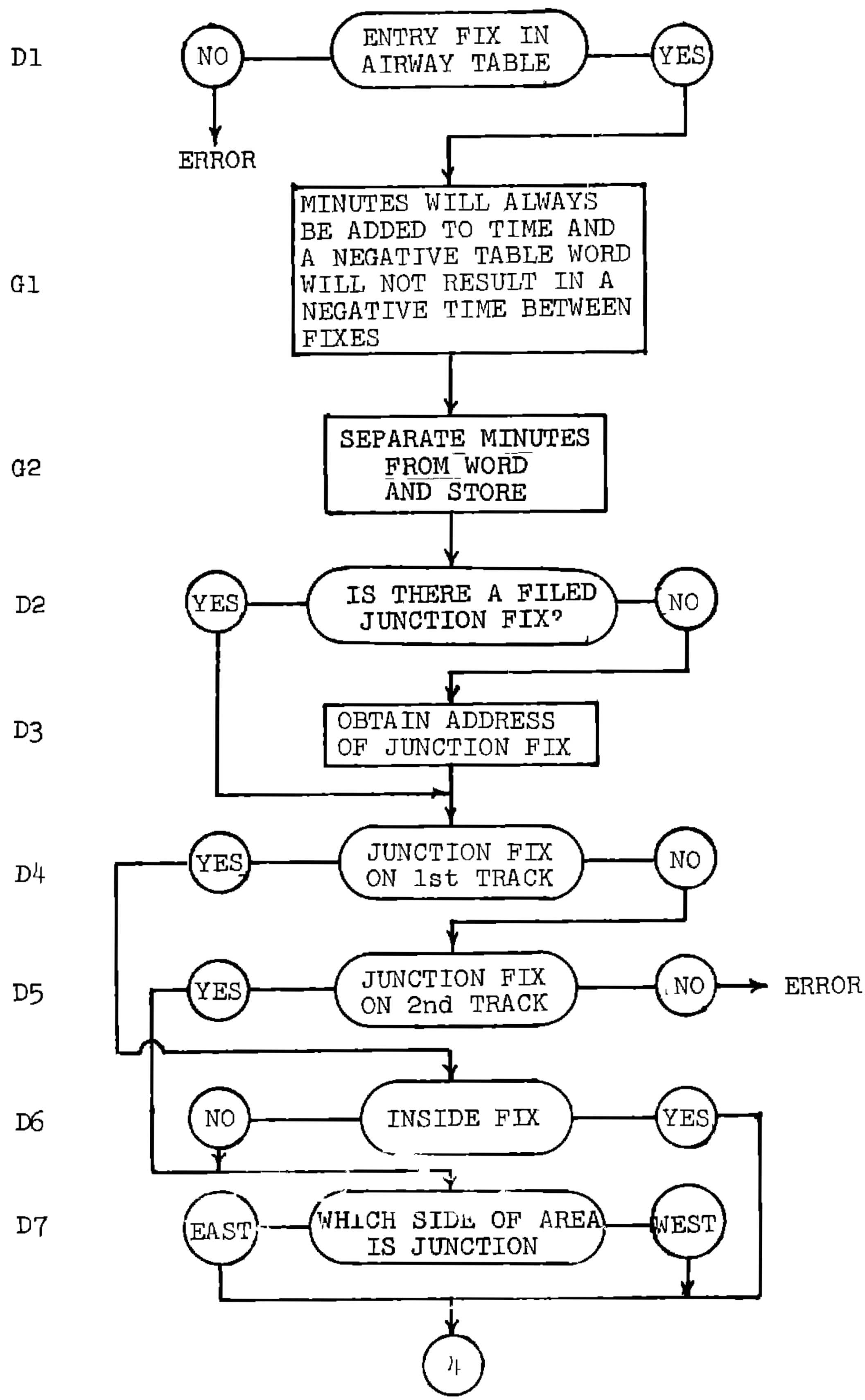

FIG. 27C SEMI-DETAILED FLOW CHART OF AIRWAY ROUTINE

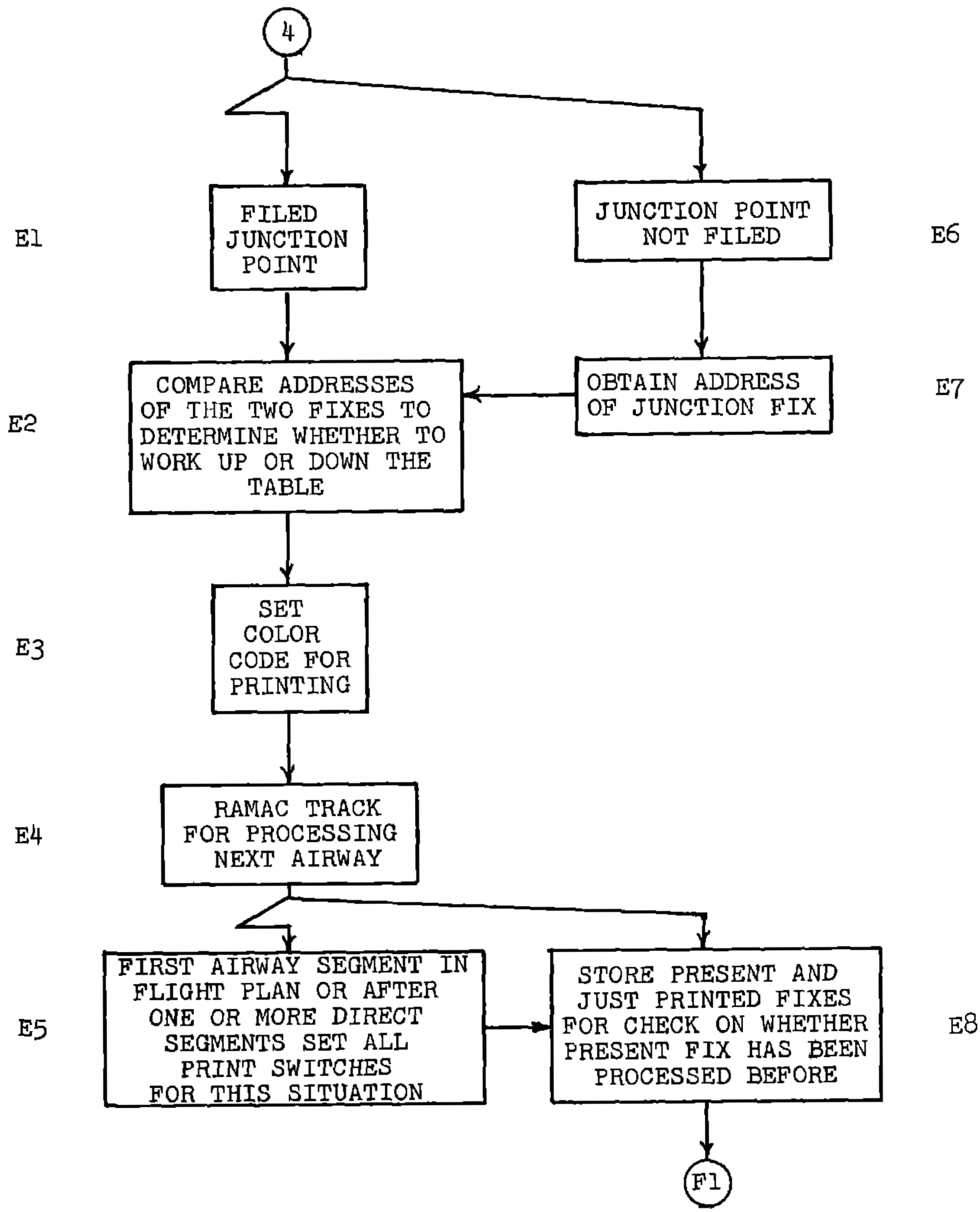

FIG. 27D SEMI-DETAILED FLOW CHART OF AIRWAY ROUTINE

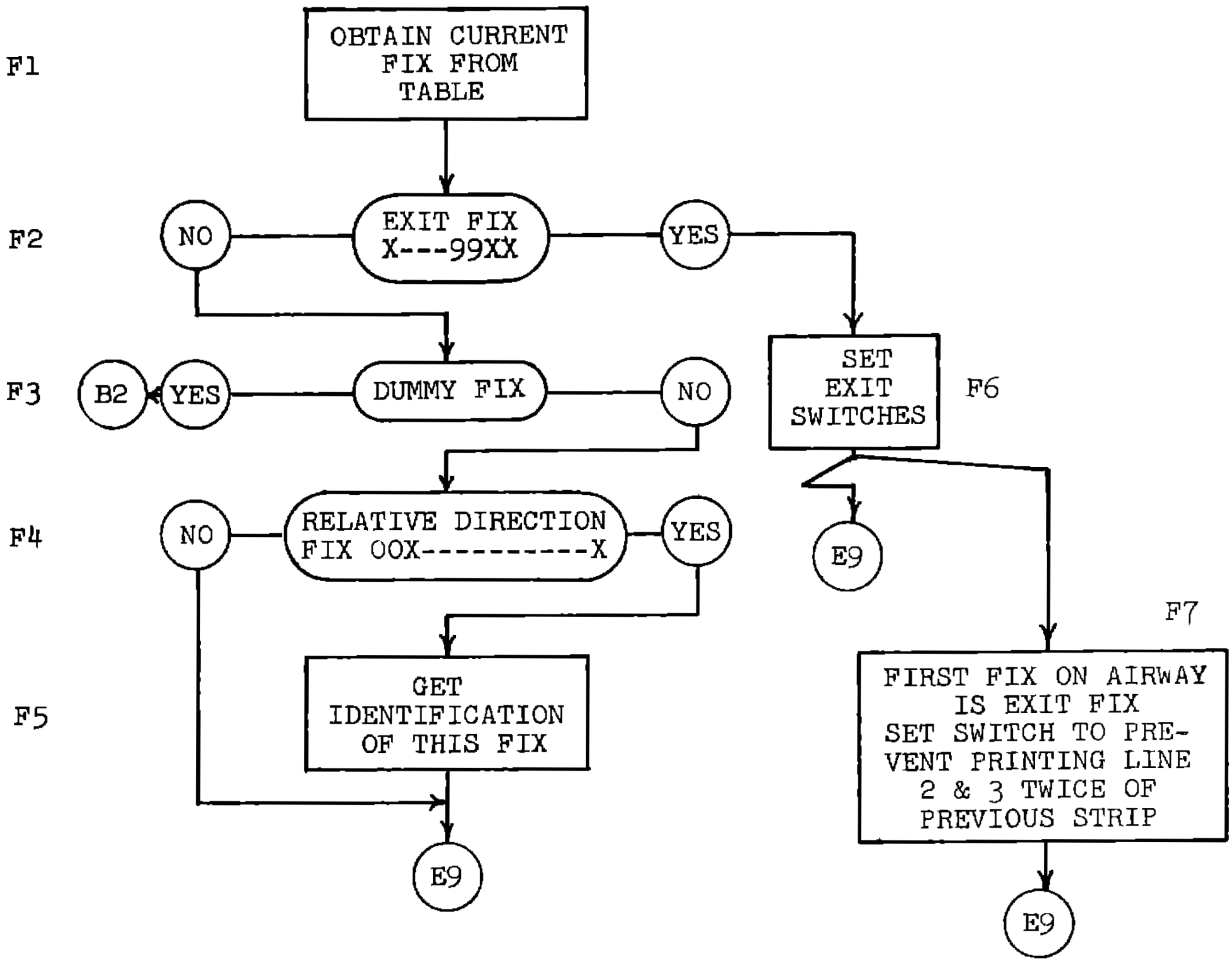

FIG. 27E SEMI-DETAILED FLOW CHART OF AIRWAY ROUTINE

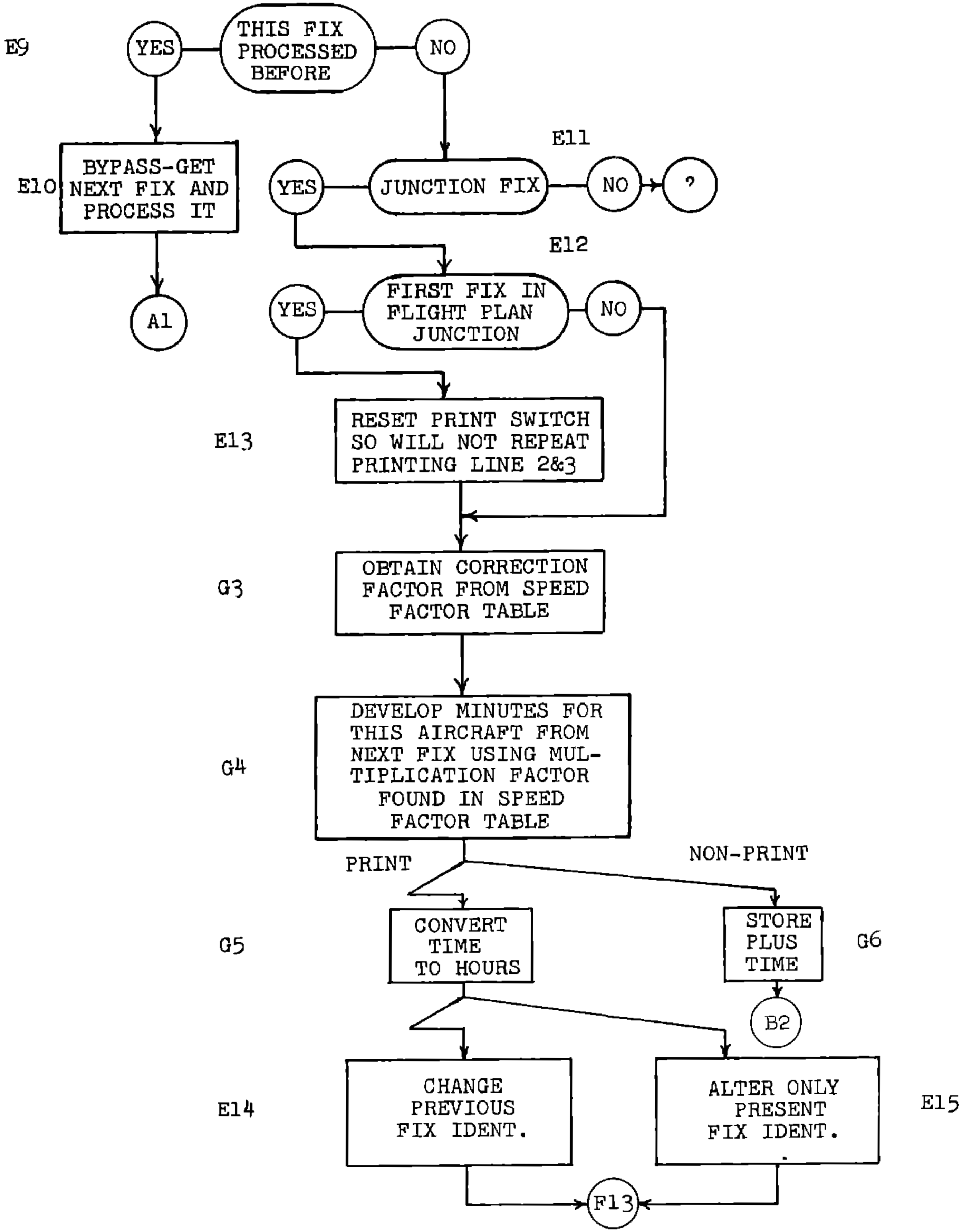

FIG. 27F SEMI-DETAILED FLOW CHART OF INPUT ROUTINE

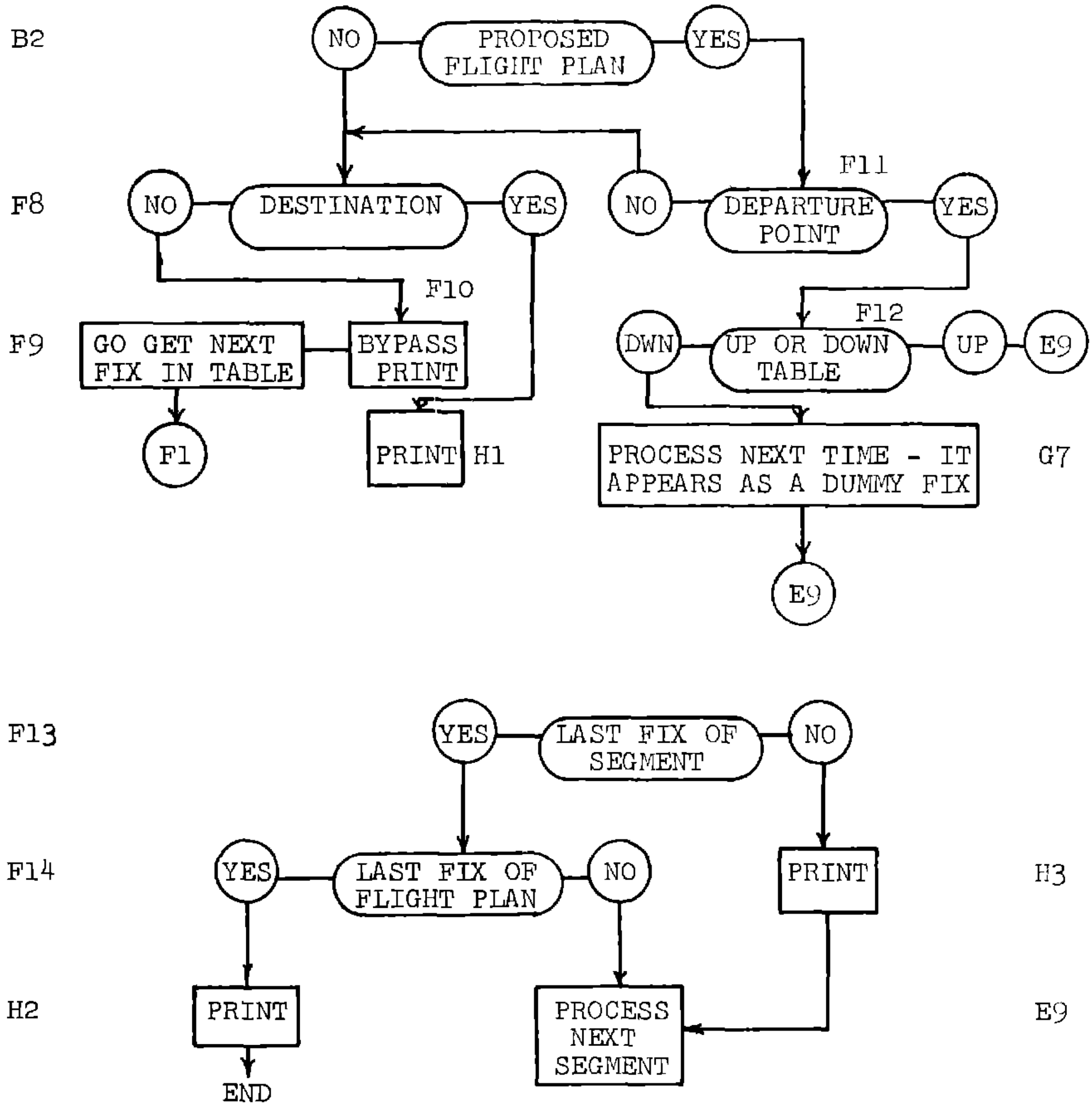

FIG. 27G SEMI-DETAILED FLOW CHART OF AIRWAY ROUTINE

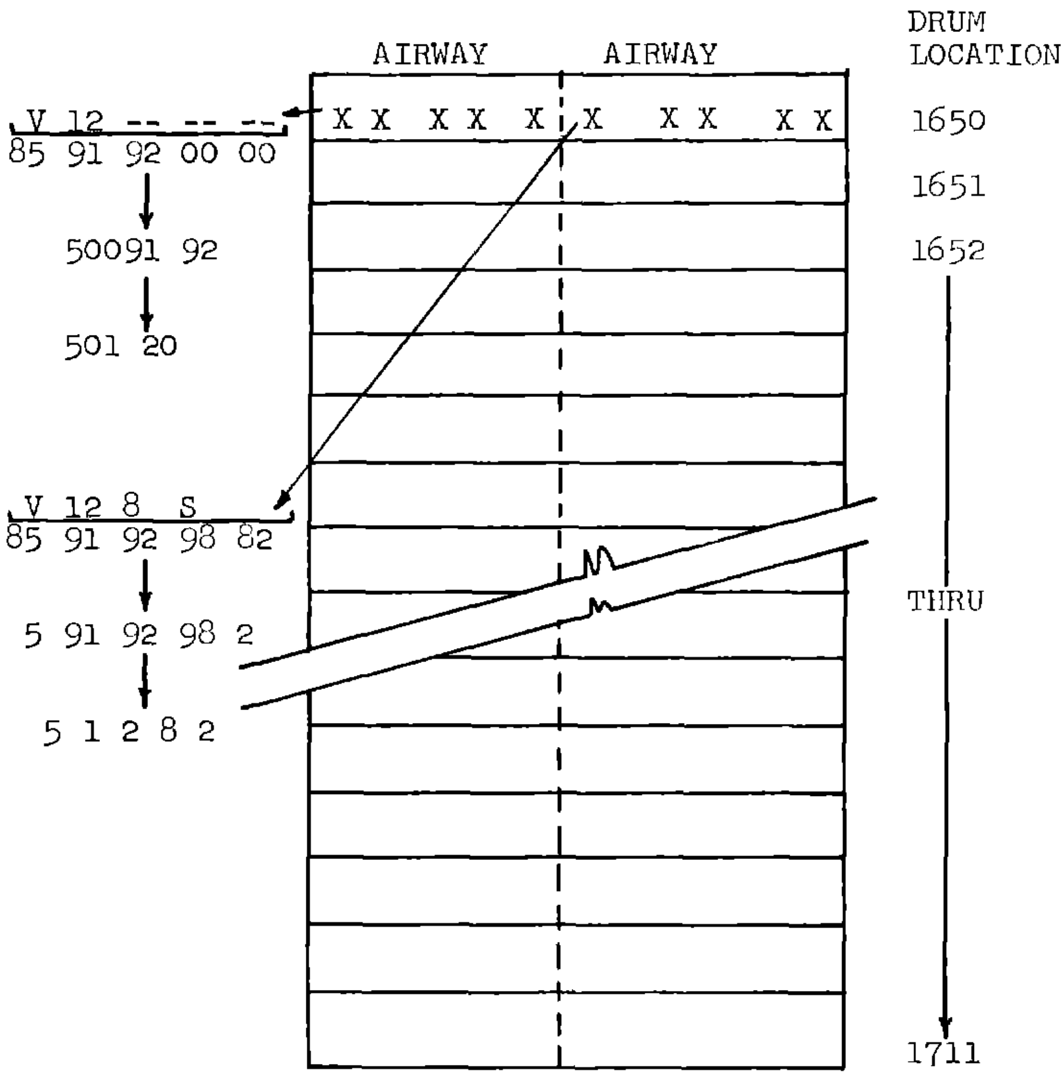

FIG. 28 AIRWAY RAMAC ADDRESS TABLE

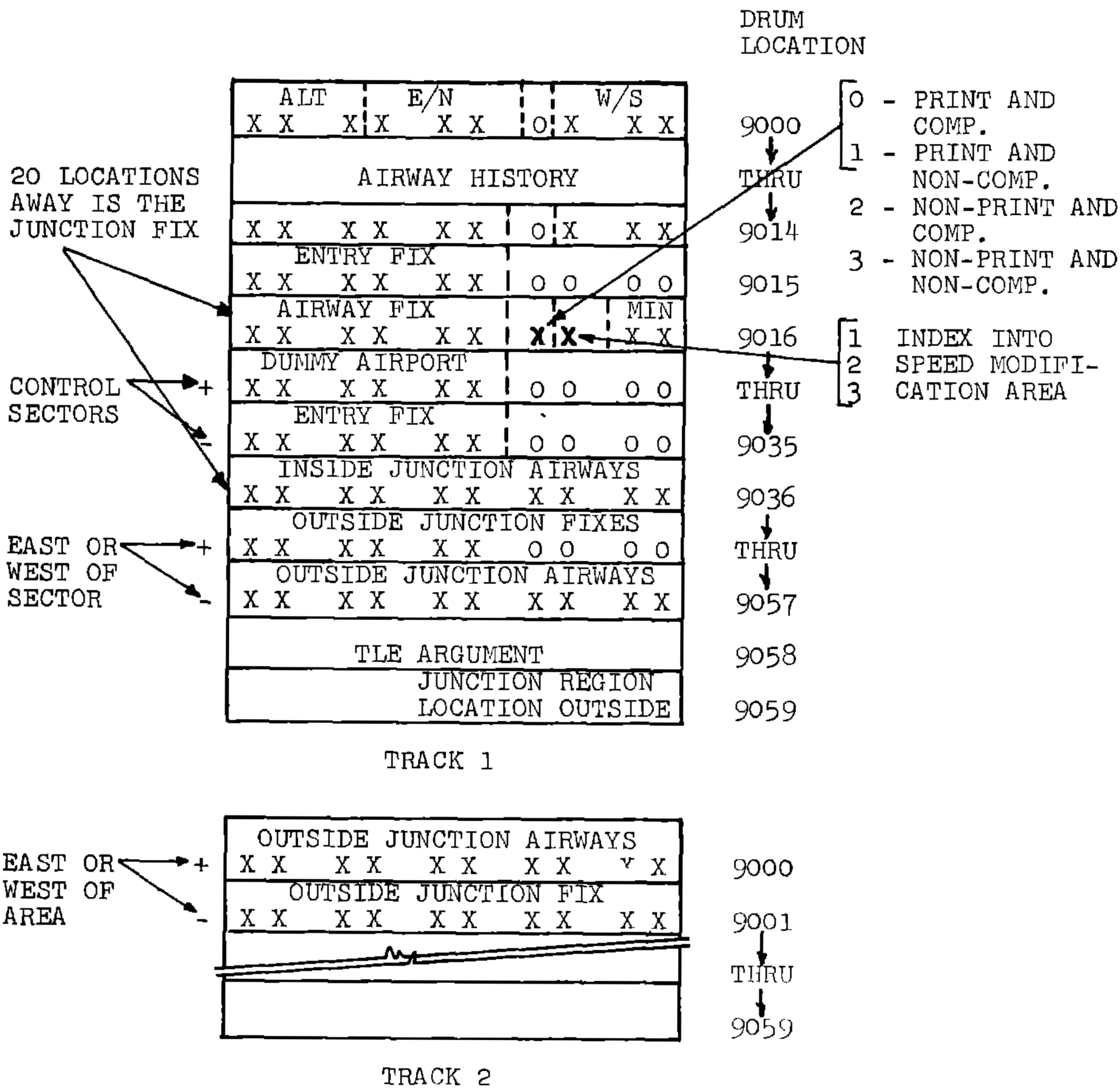

FIG. 29 AIRWAY TABLE

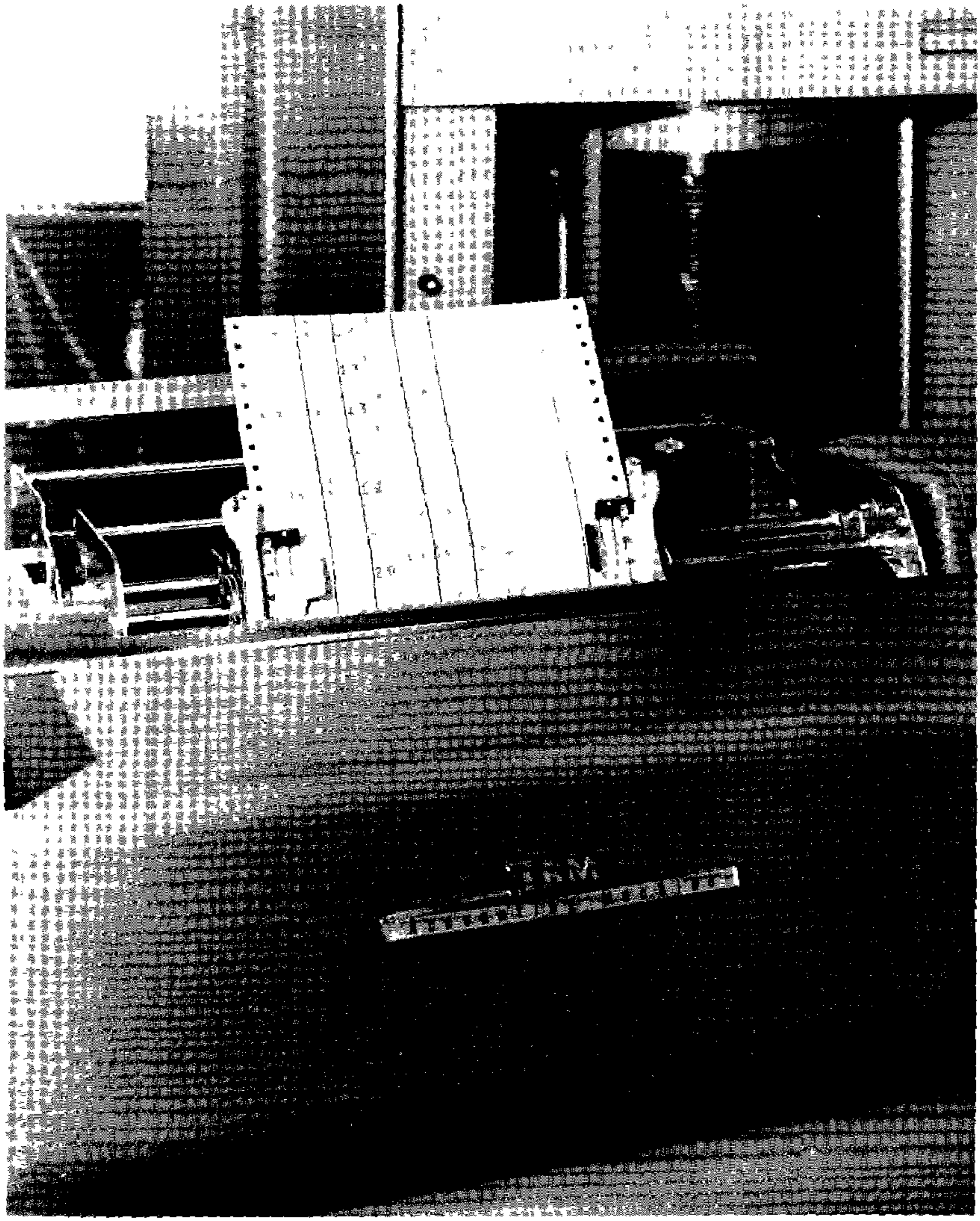

FIG. 30 - FLIGHT PROGRESS STRIPS PRINTED BY THE TYPE 407 ACCOUNTING MACHINE.