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PRELIMINARY TESTS
OF APPLICATION OF COMPUTERS
FOR PROCESSING OF TABULAR FLIGHT DATA

FOR LIMITED DISTRIBUTION

by

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SUMMARY

This report covers an operational analysis of some of the workload factors involved in the present method of processing flight-plan data and in the preparation of tabular displays in Air Route Traffic Control Centers. It describes simulation tests of various techniques for the automatic processing of flight data.

It is concluded that use of computers and automatic data processing equipment in the air traffic control system to provide printed flight progress strips will provide an evolutionary step forward in improved data processing with a considerable reduction in assistant controller workload.

INTRODUCTION

One of the large workload factors in air traffic control (ATC) today is the processing of flight-plan data. This processing includes initial transmission of the flight plan to the Air Route Traffic Control Center (ARTCC), the preparation of flight progress strips for the controller's display board, and the forwarding of these data from sector to sector and to other ATC facilities. This report deals solely with the problem of tabular flight-data processing, and the improvements that may be realized through the introduction of automatic equipment within the existing ATC system. Until such time as ground-derived position information (radar and beacon) or air-derived position information (data link) is available for all aircraft requiring traffic control service, it is probable that a tabular arrangement of flight data will continue to be the main display of the traffic controller.

The implementation of the input devices, computers, and communications circuits required to produce printed flight progress strips does not detract from the longer range investigation of automatic tabular displays or pictorial displays. Rather, the system described in this report should, in addition to providing immediate relief to the controller, provide a firm basis for more advanced systems of data processing and data display. It is obvious that once a conversion has been accomplished from voice and handwritten flight data to encoded data, a major breakthrough will have taken place in the evolutionary development of an automatic air traffic control system.

The testing and simulation work described in this report were accomplished during the period from June 1955 through December 1956. The project was carried on under the sponsorship of the Air Navigation Development Board under Project 1.2.

DESCRIPTION OF PRESENT SYSTEM OF TABULAR FLIGHT-DATA PROCESSING

A thorough understanding of air traffic control and the present system of manual data processing is essential to any attempt to alleviate the workload of the assistant controller who is required to spend as much as 50 per cent of his time performing routine clerical tasks. In the past, some theoretical studies have suffered due to a lack of understanding by the investigators of air traffic control fundamentals and a lack of appreciation of the technical skill required by the controller. Air traffic control authorities recognize that an average controller requires three or four years on the job in the same facility before he is considered a "good" controller. This represents the average period of training required to comprehend fully the complexities of air traffic control. Because the present system demands that he participate in the routine data-processing operation, an assistant controller is less than 50 per cent effective in performing actual control activities.

The Indianapolis ARTC Center was used in this analysis to provide an accurate environment for the tests of automatic data processing. One of the measures of ARTC Center activities is the annual total of flight progress strips. Table I shows that the Indianapolis ARTC Center ranks fifth among the top ten Centers in the 1956 count of flight progress strips.

Another reason for using the Indianapolis ARTC Center is that it is directly associated with the Airways Operations Evaluation Center (AOEC) in a thoroughly practical environment for evaluating new concepts and procedures. Such an environment is essential in relating the research and development effort to operational requirements. This practical environment has been carefully cultivated at the Technical Development Center (TDC).

The Indianapolis ARTC Center is one of 26 such facilities in the United States. This Center is responsible for the control of instrument flight rule (IFR) traffic in the area shown in Fig. 1. This illustration also shows the ARTC areas adjacent to the Indianapolis area. This area contains 8,810 miles of controlled airways, 10 airports with Civil Aeronautics Administration (CAA) control towers, 7 airports with military control towers, 9 CAA communications stations, and numerous airline radio stations.

TABLE I

TOTAL FLIGHT PROGRESS STRIPS, FISCAL YEAR 1956[1]

Position	ARTC Center	Total Strips
1	New York	2,271,462
2	Washington	1,265,621
3	Atlanta	1,202,126
4	Chicago	1,092,552
5	Indianapolis	1,090,488
6	Cleveland	1,062,896
7	Kansas City	1,023,199
8	Los Angeles	956,495
9	Oakland	941,894
10	Boston	931,780

The area is subdivided further into sectors, also shown in Fig. 1. Each sector is manned by a controller and an assistant controller. Information regarding en route aircraft is displayed to the sector controller in the form of flight progress strips or fix posting. Each flight progress strip portrays the information pertaining to a particular flight at a designated position. In the Indianapolis ARTC Center there are 44 such designated positions, known as fixes. Center personnel estimate that an additional 20 fixes actually are required to display adequately the air traffic picture to the controllers. These additional fix postings are not displayed due to the shortage of space in the ARTC Center and the critical manpower shortage in Center staffing. Failure to display these postings, however, imposes added burdens on the controllers in interpolating and extrapolating aircraft position data.

Thirty-nine Service F interphone lines terminate in the Indianapolis ARTC Center. On these 39 lines, there is a total of 112 stations having a responsibility to provide flight data to the Indianapolis ARTC Center. The lines terminate at a patch panel, from which they are extended to the individual sector control boards.

The complex Service F communications network serves three prime purposes in the execution of the air traffic control function:

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[1] Federal Airways Air Traffic Activity, CAA.

1. The assembly of flight-plan data from stations of origin within the area and from adjacent ARTC Centers.

2. The relay, to the ARTC Center, of aircraft position reports received by airline, military, and CAA radio stations at points throughout the control area.

3. The relay, from the ARTC Center, of control instructions to aircraft.

Although a limited number of position reports and control instructions are handled via direct radio channels between the controller and pilot, the majority of such communications are relayed via the Service F interphone.

In addition to the Service F interphone network, some flight plans are gathered by means of Service B teletypewriter circuits. The Center also requires the hourly assembly of weather information as handled on Service A teletypewriter circuits.

It is appropriate at this point to examine the processing of a flight plan received in the Indianapolis ARTC Center. If the flight plan is received via interphone from an adjacent Center, it generally represents a flight already in the air and approaching the area on a defined route in accordance with an ATC clearance. The flight plan is copied by an assistant controller onto a flight progress strip. The route of flight is analyzed by the assistant controller to determine the fixes at which the flight is to be displayed. A flight progress strip is prepared for each fix (an average of five strips per flight). The estimated time of arrival (ETA) at each individual fix is calculated by the assistant controller, entered on a strip, and the completed strips are posted at the proper sector control boards.

A flight plan filed with the ARTC Center concerning a proposed departure from an airport in the area is handled in essentially the same manner, except that the estimated times are not placed on the fix-posting strips until the flight actually has received a clearance and departed. In the latter case, the departure strip is passed to the controller at the proper sector while the remaining strips are held in abeyance until the flight has departed.

A proper appreciation of the technique of calculating estimates is important to the understanding of the controller's workload in the manual processing of flight data. In the process of calculation, the assistant controller generally has been furnished with the aircraft's speed, either ground or air, upon which subsequent time estimates are to be based. To arrive at an accurate set of time estimates, however, the assistant controller must apply correction factors obtained from U. S. Weather Bureau Winds-Aloft Reports as well as historical data from flights that recently have traversed the same airspace. A cognizance of the aircraft type also is necessary as a rough validity check on the speed. As wind conditions differ with altitude, so will the store of correction data differ with the altitude of the particular flight.

As a flight progresses along an airway or a prescribed direct route, the pilot is required to make periodic position reports. These reports are made directly to the sector controller via the assigned radio channel, or are relayed to the controller via interphone through an intermediate radio station.

The Civil Air Regulations currently prescribe that a position report shall contain the following elements:

1. Aircraft identity.
2. Position (over a fix, or an estimated distance and direction from a fix).
3. Time.
4. Altitude.
5. Pilot's estimate of next fix.
6. Name of fix following the next fix.*

*A new requirement in position-reporting procedure, designed to give the controller assurance as to the intended route of the aircraft. The need arose partially from the ambiguous nature of some of the civil airway designations.

Example: (Position report given directly to the controller by the pilot.)

Pilot: "Indianapolis Center, this is TWA 72, over."

Controller: "TWA 72, this is Indianapolis Center, go ahead."

Pilot: "TWA 72 over Dayton VOR at '32' (1132), (altitude) 19,000 feet, estimate Appleton at '55' (1155), Roscoe."

Controller: "Roger TWA 72, Indianapolis Center out."

Upon receipt of a position report from an aircraft, the controller enters the time reported upon the appropriate flight progress strip, calculates the ground speed maintained from the previous position reported, revises the estimate at any fix posting within his own sector, and notifies the controller in the adjacent sector of the change in time and speed. This notification may take place in several different ways. It may require an interphone call to an adjacent ARTC Center; it may require an interphone call to another sector within the same Center; the revised data may be passed orally to the adjacent controller, or a sector coordinator may be requested to see that the revisions are passed to the proper sector. The subsequent handling of the revised data is a repetition of that just described, until the revision reaches the arrival sector for the particular flight.

NEED FOR IMPROVEMENT OF PRESENT SYSTEM

There appears to be a universal appreciation of the need for improving the present system of air traffic control. From this point of common agreement, the opinions on how the system might be improved diverge rapidly. One of the more dramatic approaches to the problem considers the present system of air traffic control obsolete; hence, it must be replaced. The development and implementation of new and complex devices are proposed, and a rather large increase in efficiency and capacity of the ATC system is purported. An analysis of the many proposals for improvement of air traffic control, advanced since the days of World War II, reveals one marked similarity which, ultimately, turns out to be the largest deficiency in such proposals. There is a tendency to ignore the present needs of the ATC system and the absolute necessity for an orderly transition from the present manual system to a system wherein a certain portion of the manual operations are taken over by a machine.

It is significant that the technique of displaying tabular flight data on handwritten flight progress strips was condemned in 1942 as being obsolete and imposing a serious restriction on the growth of the system.[2]

In 1947, an estimated fleet of 900 air-carrier aircraft contributed to a total of 10 million flight progress strips in ARTC Centers in the United States. In 1957, there were 1,600 air-carrier aircraft flying the airways, and approximately 24 million flight progress strips were prepared.

The number of military aircraft in constant use on IFR flight operations is indeterminate. Suffice to say that in 1947, the military services were responsible for 10 per cent of the total flight progress strips. In 1957, this reached 45 per cent.

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[2] "Development of Automatic Posting Systems for Air Traffic Control," paper prepared by the Air Traffic Control Division, Office of Federal Airways, CAA, dated January 28, 1942.

The foregoing is not intended as a justification for the continued use of flight progress strips. It does, however, point up two fundamental facts. The first is that the display of tabular flight data by a method that was judged obsolete in 1942 still is surprisingly adequate in 1957. The second is that any proposed system that fails to provide for a logical progression from the present system will encounter serious obstacles.

The handling of individual flight plans and individual position reports was covered earlier in this report. To obtain a proper understanding of the magnitude of the present communications and data processing problem, it is appropriate to consider some statistics that are available. A Bell Telephone Laboratories report[3] gives some authentic and pertinent figures on interphone communications time that may be applied to any ARTC Center. For example, the average time per message spent by an assistant controller in the Hartford Sector of the Boston ARTC Center in accepting an incoming message was 30.3 seconds. The average time spent on outgoing messages by the same assistant controller was 51.0 seconds.

The difference in average communications time between the incoming and outgoing calls is due to the delay in waiting for the operator on the other end of the line to answer the phone. It is important to note that the originator of the call is not in a position to undertake any other activities during the "waiting" period, and that the "waiting" period constitutes nearly one-half of the interphone time of the assistant controller in making an outgoing call.

An analysis of 4,505 readable flight progress strips, representing the activity of the Indianapolis ARTC Center for an average day, reveals that 778 flight plans (intercenter data transfer messages) were transmitted by the Indianapolis ARTC Center to the seven adjacent ARTC Centers. Applying an outgoing message time of 51 seconds per message, this represents a total of 39,678 seconds, or 11 hours of continuous data transfer time during a 24-hour Center operation. Incoming messages from adjacent Centers consume approximately 60 per cent as much time as outgoing calls, or another 6.6 hours of data transfer.

[3] "Traffic Study of Communications and Related Operations, Part I - Hartford Sector," Final Report, Task A, prepared by Bell Telephone Laboratories, Inc., on behalf of Western Electric Co., Inc., under contract with U. S. Signal Corps for the Air Navigation Development Board, June 15, 1955.

The transmission of this same number of computer-processed incoming and outgoing messages via teletypewriter at a standard rate of 75 words per minute (wpm) would require 2.5 hours as compared to the 17.6 hours via interphone. This is a significant reduction in communication time. It is a firm indication that immediate relief can be forthcoming with the implementation of some tried and proven equipments.

These figures, based on an average day in the Indianapolis ARTC Center, can be extrapolated to fit the New York ARTC Center on one of its peak activity days. Such a peak day will total approximately 13,000 flight progress strips, or nearly three times the average day in the Indianapolis ARTC Center. On such a day in the New York Center, the total interphone communications time involved in transmitting and receiving intercenter flight-data messages would be approximately 50 hours, as compared to 7.5 hours necessary to transmit the same amount of data via teletypewriter. This is a tangible improvement, and represents a reduction in clerical workload that can be realized with existing equipment.

The objections to the flight progress strip as a means of displaying flight data have been numerous and have emanated from a variety of sources. It must be agreed that the most valid objections are those that come from the controllers qualified in the task of air traffic control. Surprisingly enough, their objections deal principally with the technique for gathering, processing, and distributing the flight data. Unwieldy as the flight progress boards have been described, they remain the most effective, available display of tabular flight data, and can be made even more effective with some rather simple innovations. Consider the handwritten flight progress strip. The time required to write 13,000 strips, including the calculation of estimates, is estimated to be 108 man hours. The production of 13,000 flight progress strips by a computer such as the IBM 650 or the Remington-Rand UNIVAC File Computer would require approximately 10 hours. This represents a tangible improvement in terms of existing equipment. More complex and expensive computers, coupled with very-high-speed output printers, could produce flight progress strips at rates approaching 28,000 strips per minute. Such a production rate far exceeds the demand anticipated in the near future.

Similar improvements logically could be expected to accrue from an adequately implemented system of two-way radio communication between the pilot and the controller. The average controller today can generate little enthusiasm about the proposed automatic ATC systems when he has not yet been provided with a rather fundamental tool; that is, two-way radio communication with all aircraft under his jurisdiction. Another degree of improvement could be realized from the reorganization of airways and routes along sound traffic engineering principles.

The foregoing points illustrate some areas wherein immediate improvement in air traffic control can be realized. They deal principally with controller workload, and emphasize the reduction in clerical effort that can be accomplished through a simple means of encoding and processing flight data.

With relatively little improvement in the tools for processing flight data, the total of fix postings in ARTC Centers has grown from 8.8 million in 1946 to 16.9 million in 1954.[4] This rate of growth produced approximately 24 million fix postings in 1957, and the forecast for 1965 is 33 million.

There is no feeling of pride or accomplishment in the fact that the system described as archaic, while handling 8.8 million fix postings in 1946, was able to handle 16.9 million fix postings in 1954. There is a recognized need for improvement, and there is the distinct possibility that some of the basic improvements outlined in this report may permit the system to absorb some of the growth forecast for the next five years.

SIMULATION TESTS OF AUTOMATIC DATA-PROCESSING TECHNIQUES

Components.

A series of tests was conducted to provide additional information on the data-processing and data-display techniques postulated earlier in this report. These tests were conducted in an environment of automatic tabular displays, typed flight progress strips, a magnetic storage drum, a teletypewriter network including an automatic switching center, and a postion report input device.

These devices and equipments were controlled by the operation of a simulated computer. This simulated computer consisted of a group of 12 automatic communications equipment (ACE) operators, highly skilled in the processing of flight data and assigned duties similar to the functions of an electronic computer. These ACE operators essentially were the same group that participated in the operational evaluation of a selective weather information distribution system, described in a report by Bell Telephone Laboratories.[5]

[4] Federal Airway Plan, Fiscal Years 1957-1961, U. S. Department of Commerce, CAA, December 1955.

[5] "Air Traffic Control Communications," Task D, Part 1, Final Report, Bell Telephone Laboratories, October 21, 1955.

The simulated computer utilized teletypewriter communications for input and output, paper-form storage as a permanent record of computed flight data, a magnetic drum for temporary storage, charts and airway tables, and an assignment of ACE operator duties. See Fig. 2.

Type C Board.

The automatic tabular displays used in the tests were the Type C data display and transfer boards shown in Fig. 3. These display boards, constructed by the Union Switch and Signal Division of the Westinghouse Air Brake Co. for TDC, were proposed to present to the controller, in an automatic fashion, the same type of flight data currently shown on the flight progress board. Each Type C board consists of 11 rows of indicators, with 60 indicators in each row. The individual indicator, a cutaway model of which is shown in Fig. 4, is capable of displaying any one of 64 characters upon receipt of the appropriate teletypewriter signal. Data can be transferred between Type C boards or to a magnetic drum storage unit at a speed of 1,000 wpm. Type C boards also can be used to send and receive at standard teletypewriter speeds of 75 wpm. A description of the Type C boards and some of the original tests conducted with them may be found in another report.[6]

Magnetic Drum.

The magnetic drum storage used in these tests consisted of the Engineering Research Associates (ERA) magnetic drum storage system. The general operating characteristics of this equipment, which was built to TDC specifications by ERA, have been described in a previous report.[7]

Teletypewriter Switching Center.

With the exception of the high-speed circuits used between the magnetic drum and the Type C boards, all other flight-data transfer was conducted on teletypewriter circuits. An 81D1 automatic teletypewriter switching system was used in these tests to facilitate the assembly of flight-data messages from a variety of input stations and to distribute the prepared data to the appropriate ARTC sectors. The 81D1 switching equipment owned by the

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[6] Appendix 7 of the "Interim Report on Air Traffic Control Communications," prepared for the Air Navigation Development Board by Bell Telephone Laboratories, dated June 30, 1956. This report is based on work conducted jointly by the Technical Development Center and Bell Telephone Laboratories.

[7] Francis J. Gross, "Applicability of Magnetic-Drum Information Storage to the CAA Teletypewriter Circuits," CAA Technical Development Report No. 233, April 1954.

Bell System was installed at TDC as part of a contract between the Western Electric Co., Inc., and the U. S. Signal Corps. The operation of the 81D1 switching center has been described in the Bell Laboratories Record.[8]

Input Device.

A position-reporting device was constructed to permit the controller to transmit aircraft position data to the simulated computer. This device, shown in Fig. 5, provided for the insertion of aircraft position information in columns of digital pushbuttons. Each aircraft in the system was assigned a two- or three-digit identification by the simulated computer. This identity was printed on the flight progress strips and was used by the controller when transmitting position reports to the computer. The aircraft position-report information inserted by the controller consisted of the following:

Aircraft Identity - A sequential identity assigned by the computer. Entered in Section A of the input keyboard.

Time - The time reported by the pilot in four digits. Enter in Section B.

Fix - A single-button operation in Section C.

The input device utilized a standard teletypewriter transmitter equipped with a continuous tape containing the necessary address and format. Upon insertion of the variable data via the keyboard and activation of the start button, the keyboard data combined with the continuous-tape loop to form a message to the simulated computer. At the termination of the transmission, the continuous-address loop was repositioned to START preparatory to the transmission of a new message. Figure 6 is an artist's concept of a position report input device utilizing a ten-key, adding-machine-type keyboard. The position information would be displayed to the operator for checking prior to transmission to the computer.

Arrangement of Test Facilities.

Automatic Tabular Displays.

The Type C display boards were used as automatic tabular displays of flight data. The area simulated is shown in Fig. 7. The two fixes selected to be displayed on the C boards were Terre Haute (HUF) and Indianapolis

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[8] G. A. Locke and E. R. Robinson, "Automatic Private-Line Teletypewriter Switching System," Bell Laboratories Record, September 1955

(IND). Flight-data messages (fix postings) for all other fixes in the two sectors were printed on teletypewriters and displayed on flight progress boards. Figure 8 is a block diagram of the equipment used in this portion of the test.

Flight-data messages addressed to the simulated computer were introduced at input stations A or B, Fig. 8. These messages represented the type of traffic that normally would be transmitted from one ARTC Center to another, or were in the form of proposed flight plans originating within the area. These sample messages were routed through the 81D1 switching center to the simulated computer. Upon receipt of the flight plans in the simulated computer, an analysis of the route of flight occurred. By this analysis, the number of fixes within the area for which display messages should be prepared was determined. The calculation of the estimated times and the preparation of the individual messages in teletypewriter format also took place in the simulated computer. See Fig. 2. The output messages from the simulated computer were routed through the switching center to the magnetic drum. The magnetic drum, serving as a storage device, performed two main functions:

1. It held in abeyance those original display messages that were not immediately required by the controller. The display messages that were required immediately were transmitted by the drum to the display. Those having estimated times beyond the normal display leadtime were held for future transmission on a clock-readout routine.

2. The flight-data messages stored in the drum provided the "file" used by the simulated computer in updating subsequent messages.

The computed display messages were routed from the drum to the displays via the 81D1 switching center. The HUF and IND fix postings were transmitted to the C boards as shown in Fig. 8. Fix-posting messages for other fixes in the two-sector display area were routed to teletypewriter stations C and D. The messages appeared in a straight-line format and the paper was merely torn into strips, which in turn were placed in flight progress strip holders. It should be noted that this portion of the test was concerned primarily with the automatic tabular display characteristics of the Type C boards. Since two fixes only could be displayed on the Type C boards, the printed copy display was maintained to provide a complete two-sector environment.

The arrangement of the flight-data message on a single row of indicators, as illustrated in Fig. 3, was different from the familiar flight progress board format. Although certain assumptions were made as to the functions of the board that would be performed automatically, the C boards used in these tests were not fully automatic. In particular, the automatic resequencing entailed a series of pushbutton operations by the controller. The entry of new or revised data by the controller and the transmission of such data to the computer also involved more pushbutton manipulation than would be considered desirable in an operational environment. What might appear to have been excessive pushbutton operation actually contributed to the flexibility of the C boards under different test conditions. An automatic tabular display obviously would sacrifice such flexibility for simplicity of operation.

Since each board was limited to the equivalent of ten flight progress strips, a real-time comparison of the automatic display versus a manual board was not possible. In spite of this limitation, a subjective evaluation of the operational suitability of such a display was made over a period of two months. The conclusions reached were as follows:

1. It is assumed that the electromechanical indicators of the type developed for this project are as small in frontal area as the state-of-the-art permits. In the display area, these indicators occupy a space 1 3/4 inches high by 5/8-inch wide. With the most efficient display of the flight progress strip information posted in a present-day sector, the display area required would be 6 feet high and 20 feet long. This assumes 5 bays which are 40 rows high and 60 indicators wide each, with additional space required for pushbuttons, lights, and so forth. From the standpoint of useful size, such a display is not practical. Present-day flight progress boards have a display area 2 1/2 feet high and 3 1/2 feet wide.

2. Even with the simple pushbutton operations built into the Type C boards, the controller is required to spend an appreciable amount of time resequencing and entering data into the display. This points out the requirement that, in a tabular display of fix-posting information, automatic resequencing should be used in accordance with time or altitude or whatever basis is used for control. In addition, controller effort required for entering data into the display or back into the automatic system will be an extremely important criterion in evaluating automatic systems. In line with the above statements on automatic resequencing, another logical conclusion follows: this type of operation should be permissible on the part of the traffic controller rather than fully automatic. In this way, the arrival of new data destined for posting could be indicated by a flashing light, or displayed in an abeyance section until the controller, by operating a pushbutton, indicated his readiness for its insertion. In the Type C display board, resequencing is performed serially, one row at a time. Although each row may be transferred in parallel to another row, it requires 1.5 seconds for each transfer. This means that several seconds will be required for a simple

resequencing, and if a new fix posting is to be inserted in the middle of a board, it would require the laddering of from 1 to 20 rows of data to insert a single new flight. Although this delay could be avoided by mass storage and full parallel insertion, it appears that such an approach would be far too costly and complex for this type of display.

3. The operational trials demonstrated that an outstanding feature of the Type C boards, when used to display flight-progress information, is their ability to accept automatically a message containing revised estimates for a posted flight and to find automatically the corresponding posting in the display and substitute the new information for the old. Another advantage of the Type C boards is the ability to alter any portion of a displayed message without disturbing or retyping the remainder of the message. Although the C boards provide for a buffer-row input with subsequent transfer to the desired row, it would be desirable to type directly into the message row to be altered. A keyboard speed greater than 7 wpm would be desirable provided that the typed characters were displayed before the succeeding key was operated. Still other advantages of the Type C display boards follow. Any displayed message may be transmitted to a specific destination by simply altering the address code and operating the transmit button. The displayed message on the transmitting C board remains undisturbed by this action. The equipment is capable of operating speeds up to 1,000 wpm.

Typed Flight Progress Strip Tests.

The testing of a display system using printed flight progress strips was carried on during the winter of 1955 and the spring and summer of 1956. The arrangement of the test environment essentially was the same as in the tests of automatic tabular displays. The principal difference existed in the display units. The air traffic control test area was the same two-sector arrangement of the Terre Haute and Indianapolis sectors. The displays were standard flight progress boards. The flight progress strips were produced by teletypewriter machines that had been modified slightly.

Each printer was equipped with a sprocket-feed platen to permit the handling of continuous fanfold perforated flight progress strip stock, Fig. 9. Each sector utilized two printers. One machine was fed a buff-colored stock of flight progress strips while the other machine used a green-colored stock. The sole purpose of the dual-printer arrangement was to provide the direction-of-flight indication by color of strip. Figure 10 shows that part of the equipment arrangement which differed from the configuration shown in Fig. 8.

Three methods of operation were evaluated in the tests of typed flight progress strips:

1. An original flight progress strip message in teletypewriter format was prepared by the simulated computer for each fix in the two-sector area that lay on the designated route of flight. These messages were routed to the proper sector (HUF or IND) and to the appropriate printer within the sector (buff or green paper stock) by insertion of a special teletype address. The messages were transmitted to the magnetic drum for storage, and were retransmitted to the display at the designated leadtime. Fictitious position reports were entered by the controller and transmitted via the position report input device to the simulated computer. See Fig. 11. These position reports were utilized in the computer to update the stored information on subsequent fix postings. However, no attempt was made to provide the controller with revised flight data once the original flight progress strip was typed. Figure 12 offers a comparison between printed and written strips.

2. The second method of operation involving typed flight progress strips called for the transmission of a revised flight progress strip for each fix posting subsequent to the fix reported. The revised strip was placed in proper sequence on the flight progress board, and the original strip was discarded.

3. The third method was identical to the second except that the revised information appeared on the typed strips in red print.

The teletypewriter printers were modified to provide a ribbon shift that could be actuated by a teletype symbol. A two-color ribbon was used. See Fig. 10. The normal flight data were printed in black and revised flight data were printed in red. In the composition of a revised flight-data message by the simulated computer, each revised group of data was preceded by a teletypewriter symbol "N," which, when received by the printer, caused the ribbon to shift to red. The revised group was followed by the teletypewriter symbol "V," which returned the ribbon to black.

The appearance of the red printing on a flight progress strip conveyed two significant facts to the controller. First, the red printing indicated that the strip was intended to replace a previous strip on the display. Second, the groups shown in red type were the actual items that were changed from the previous printing.

As in the previously described portions of this test, the position report input device served as a means of providing the computer with current position information upon which subsequent revisious would be based. For the first method of operation, printing original strips only, traffic samples were prepared which would provide a random flow of aircraft through the HUF and IND sectors with fix postings at each of the fixes currently in use in the Indianapolis ARTC Center. These fixes were:

HUF Sector	IND Sector
LAF	OKK
HUF	IND
XPV	XMX
EVV	SCJ
HAL	
XCR	
XRS	

Teletypewriter Printer Speed Tests.

Flights were introduced by copying directly from the sample onto the individual computer forms, simulating the data transfer from the observer in the normal center. The rate of entry into the problem was regulated by the operating capacity of the computer section.

The completed computer form, with estimates for each fix in the two-sector area, was given to one of three teletype positions. All messages were addressed to a single teletype printer, and allowed to print out on a continuous log. A measurement clock was started at 1200, and the clock time was entered on the output log every 10 minutes. It was necessary to stop the problem at two different intervals during the operation. Each time the clock was stopped, however, the switching center was not interrupted. Since a backlog existed in the switching center during most of the test, the printer continued to print during these interrupted clock times. This accounts for the high message count during two of the ten-minute periods. These are indicated by an asterisk in Table II.

From these tests it was shown that the maximum output of a single 75-wpm printer is approximately 25 flight progress strips per 10-minute period, or about 2 1/2 strips per minute. Since the rate of production was maintaining a constant backlog in the switching center, it is apparent that the simulated computer was producing something in excess of 150 flight progress strips per hour. All available figures on actual strip count in the Indianapolis Center at that time failed to show any 8-hour period wherein the average hourly strip count for the two sectors, HUF and IND, reached 100.

TABLE II

FLIGHT PROGRESS STRIP PRINTING - ONE PRINTER

Output Interval	No. of Strips Printed
1200-1210	5
1210-1220	21
1220-1230	26
1230-1240	25
1240-1250	35* (clock stopped approx. 4 min.)
1250-1300	23
1300-1310	26
1310-1320	36* (clock stopped approx. 4 min.)
1320-1330	27 (last message typed at 1328)
1330-1340	26
1340-1350	10 (last message printed at 1343)

Simulated Computer Output Test.

In order to arrive at a better measure of output of the simulated computer, additional tests were conducted. In these tests, two printers were used as the output of the computer. All messages destined for the HUF sector were addressed to the printer, and all messages for the IND sector were directed to another printer. It was believed that this division would take care of the backlog encountered in the first test. Also, in order to provide a more realistic input, the flights were phoned in from a position in the switching center. A sample consisted of 100 flights.

Operating Conditions.

Measurement clock was started at 0900.
Phone and copy completed at 1012.
Completed except for "times" - 1013.
Estimated - 1014.
Typed and transmitted - 1025.

TABLE III

FLIGHT PROGRESS STRIP PRINTING - FOUR PRINTERS

Output Interval	HUF	IND	Total
0900-0910	3	2	5
0910-0920	14	12	26
0920-0930	14	13	27
0930-0940	15	23	38
0940-0950	16	17	33
0950-1000	12	20	32
1000-1010	19	17	36
1010-1020	17	20	37
1020-1030	12	14	26
Totals	122	138	260

The average output for the period 0930-1020 was 35 strips per 10-minute period, or 210 strips per hour for a two-sector operation. This test was important to establish the fact that the system could function in a real-time environment, thereby adding to the validity of the results. Available peak-day traffic figures in the Indianapolis ARTC Center showed that at this time the 8-hour average for either of the two sectors under consideration had not exceeded 50 flight progress strips per hour.

Complete System Tests.

During the complete system tests, every effort was made to provide realism and a real-time environment. Several different traffic controllers were used to provide a diversified opinion, but due to lack of manpower, it was not possible to make a one-to-one comparison with handwritten strip techniques for the same traffic sample at the same time.

The following analysis of each type of operation is based upon the subjective opinion of the traffic controller personnel who participated in the tests. Comparisons were made based upon past experience and judgment.

Method I - Original strip preparation only.

Advantages:

1. Better legibility.
2. Saving of assistant controller time.

Disadvantages:

1. None.

Method II - Printing original and revised strips (same color).

Advantages:

1. Saving in coordination time.

Disadvantages:

1. Confusion between old and new strips.
2. Time required to replace old strips with new.

Method III - Printing original and revised strips (revisions in red).

Advantages:

1. Revisions may be detected easily.
2. Saving in coordination time.

Disadvantages:

1. Time required to replace old strip with new.
2. Old ETA data not available on new strip for comparison.

A general analysis of the controller's input device used for sending position reports indicated that there were too many keys to operate and that an adding-machine-type keyboard with display would be better.

CONCLUSIONS

Immediate improvement in air traffic control may be realized from a system of encoding and processing tabular flight data. Such a system should include:

a. Input devices to compose flight-data messages in language and format compatible with data-processing equipment.
b. Electronic computers to process the data and direct it to the display.
c. Programs within the computers to permit utilization of the stored data for confliction-search and flow-control routines.
d. A communications system with the capability of providing on-line service from the input devices to the computer, between computers, and from the computer to the display.
e. Printing devices for the preparation of typed flight progress strips.

An automatic tabular display is required to permit updating of displayed data by the computer. Although the amount of tabular data to be displayed will be reduced as improvements are made in pictorial displays, there will remain a requirement for some form of display of tabular flight data. To exploit fully the capabilities of the electronic data processors, the tabular display should be automatic. Experience with electromechanical indicators in their present state of development revealed that the required amount of tabular data could not be condensed sufficiently to provide a workable display for a controller. It appears that an electronic display, in the form of a direct-view, cathode-ray tube or a projection on a screen, would be an acceptable method of presenting tabular flight data.

The implementation of the basic data-processing system described in this report would accomplish several major objectives. It would:

a. Provide immediate relief in a critical area by reducing the clerical workload of controller personnel.
b. Aid in further defining the data-processing problems anticipated in a complete system implementation.
c. Acquaint the traffic controllers with the capabilities, as well as the limitations, of automatic data-processing devices.
d. Provide a firm basis for expansion of the system in more advanced techniques for data gathering and processing.

RECOMMENDATIONS

It is recommended that:

1. An operational computer environment be created as soon as possible, consisting of at least three adjacent ARTC Centers, each equipped with digital computers and having the following operational characteristics:

a. The ability to accept flight data automatically via a teletypewriter input (either manually prepared tape, or from the flight-plan input device).
b. Adequate communications links between computers to permit automatic exchange of flight data.
c. Automatic input from controller's position-reporting device.
d. Automatic output to printers located at the position of operation in the ARTC Centers.
e. Sufficient computer storage to permit retention of the computed flight progress strip for other routines such as confliction search, clock readout, updating, and so forth.

2. The investigation of flight-data computer outputs continue along two lines:

a. Automatic cathode-ray tube presentation of tabular flight data, with provisions for automatic updating, sequencing, confliction detection, and so forth. The development of the automatic display also entails the development of an adequate means of "backup" or providing the controller with "hard copy" in the event of equipment failure.
b. Automatic pictorial display of moving targets whose course and speed are determined originally by the input of flight-plan data, and subsequently corrected by periodic position reports transmitted to the computer from the controller input device.

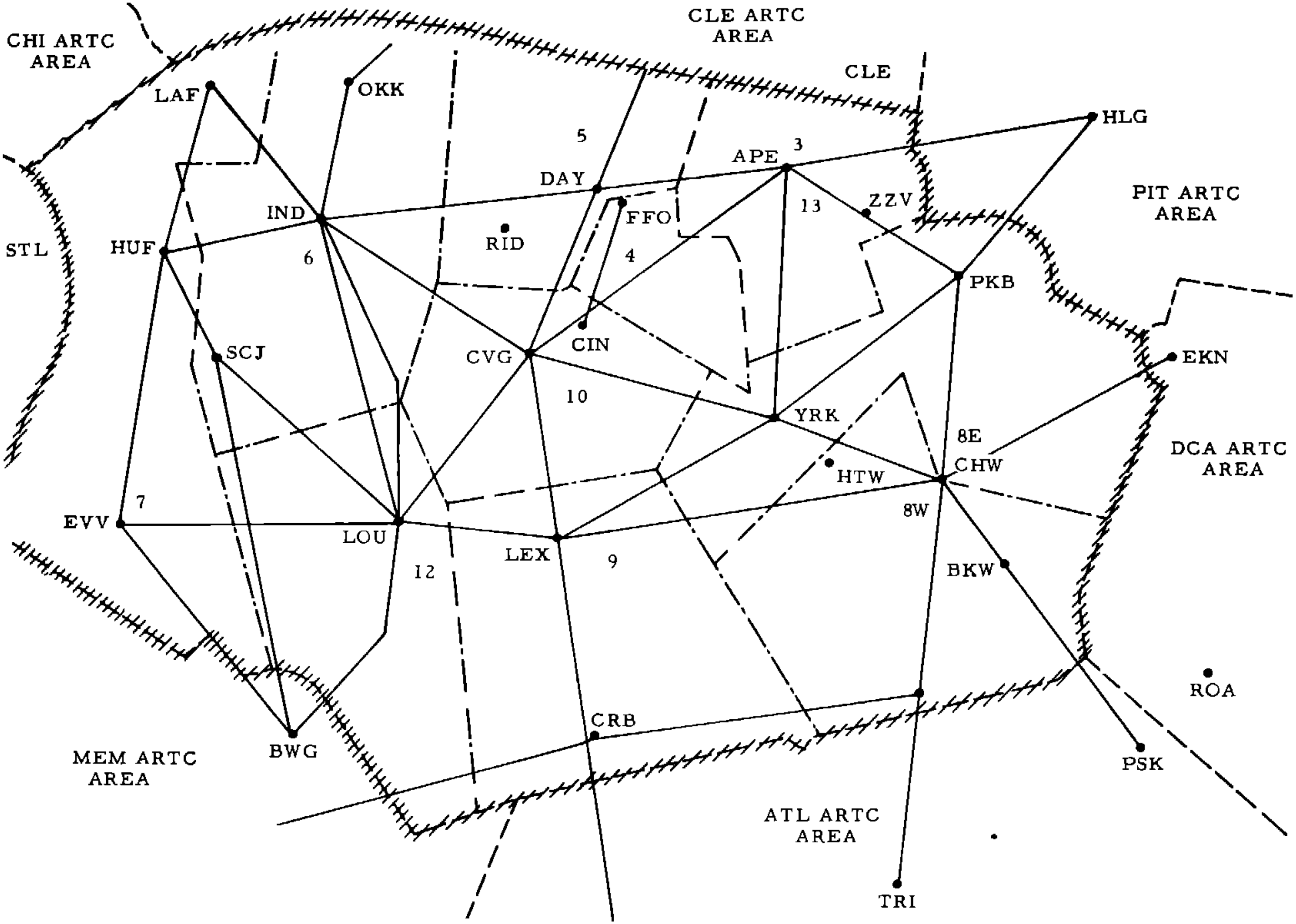

FIG 1 INDIANAPOLIS ARTC AREA AND SECTOR ARRANGEMENT

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FIG 2 SIMULATED COMPUTER
AUTOMATIC COMMUNICATIONS EQUIPMENT OPERATORS AND
DUTY ASSIGNMENTS

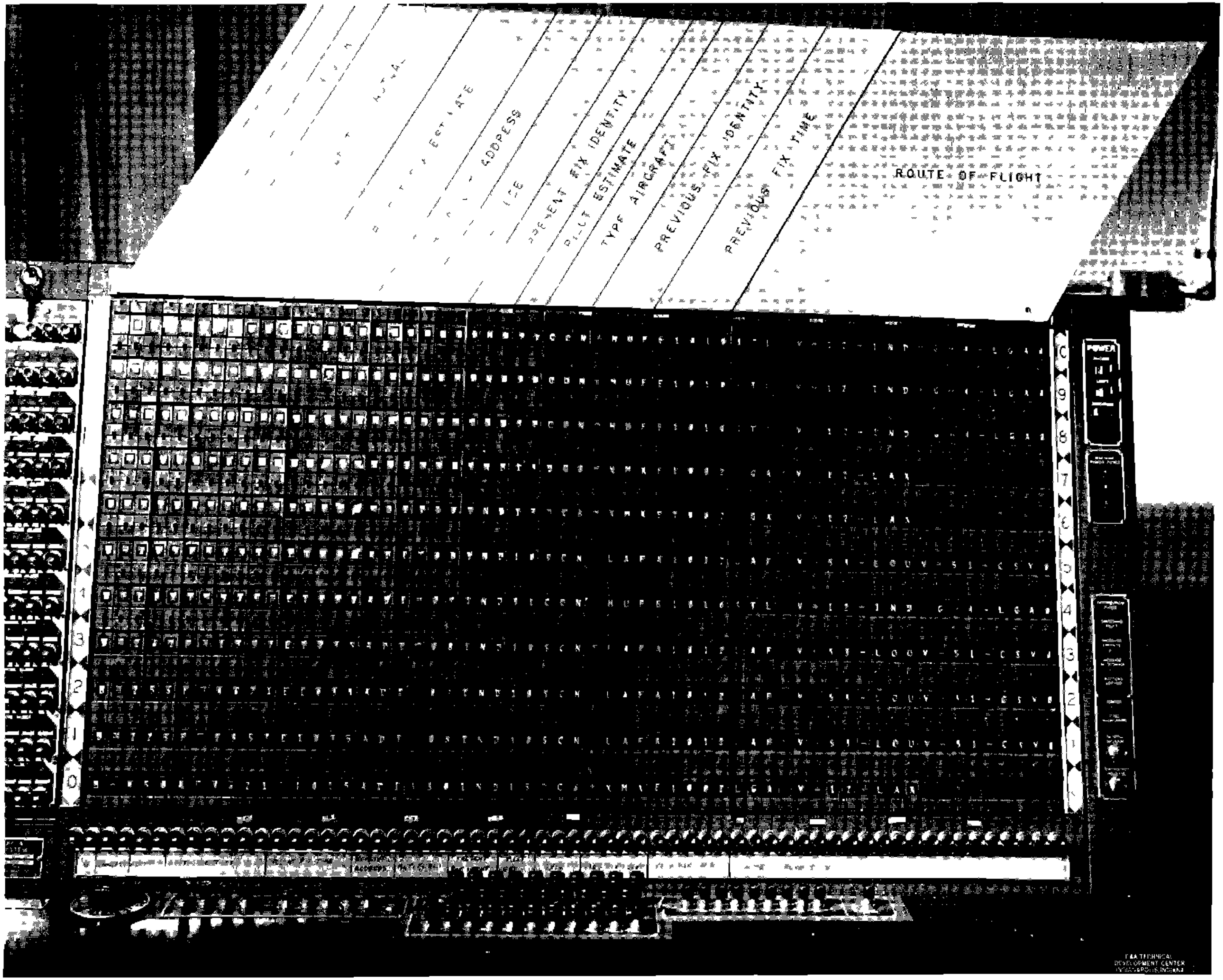

FIG. 3 DATA DISPLAY AND TRANSFER BOARD USED AS AN AUTOMATIC TABULAR DISPLAY

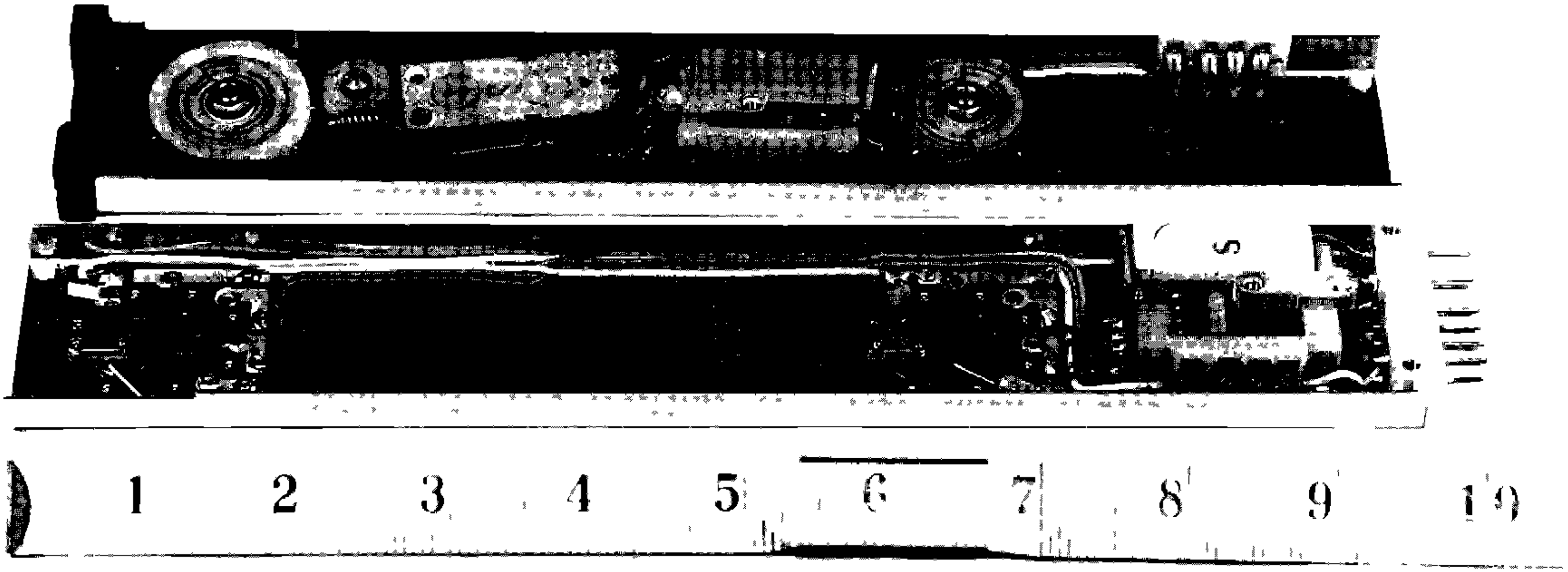

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FIG 4 CUTAWAY VIEW OF INDIVIDUAL DATA DISPLAY INDICATOR

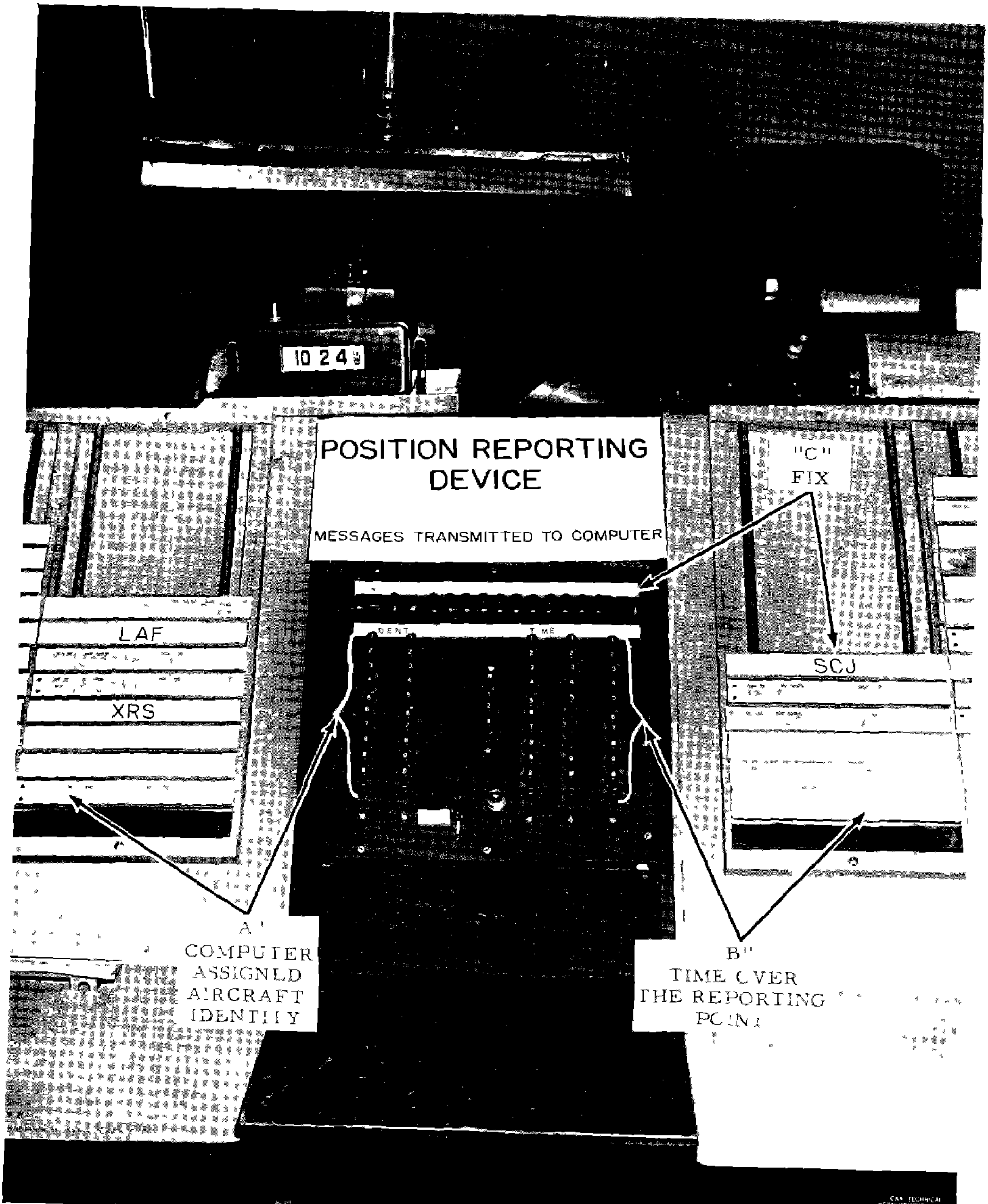

FIG 5 POSITION REPORT INPUT DEVICE

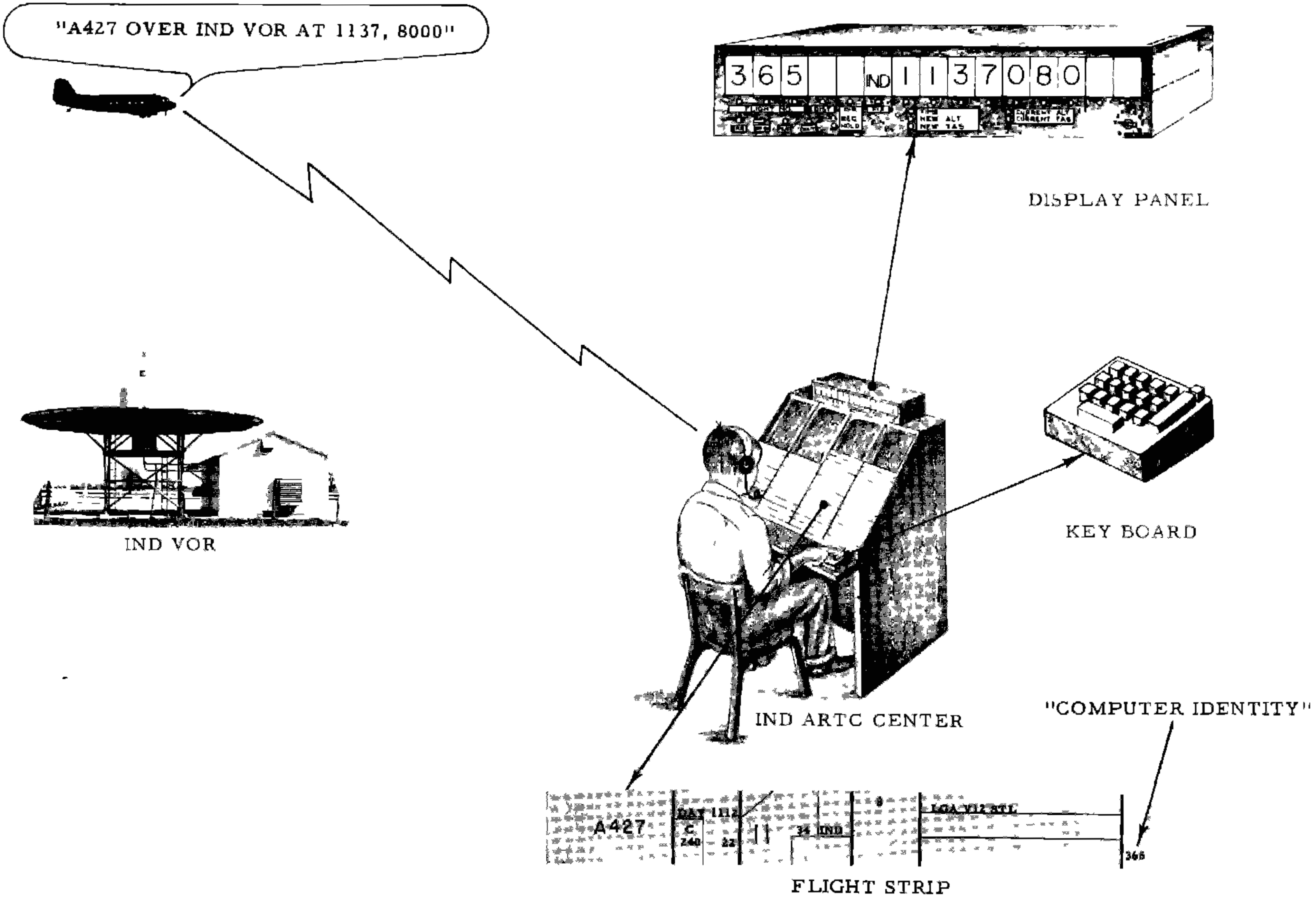

FIG 6 POSITION REPORT INPUT DEVICE

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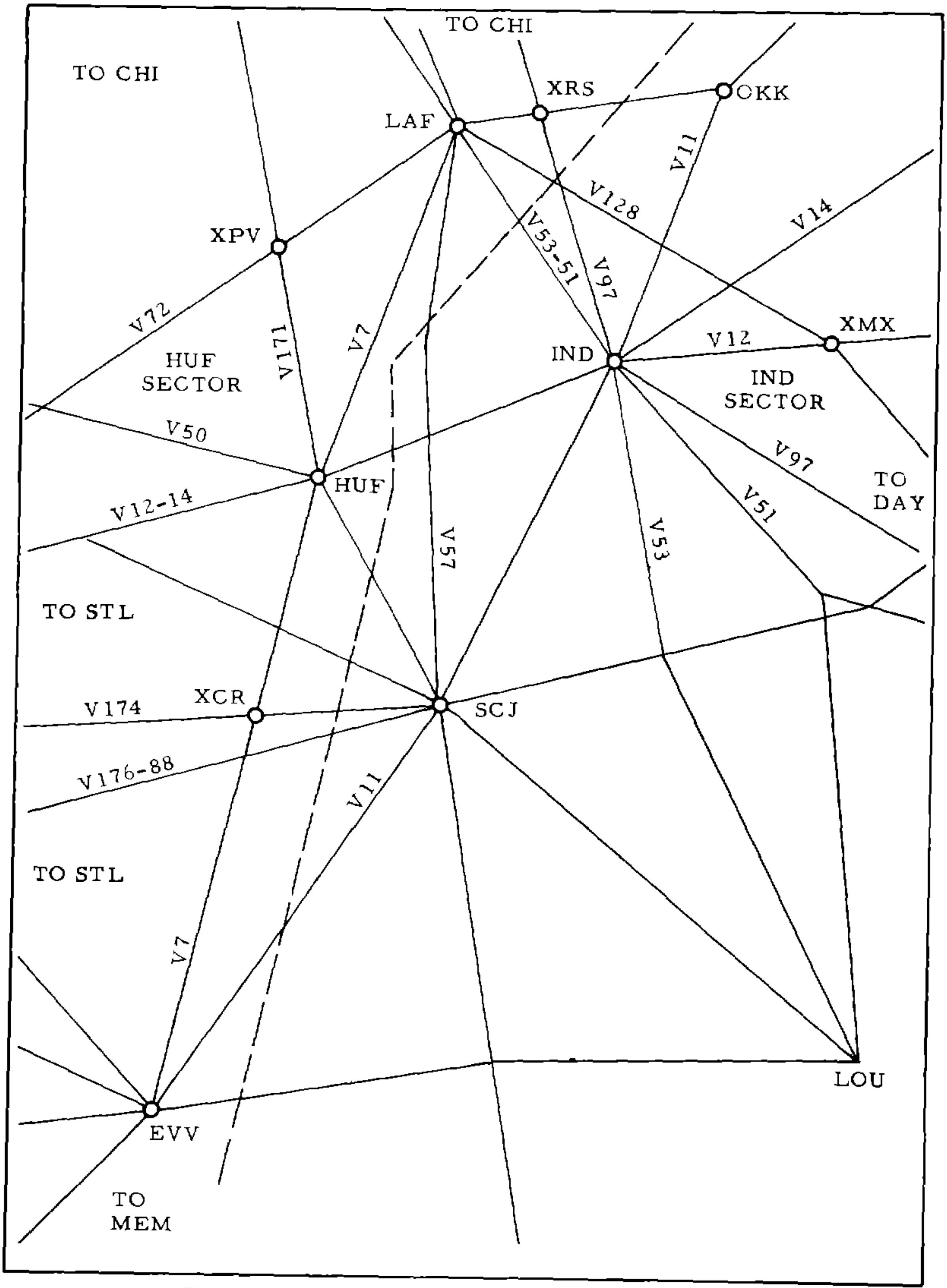

FIG 7 TWO-SECTOR AREA USED IN SIMULATION

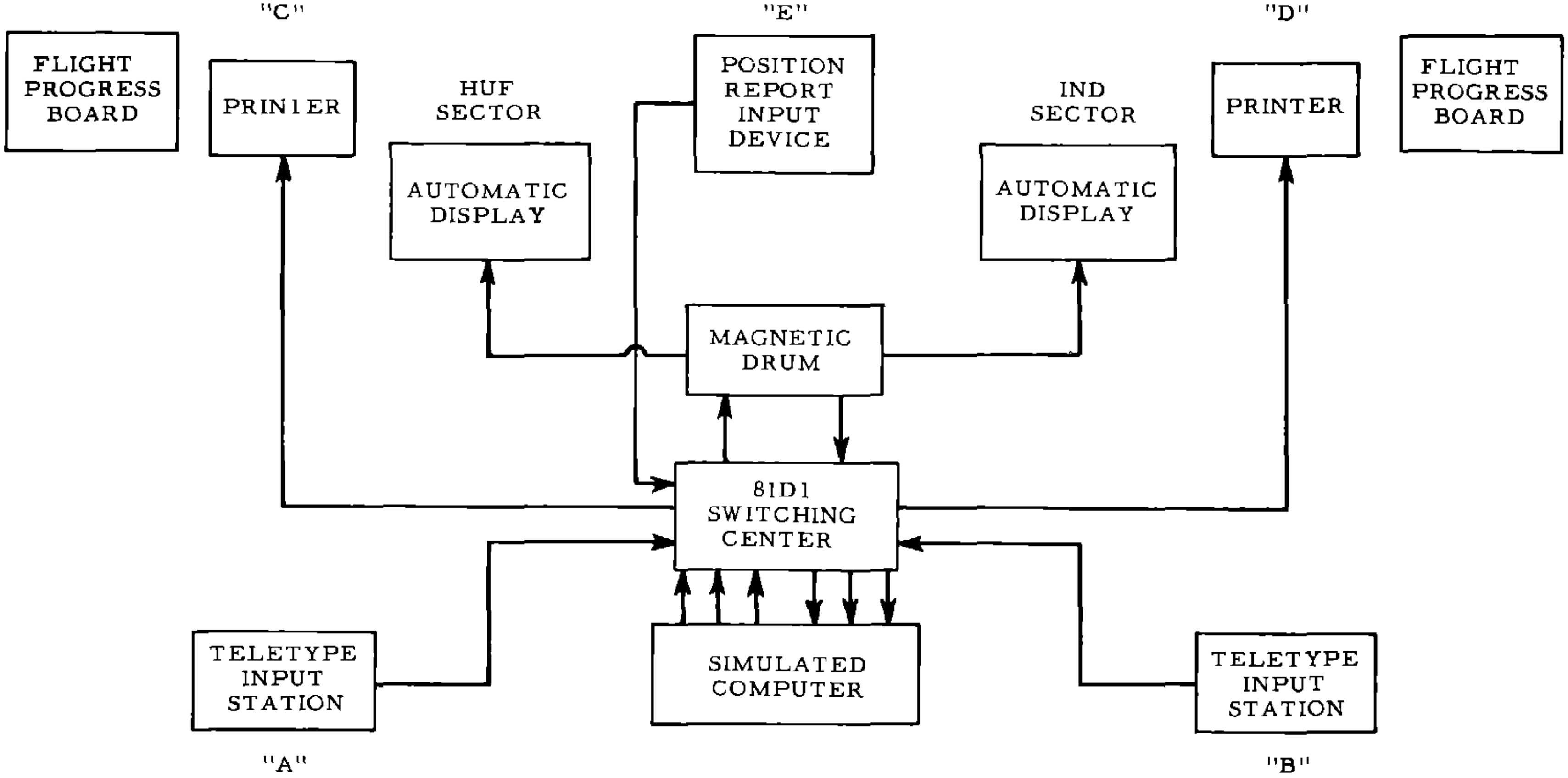

FIG 8 BLOCK DIAGRAM OF EQUIPMENT ARRANGEMENT C BOARD TABULAR DISPLAY

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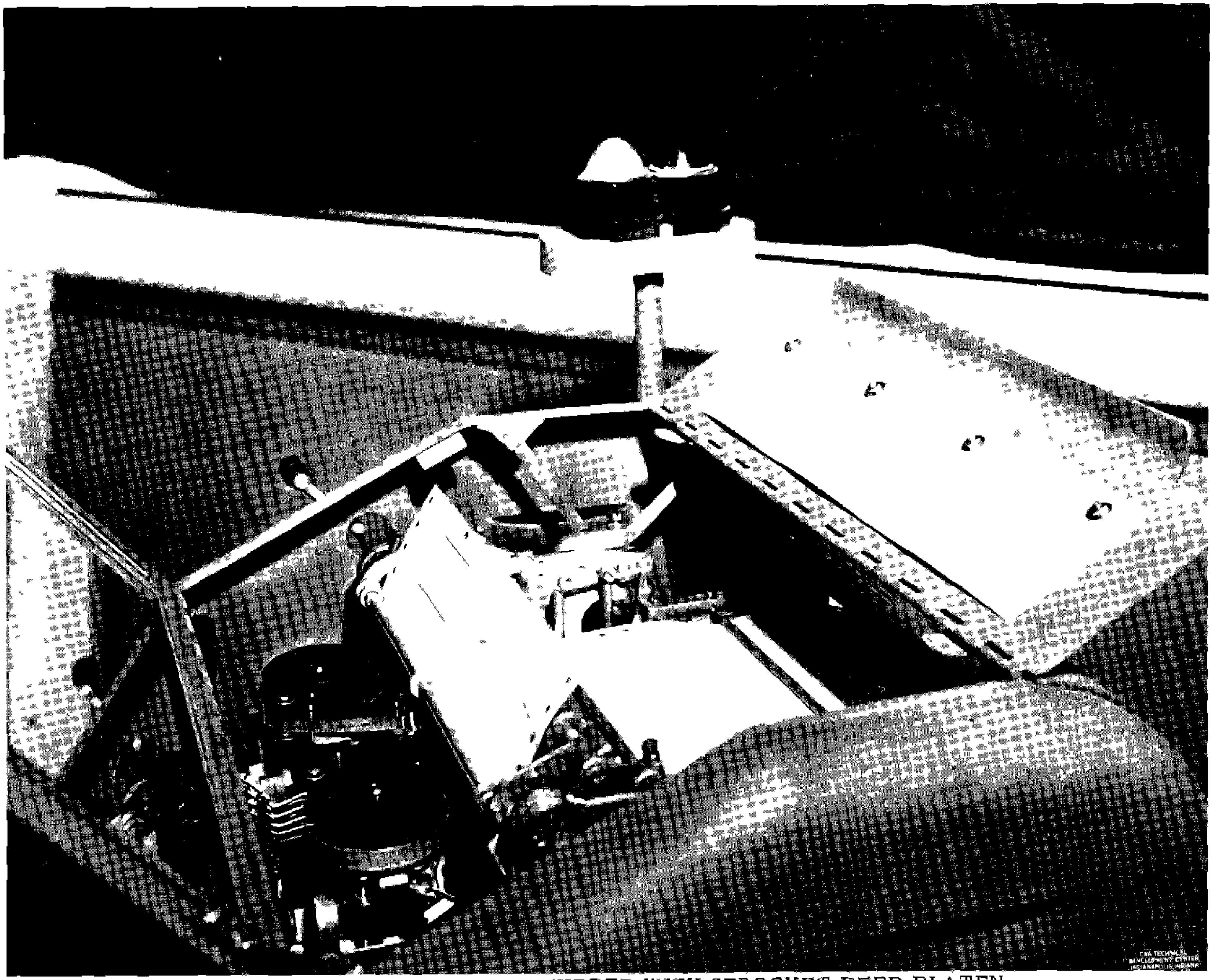


FIG 9 MODEL 15 PRINTER EQUIPPED WITH SPROCKET FEED PLATEN AND RIBBON SHIFT ADAPTER

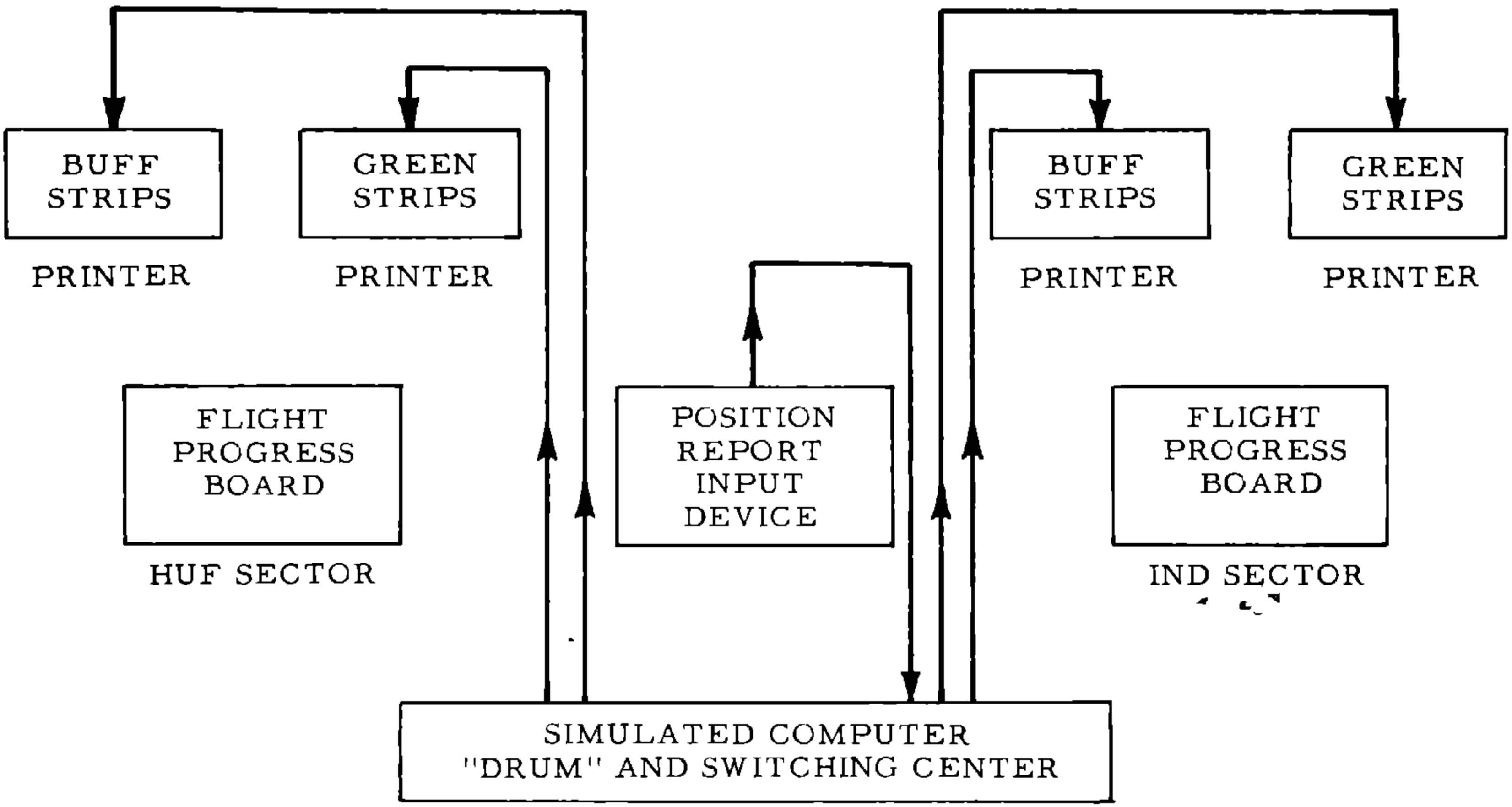
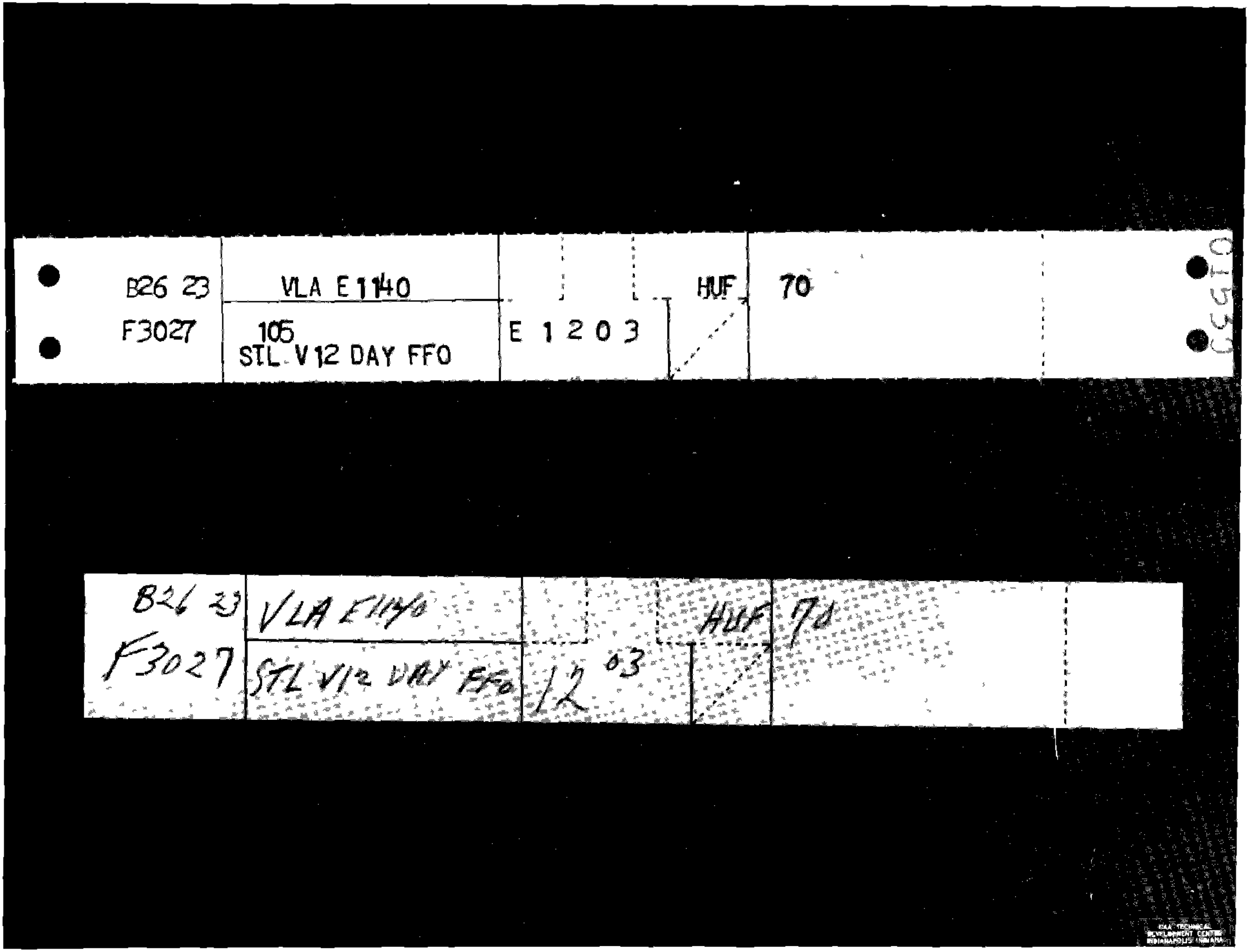


FIG. 10 ARRANGEMENT OF EQUIPMENT FOR STRIP PRINTING

FIG 11 TWO-SECTOR ARRANGEMENT SHOWING CONTROLLER USING INPUT DEVICE



B26 23
F3027
VLA E1140
105
STL V12 DAY FFO
E 1203
HUF
70

B26 23
F3027
VLA E1140
STL V12 DAY FFO
12 03
HUF
70

FIG 12 COMPARISON OF TYPED AND WRITTEN FLIGHT PROGRESS STRIPS