CAA TYPE II
AUTOMATIC FLIGHT AND NAVIGATION EQUIPMENT

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CAA TYPE II AUTOMATIC FLIGHT AND NAVIGATION EQUIPMENT*

SUMMARY

This report discusses the operation of the CAA Type II Automatic Flight and Navigation Equipment and describes some of the circuits which were combined in it. Basically, the equipment is an airborne course-line computer which operates upon data from a self-contained storage unit and from omnibearing-distance (OBD) information to produce left-right guidance along a selected course and to provide airplane-to-waypoint-plane-distance indications. Additional features which make the equipment unique are the data-storage and read-out arrangement and the method of combining course-deviation and heading signals to produce improved automatic flight along a rather wide course-line-computer course.

The equipment is simple to operate but requires detailed preflight planning, and its inflight use, while not confined to any particular sequence of courses, is limited to courses corresponding to data stored in a punched tape. There is provision for storing data for 300 courses. These may be course-line-computer courses, automatic ILS approaches, or magnetic headings. A particular course may be terminated at any time by the selection of a different course, or the courses may be flown in sequence. When the courses are flown in sequence, the equipment will automatically set in the data and will transfer control to the next succeeding course each time the airplane arrives at a waypoint. Provision for holding patterns is made in the equipment by arranging two parallel courses to be flown alternately and in opposite directions.

The accuracy of the Type II equipment is as good as that of other course-line computers which have been tested at this Center. The computer may cause about 1/2 mile of position error. The OBD information theoretically may cause an error of as much as 5 1/2 miles when the airplane is 57 miles from the OBD station, so that it is possible to have an over-all system error of 6 miles. In limited flight tests, no error in excess of 2 miles has been observed.

INTRODUCTION

With the implementation of the very-high-frequency (VHF) omnirange (VOR) and the distance-measuring-equipment (DME) programs, there was a growing interest in the adaptation of the automatic approach equipment to provide radio-controlled flight on computed course lines. Prior to the completion of the Type II computer, little work was done in this direction.

The problems of automatic flight control on computed course lines are quite similar to those associated with the flying of the omnirange course lines, with one important simplification. While the omnirange courses are of constant angular width which results in the positional sensitivity changing with distance, the computed course lines normally have a constant linear width which results in a constant positional sensitivity throughout the entire length of the course line. This constant positional sensitivity is desirable because it eliminates the effect of distance on the control-system stability. When the Type II computer is used, no modification of the existing control characteristics of the autopilot coupler is required.

DESCRIPTION OF THE EQUIPMENT

The CAA Type II automatic flight and navigation equipment is shown in Figs. 1 and 2. It includes a data-storage unit, Figs. 3 and 4, a course-line computer, Figs. 5 and 6, the controls for the navigation receiver, the controls for a DME, and the controls for a glide-path receiver. Data for course-line-computer courses are prepared before a flight and are stored on a punched tape, a piece of which is shown in Fig. 7. The equipment provides automatic flight along consecutive course-line-computer courses, instrument-landing-system (ILS) courses, and magnetic-heading courses.

As indicated in the block diagram, Fig. 8, the equipment combines the outputs of the navigation receiver, the glide-path receiver, the DME, and the Gyrosyn compass. It performs the functions of automatic flight on a course-line computer, together with a punched-tape data-storage function for setting up predetermined courses and tuning the radio equipment. It

*Manuscript submitted for publication December 1953.

provides four indicators for the use of the operator. These are the course-deviation, DME-distance-to-OBD-station, omnibearing, and waypoint-distance indicators. The control box, Figs. 1 and 9, provides a master power switch, an engage button, a course-number selector, a course-number indicator, and pilot lights for "on" indication and for "positioner-tuning" indication.

The operator is given a chart of the course lines which are set up in the storage unit. This chart shows roughly the position of the courses and their assigned course-line numbers. In operation, after the operator sets in the course-line number of the first course it is desired to fly, the airplane is flown manually until within range of the omnidistance station which furnishes data for the first course, at which time the engage button is operated. If the airplane is a greater distance than 3 1/2 miles from the first course, the airplane will turn and will fly approximately perpendicular to the course until the deviation indicator shows less than full-scale deviation. At that time the airplane will turn, bracket, and fly along the course to the first waypoint. When the first waypoint is reached, the computer automatically advances to the next course in the sequence and the airplane proceeds along the new course. This procedure is continued until the flight is terminated in either a holding pattern, a magnetic-heading course, or an automatic approach to a runway. The holding patterns are formed by having two parallel courses laid out quite close together. At the completion of the second course, the storage tape moves backward to the last course instead of advancing to the next sequence number so that the airplane flies the last two courses alternately in a holding pattern until released by the operator. All data for the operation of this computer, with the exception of the selection of the initial course number, are calculated before the storage tape is prepared. Punchings in the storage tape contain the information shown in Table I for each of the courses.

OPERATING PROCEDURE

The following sequence of operations is normally followed in the operation of the CAA Type II automatic flight and navigation equipment

1. All associated equipment including DME, navigation receiver, Gyrosyn compass, autopilot, and autopilot coupling unit is energized during taxiing to the take-off runway. Normally the associated equipment will be in operating condition by the time the airplane has climbed to 500 or 1,000 feet.
2. The computer is turned on after take-off. Approximately 15 seconds are needed for

Fig. 1 Front View of Complete Airborne Equipment

warmup of the computer equipment.
3. The autopilot is engaged.
4. The computer is engaged. When the computer is engaged, all control circuits are transferred to the storage unit.
5. As soon as the flag on the waypoint-distance indicator disappears indicating that all circuits are working, the approach coupler control switch on the autopilot control box is set to the "navigate" position and the airplane is then flown by the signals from the computer. The data for as many as 300 desired courses may be stored on a punched tape.

THEORY OF OPERATION OF THE COMPUTER

The course-line computer function will be described only briefly in this report since it has been fully covered in a report on the CAA Type I course-line computer.[1]

The combining of heading signals with signals from the course-line computer in order to obtain an improved damping factor[2] is a noteworthy improvement over earlier course-line computers.

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[1] Chester B. Watts, Jr., and Logan E. Setzer, "CAA Type I Course Line Computer," CAA Technical Development Report No. 152, January 1952.

[2] Chester B. Watts, Jr., and Logan E. Setzer, "Some Recent Developments in Radio-Controlled Flight and Landing," CAA Technical Development Report No. 118, Appendix I, July 1950.

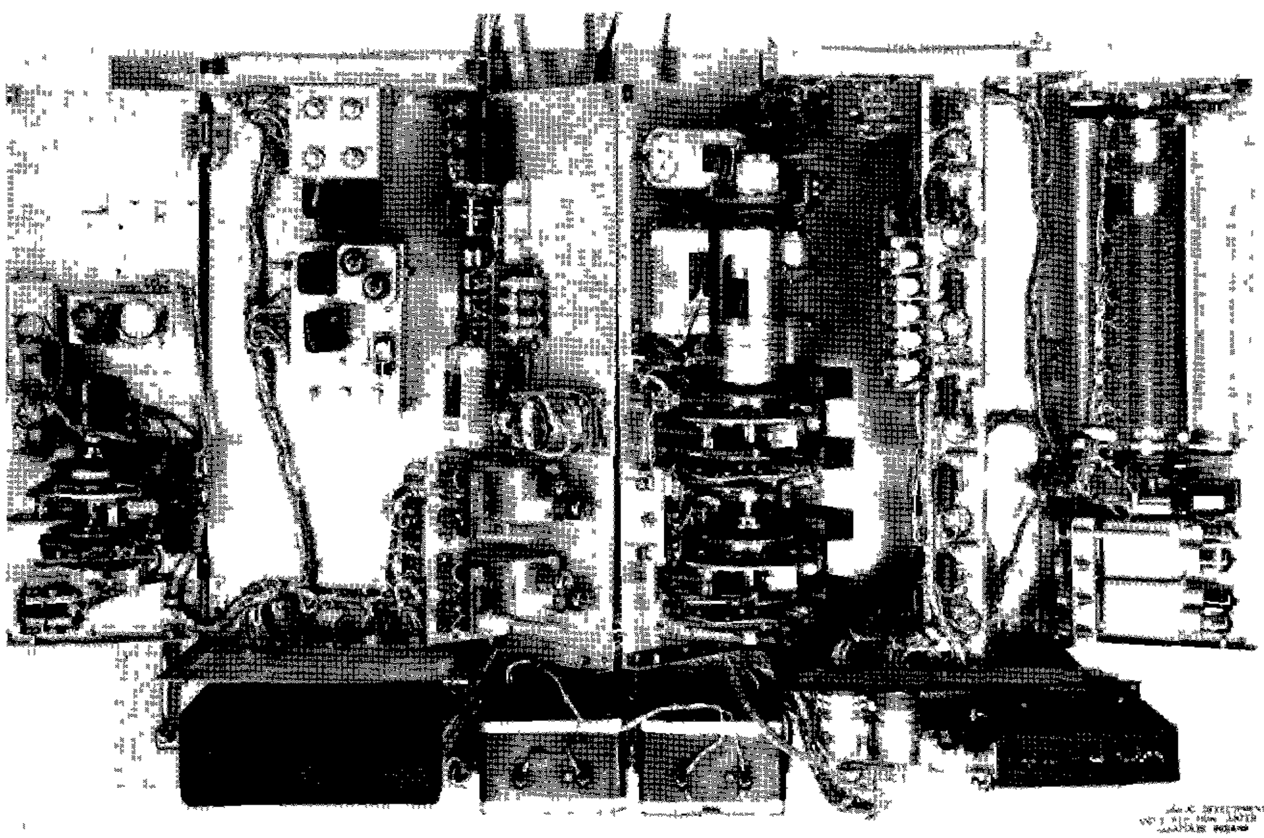

Fig. 2 Top View of Airborne Equipment With Side Down

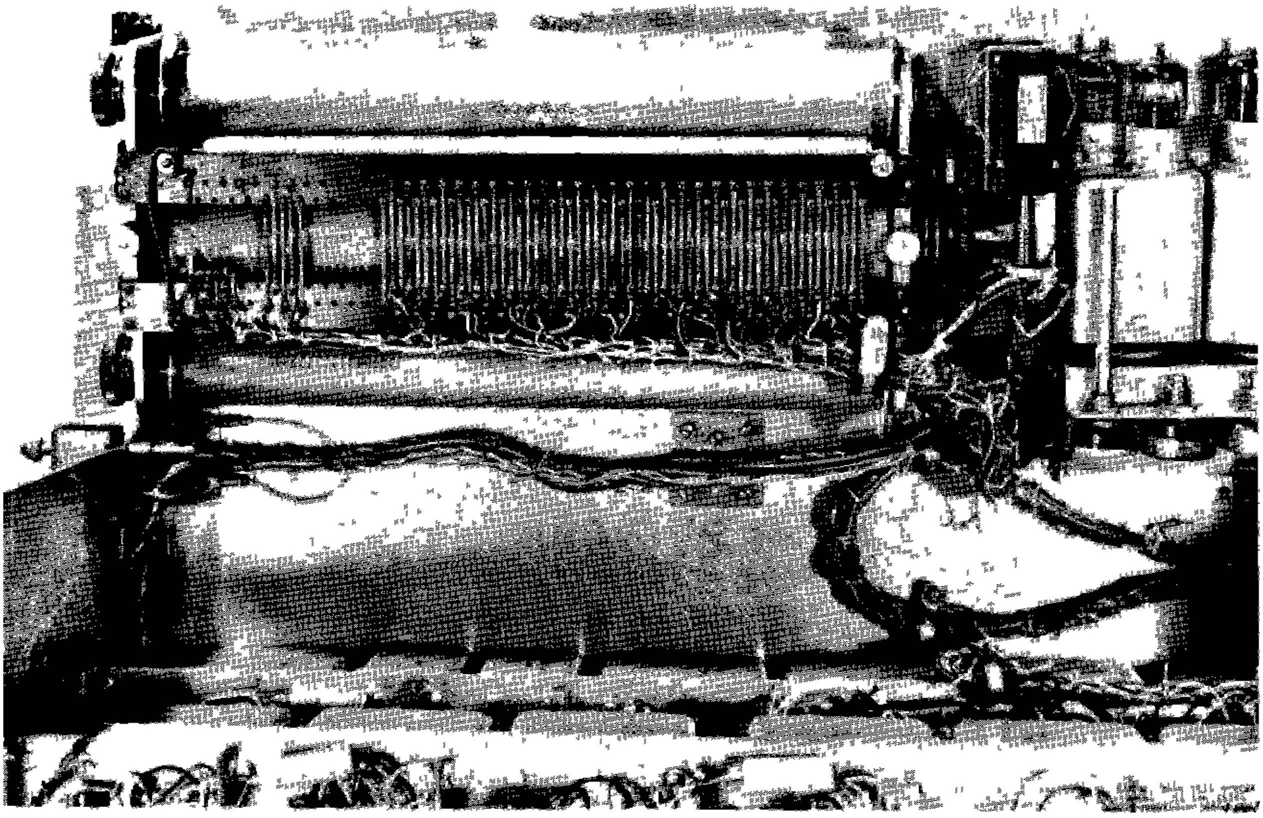

Fig. 3 Data Storage Unit Assembled

As indicated in Fig. 10, it has been shown that the deviation from the selected course-line computer course is given by the equation

$$e = r_d \cos \ {}_2 - r \cos \ {}_1, \tag{1}$$

that the airplane-to-waypoint-plane distance is given by the equation

$$D_d = r_d \sin \ {}_2 + r \sin \ {}_1, \tag{2}$$

and that electrical signals proportional to these distances can be produced by an electromechanical arrangement shown in a simplified schematic diagram,[3] Fig. 11. The electromechanical arrangement for combining the Gyrosyn-compass signals with the course signal to produce a difference signal is also shown in Fig. 11. Single-speed synchro signals, that is, signals from a synchro which has its shaft driven one revolution for each 360° change in the heading of the airplane, are fed from the Gyrosyn compass to the heading repeat-back synchro. Signals from the rotor of the heading repeat-back synchro are fed to the heading servoamplifier which drives the heading servomotor. A three-turn potentiometer, a two-phase synchro, and the differential gear train are driven by the heading servomotor. The differential gear train is also connected to the course co-ordinate setting mechanism and, through a 2 1 reduction gear, to the shaft of the heading repeat-back synchro. In this way, when the heading of the airplane i the same as the course co-ordinate the wiper of the potentiometer is at the middle of the potentiometer resistance winding and the output from the two-phase synchro is zero. Both the potentiometer and the two-phase synchro are excited from a 13-volt, 400-cps source. A centering

[3]CAA Report No. 152, op. cit.

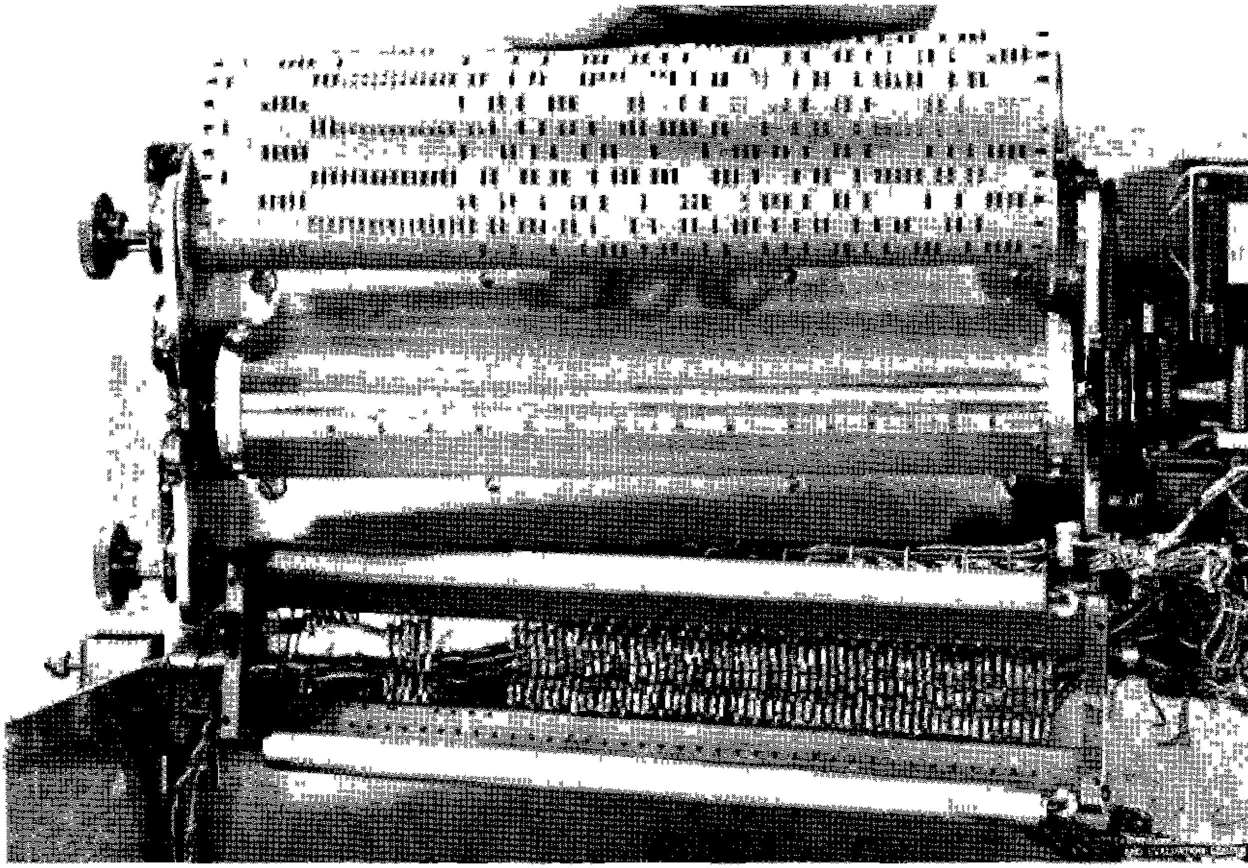

Fig. 4 Data-Storage Unit Unassembled

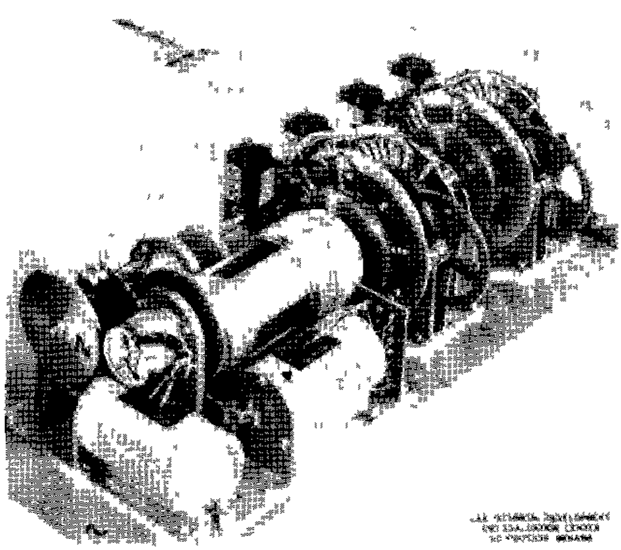

Fig. 5 Course-Positioning Unit, Waypoint-Azimuth Co-Ordinate Positioning Unit, Computer Cylinder and Servomotor

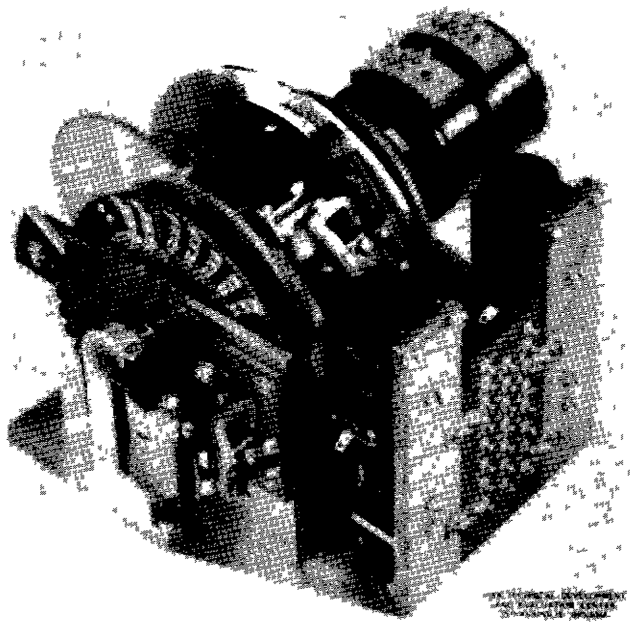

Fig. 6 Waypoint-Distance Co-Ordinate Positioning Unit, Top Oblique View

potentiometer with a grounded wiper is also excited by the 13-volt source. Thus, the output at the wiper of the heading potentiometer varies linearily, both positively and negatively, as the heading departs to the left or the right of the course co-ordinate. The output of the two-phase synchro is a sine function of the departure of the heading from the course co-ordinate. These two signals are combined to produce a nonlinear, left-right signal which is combined with the course-deviation signal to produce the steering signal. The steering signal is fed through an approach coupler[4] to the autopilot to obtain automatic flight on the course.

The rate component of the damping factor is developed in the approach coupler and, combined with the heading-departure and course-deviation signals, produces stabilized flight along the course. The course-deviation signal is limited so that when the airplane is further away from the course than approximately 20 per cent more than full scale the course-deviation signal is constant. This limiting value of deviation signal is selected to be equal to the heading signal produced when the heading differs from the course by approximately 90°. Therefore, if the autopilot is engaged and is fed signals from the automatic navigation equipment when the airplane is at a great distance from the selected course, the airplane will turn and fly a heading approximately perpendicular to the course until the deviation from the course is approximately 20 per cent greater than full scale on the deviation indicator. Then the airplane will turn and fly along the selected course.

CIRCUIT DESCRIPTION

The servoamplifiers are made up of a 12AT7 twin triode in cascade and a 12AU7 discriminator output operating a differential relay. See Fig. 12. This relay controls the forward and reverse movement of the servomotors. A velocity generator, which is a part of the servomotor, provides damping of the servomotor by feeding back to the input stage of the servoamplifier. A signal proportional to the angular velocity of the servomotor and of opposite phase to the input signal is provided. A waypoint amplifier uses the phase change of the airplane-to-waypoint-distance signal to close a relay when the computer distance nears zero. The point of

[4] Ibid.

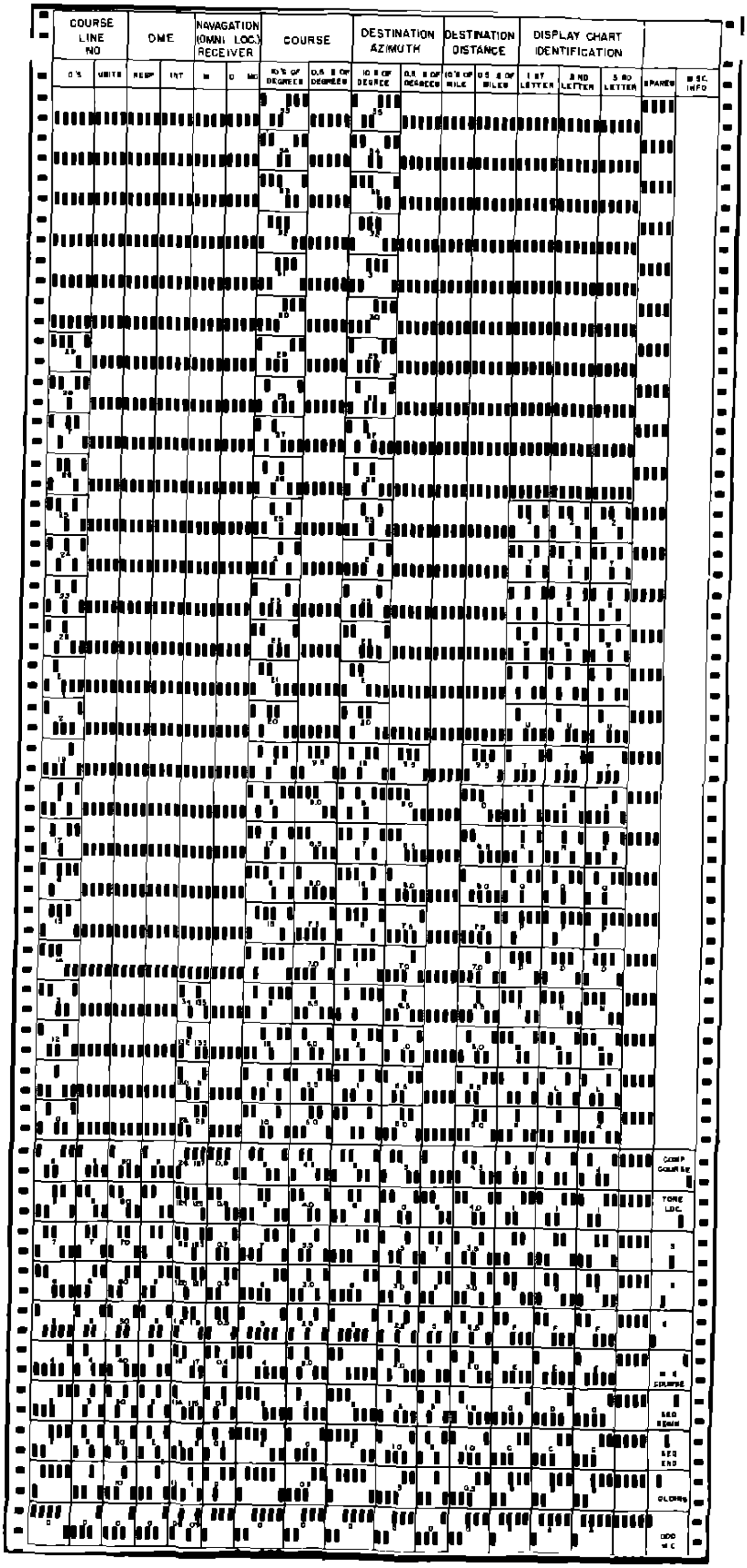

Fig. 7
Data-Storage Tape

TABLE I

ARRANGEMENT OF THE DATA STORAGE TAPE

Group No.	Group	Serial No. of Spaces in Group	No. of Spaces in Group	Possible Positions from These Spaces	Positions Used
1	Course-line number, tens	1-5	5	510	300
2	Course-line number, units	6-9	4		
3	DME tuning, responder	10-13	4	254	100
4	DME tuning, interrogator	14-17	4		
5	Navigational receiver tuning, even Mc.	18-21	4	254	140
6	Navigational receiver tuning, even Mc.	22-25	4		
7	Computer course, tens of degrees	26-31	6	2,046	720
8	Computer course, half degrees from 0° to 9 1/2° inclusive	32-36	5		
9	Waypoint-azimuth co-ordinate, tens of degrees	37-42	6	2,046	720
10	Waypoint-azimuth co-ordinate, half degrees from 0° to 9 1/2° incl.	43-47	5		
11	Waypoint-distance co-ordinate, tens of miles	48-51	4	510	100
12	Waypoint-distance co-ordinate, half miles from 0 mi. to 9 1/2 mi. incl.	52-56	5		
13	Chart identification, first letter	57-61	5	not used	not used
14	Chart identification, second letter	62-66	5		
15	Chart identification, third letter	67-71	5		
16	Spares	72-75	4	not used	not used
17	Miscellaneous functions	76-80	5	10	7
		Total	80		

operation can be adjusted by changing the negative bias on the discriminator tube. When this waypoint relay closes, it causes the sequence storage unit to rotate one step forward, thus setting up co-ordinates for a new waypoint. In order that this forward step on the storage unit does not occur indiscriminately, interlocking relays are placed in all circuits that might cause the distance-to-waypoint signal to go to zero. The flag-alarm interlock is included in this interlocking circuit. If for any reason the error signal becomes too large in either the distance or the omni servoamplifiers, the flag alarm on the waypoint-distance indicator will show and the interlock will open, preventing the sequence unit from stepping.

A ten-second time-delay relay interlock is also incorporated to prevent the sequence unit from stepping while the autopositioner tuning units are moving. A DME flag-alarm interlock also prevents the sequence unit from stepping if the DME loses the signal and starts searching. In the ILS function, which is normally last in the course sequence, an interlock opens to prevent any sequence unit from stepping because of a zero-mile indication when the glide-slope DME station is passed.

DATA STORAGE

Preflight planning for the use of the Type II equipment includes compilation of the data for the courses to be flown and storage of the data in a punched tape. The data required for each course and the number of spaces required on the storage tape are shown in Table I. The storage tape shown in Fig. 7 provides 80 spaces in each of 2 rows for storing data for a given course. The first 75 spaces were punched in either one row or the other in each space but never in both rows. These first 75 spaces are divided into 16 groups. Twelve of the groups are used to store data for the controls necessary for the operation of the computer.

The first two groups store the course-number data and control the course-number indicator on the control box. The control box is equipped with two push-button switches. One of these switches drives the storage tape in the forward direction, and the other drives it in the reverse direction. The pilot selects the first course number by operating the push buttons until the desired course number is displayed on the course-number indicator. In flight, the storage tape is automatically moved forward one space each time a waypoint is reached, and the course-number indicator changes to indicate the course for which data are being fed to the computer. The capacity of the storage is limited only by the positions on the course-number

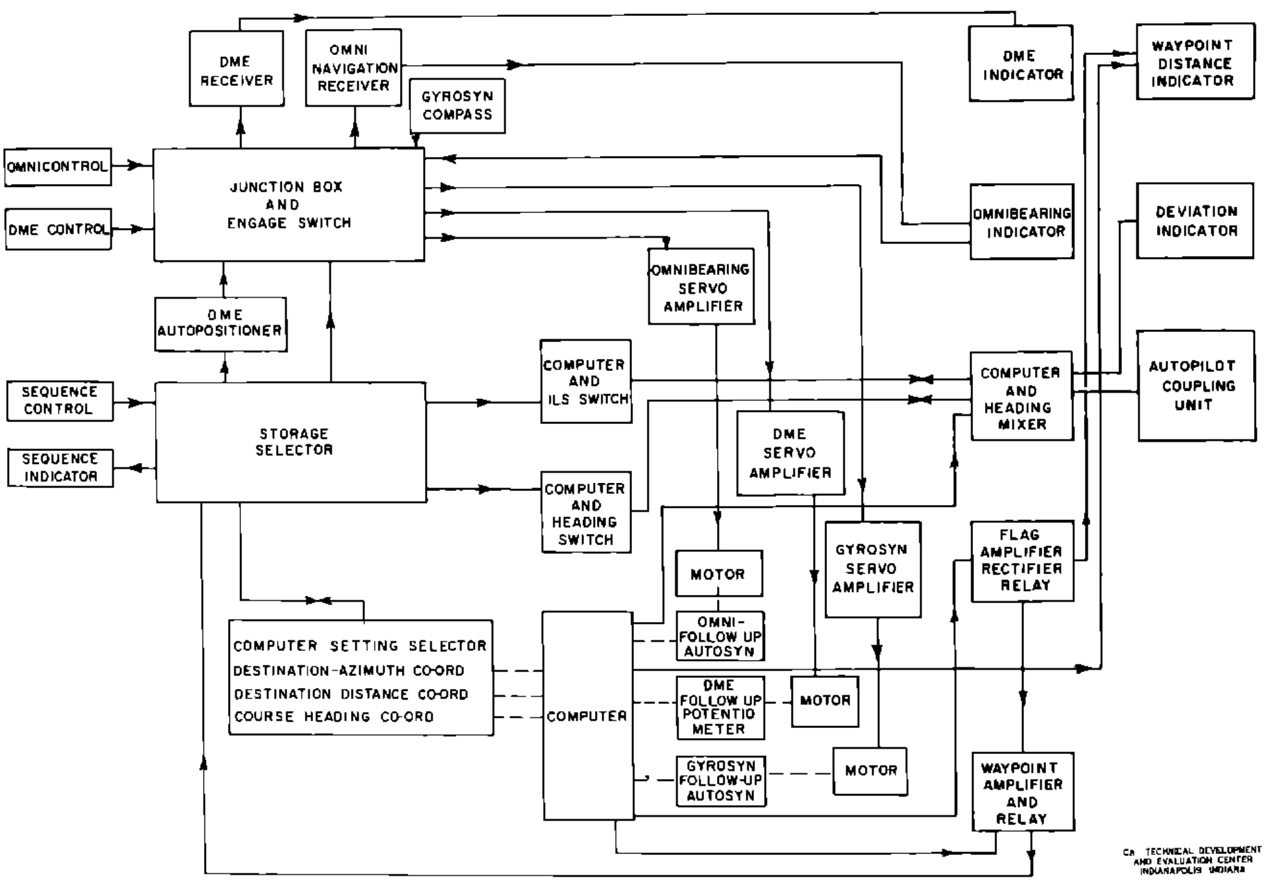

Fig. 8 Block Diagram of CAA Type II Automatic Flight and Navigation Equipment

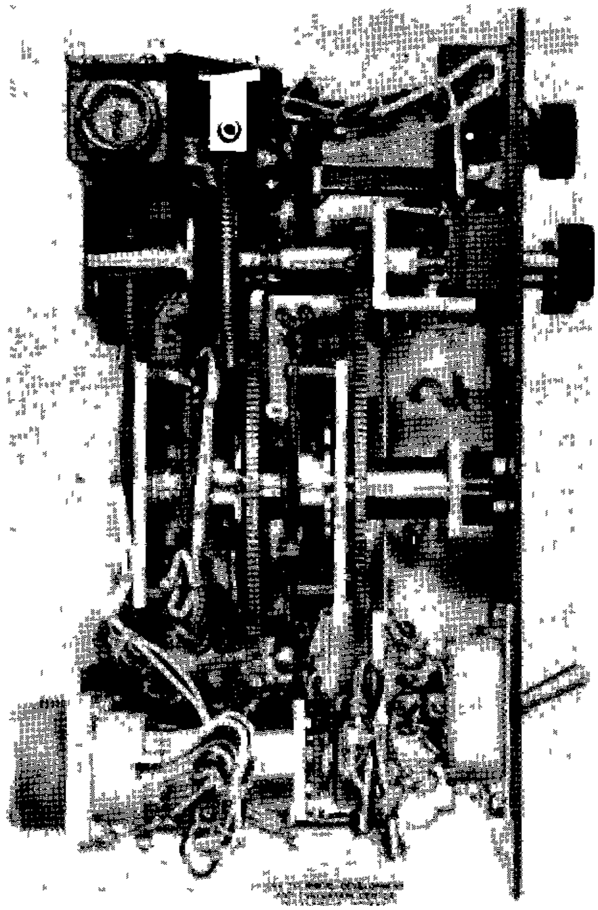

Fig. 9 Control Head, Side View
With Dust Cover Removed

indicator. The storage tape is 10 11/16 inches wide, and each course requires 5/8 inch of tape length. The 300 courses require a tape 15 feet, 7 1/2 inches long.

The next four groups (3, 4, 5, and 6) of spaces on the storage tape store data for tuning the associated equipment. Taken in order, they tune the DME responder, the DME interrogatoı the navigation receiver to even-number megacycles, and the navigation receiver to 0.1 megacycles. Another punch in the rear row of the 76th space is required in addition to the even-number-megacycle data when the navigation receiver is tuned to an odd-megacycle frequency.[4]

The next six groups (7, 8, 9, 10, 11, and 12) of spaces store the course-line-computer data for the course, the waypoint-azimuth co-ordinate, and the waypoint-distance co-ordinate.

The next three groups (13, 14, and 15) were intended to be used to store data for automatically selecting charts to be used in an associated pictorial display. This feature was not used. The storage capacity was sufficient for 17,576 different charts.

The 16th group was composed of four spaces. It was unnecessary to use any of these spaces in the manner the equipment was set up and operated.

The last five spaces were punched to provide auxiliary control functions not readily set

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[4]"51-R3 VHF Navigation Receiver," Collins Radio Company instruction book, Cedar Rapids, Iowa.

TABLE II

POSSIBLE COMBINATIONS OF FOUR WIRES
(Taken 0, 1, 2, 3, and 4 at a time)

Wire Number	Combination Number															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	O	X	O	O	O	X	X	X	O	O	O	X	X	X	O	X
2	O	O	X	O	O	X	O	O	X	X	O	X	X	O	X	X
3	O	O	O	X	O	O	X	O	X	O	X	X	O	X	X	X
4	O	O	O	O	X	O	O	X	O	X	X	O	X	X	X	X

e X indicates wire selected (grounded)
O indicates wire open

TABLE III

NUMBER OF POSITIONS AVAILABLE WITH MULTIPLE-WIRE POSITION SELECTORS

Number of Wires	Number of Positions
1	0
2	2
3	6
4	14
5	30
6	62
7	126
8	254
9	510
10	1,022

into the tape by the two-row-punch method. These functions include (1) computer course, 2) tone localizer, (3) glide-path frequency No. 3, (4) glide-path frequency No. 2, (5) glide-path ncy No. 1, (6) magnetic courses, (7) sequence beginning, (8) sequence ending, (9) holding rn, and (10) odd-megacycle frequencies for VOR. A definite space was assigned for each of these functions, and a hole was punched in those spaces that were applicable to a particular course.

Except for the spare group and the miscellaneous functions group, each group was de- d to control a position-setting mechanism through one of the multiposition wafer switches hown in Fig. 13. Fig. 14 shows the arrangement for a mechanism controlled by a four-space group. In this mechanism the fingers making contact to ground through one row of holes in the torage tape act as a selector switch, and the wafer switch on the positioning motor acts as a ition repeat-back. The mechanism operates on the principle that each combination of ounds that can be placed on the fingers of a given group will define a unique position of the repeat-back switch. Theoretically, a four-wire control could define 16 positions, as shown in Table II. In the mechanism shown in Fig. 14, this method is subject to some limitations.

Two of the positions cannot be used. These positions are Nos. 1 and 16 of Table II. If of the fingers are grounded, as shown in position No. 1, no energy is supplied to the detent noid (Fig. 14) or to the positioning motor, consequently, no operation takes place. In a r manner, if all the fingers are grounded, the repeat-back switch will stop in a position re all the wires are open. Thereafter, the punched tape cannot operate the detent solenoid or the positioning motor. Thus, for any multiple-wire positioning system, the number of posi- available for use is always two less than the theoretical number of combinations of that can be put on the wires. The number of positions available is given by the equation $= 2(n) - 2$, where p is the number of positions, and n is the number of wires corresponding to the number of spaces in each of the first 16 groups of the storage tape. The number of positions available by this method for up to ten wires is shown in Table III. If 75 wires were used in a single mechanism, then approximately 1.1803 X 10^{21} unique positions could theoretically be obtained. Breaking the storage space into a number of groups further reduces the number of positions available. As shown in Table I, none of the groups used all the storage available from the number of spaces in the group. Twelve of the groups were actually used in the operation of the equipment.

Although it reduced the over-all storage capacity, the dividing of the storage into small groups provided a comparatively simple means of setting a number of separate controls simultaneously. This advantage more than offset the loss of storage space.

The use of combinations of grounds to define unique positions as shown in Fig. 14 is subject to the selection of ambiguous positions. For the tape punched as shown in Fig. 14, no energy will be supplied to the detent solenoid or to the positioning motor when the wafer switch is in the position that brings blade position 13 under wire 2 and blade position 14 under wire 3. This ambiguity is resolved by providing both the second row for punching holes in the storage tape and a second wafer on the switch as shown in Fig. 15. Holes for the combination of grounds to be used were punched in the front row, and all other spaces in the group were punched in the

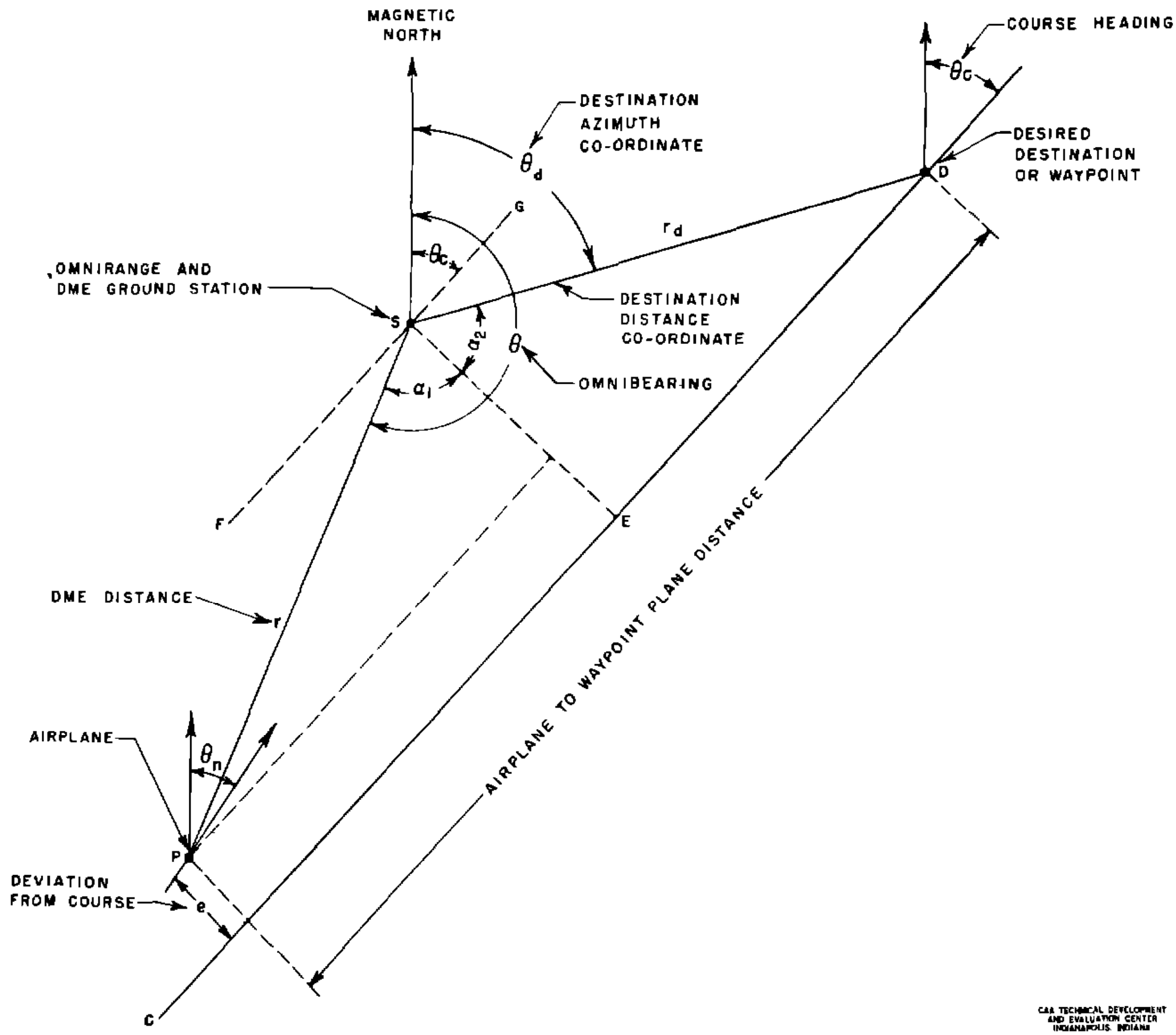


Fig. 10 Geometry of a Computed Path Using CAA Type II Automatic Flight and Navigation Equipment

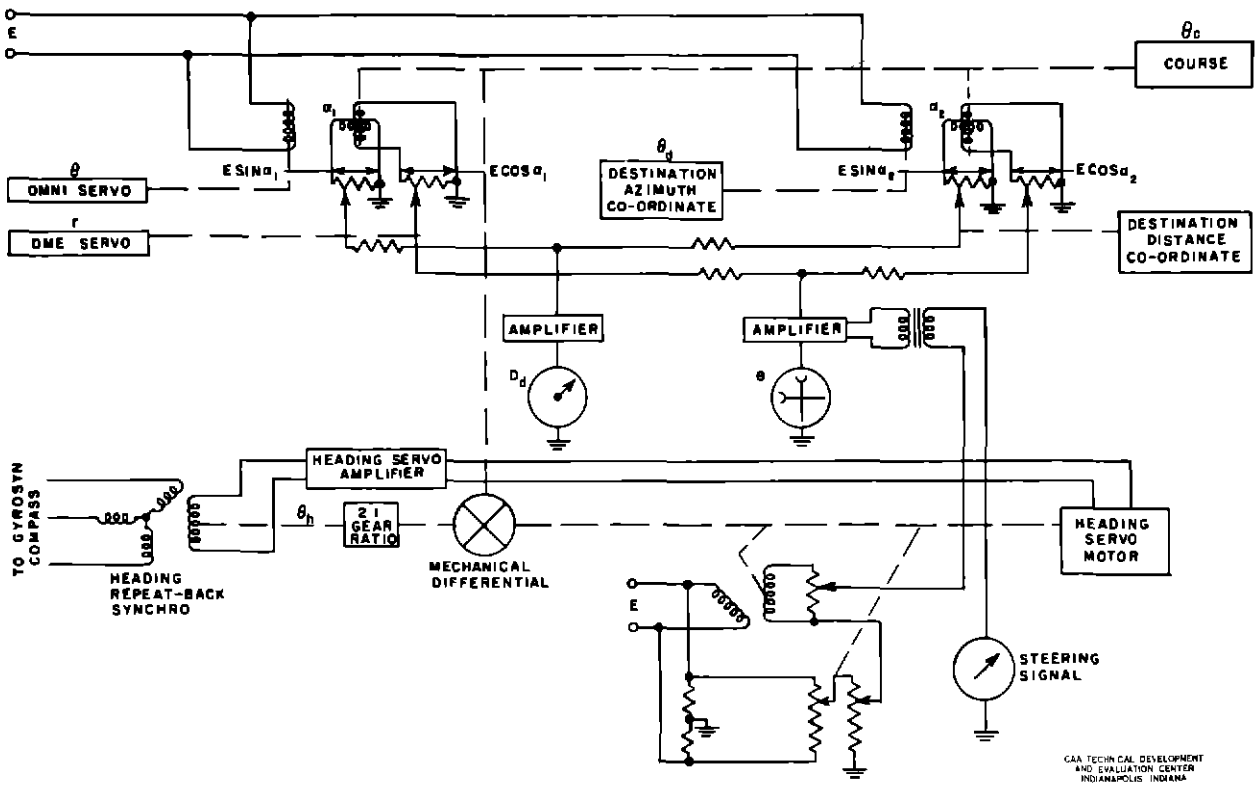


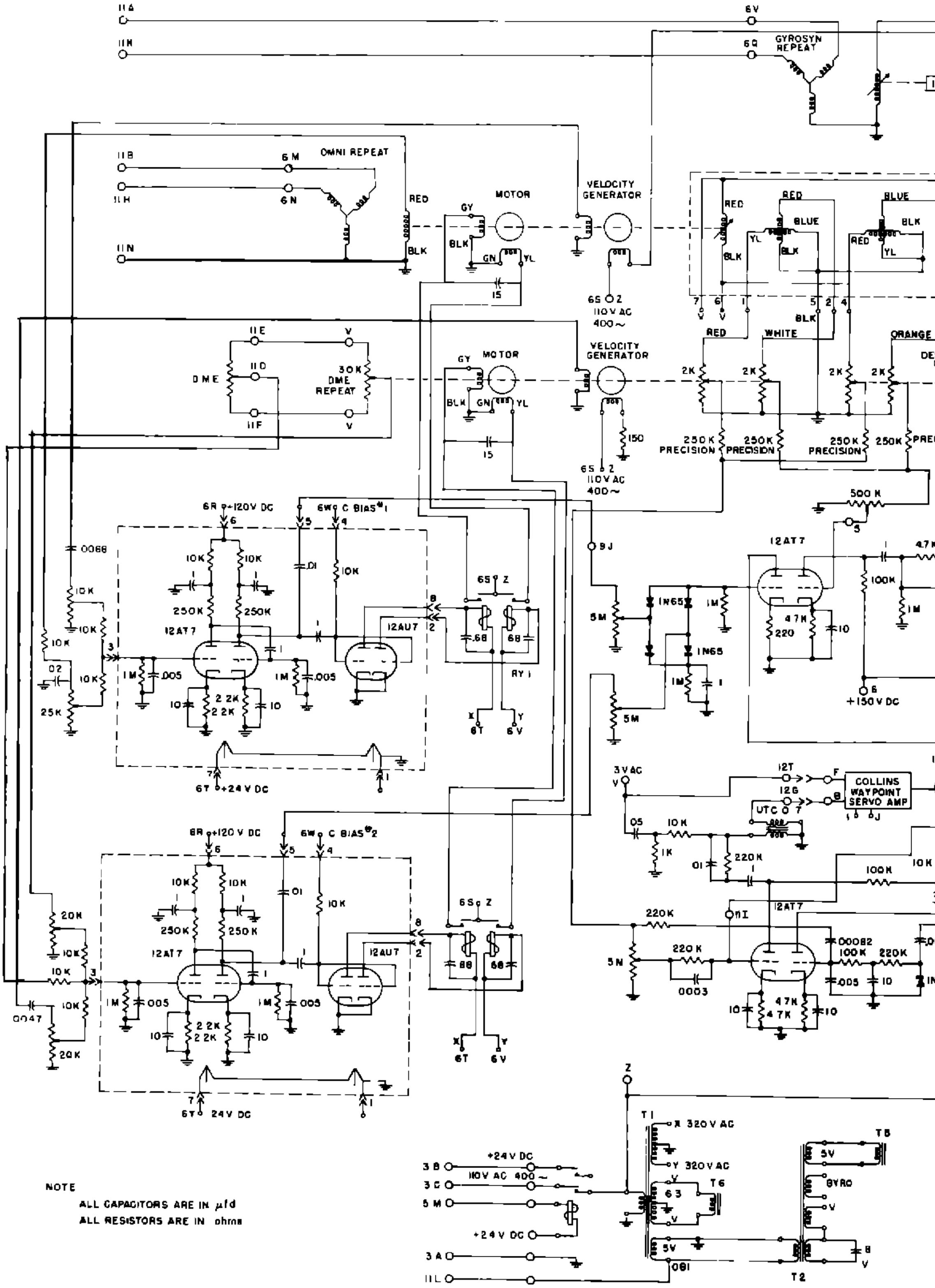
Fig. 11 Simplified Electromechanical Schematic Diagram of the Computing Circuits

rear row. The blade of the second or rear wafer switch was cut to be the reciprocal of the blade of the first or front wafer, and the wires were connected to corresponding contacts on the two wafers. Thus, wires on the front wafer and making contact with the blade were not connected to the blade of the rear wafer. With this arrangement, the wires were connected into two separate groups when the switch was in the position corresponding to the punchings in the storage tape. In most wafer positions which do not correspond to the punching in the storage tape, current will flow through one wire or through two wires in parallel and directly to ground through the storage contacts. In the potentially ambiguous switch position shown in Fig. 16, the current in the wires is as shown by the arrows, flowing from the front-switch wafer through wire 4 to the rear row of storage contacts, through wire 1 to the rear-switch wafer, and through wires 2 and 3 in parallel to the front row of storage contacts to ground.

A further restriction of the design pertains to the design of the switch wafer. The code for the consecutive positions must be laid out so that the wafer switch can progress from one position to another without repeating a given code for two positions. When the design uses all of the positions available for the number of wires or storage spaces, the layout is quite straightforward. But when the number of spaces used is less than the number available, care must be exercised in laying out the wafer if the switch is to operate continuously in one direction, and it is not possible to design a wafer for some numbers of positions. For example, a wafer for continuous operation in one direction, having 13 evenly spaced positions, and using four wires cannot be designed.

Thus, each group of spaces required a special design for the function it was to perform. The course-line number switch for tens of megacycles is a 30-position, 5-wire unit using all the positions available. The course-line-number units switch is a 10-position, 4-wire unit. The wafer was designed so that four of the possible combinations of four wires were not used. Figs. 17 and 18 are schematic diagrams of these two units. The same type of rotor and stator was used for both of these units, the contacts being installed in every third position for the ten-position switch.

The codes for the DME responder and interrogator were set up according to the Collins Radio Company's four-wire tuning system. The DME that was used requires one of a group of

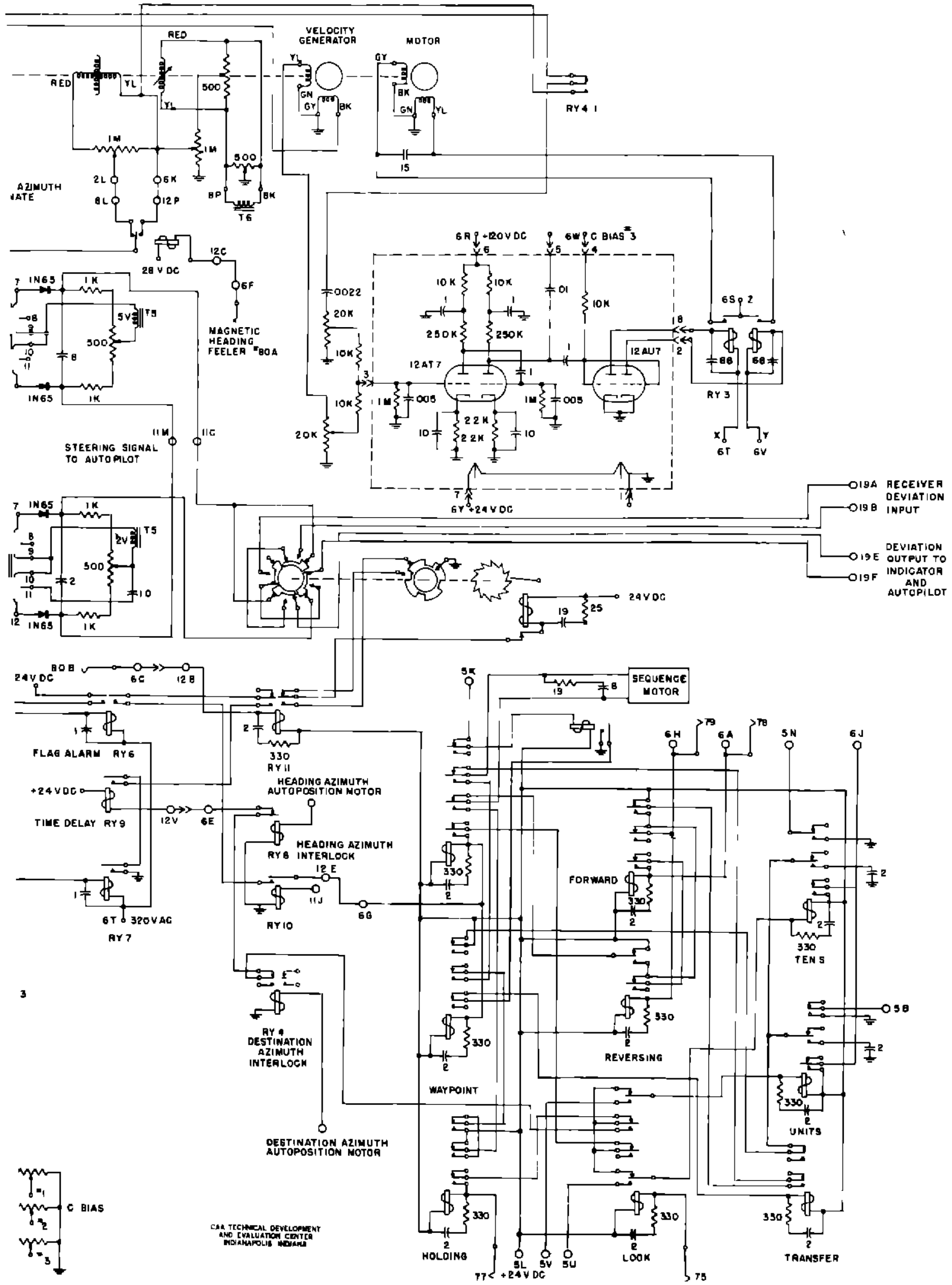


NOTE

ALL CAPACITORS ARE IN μfd

ALL RESISTORS ARE IN ohms

Fig. 12 Schematic Wiring Diagram of



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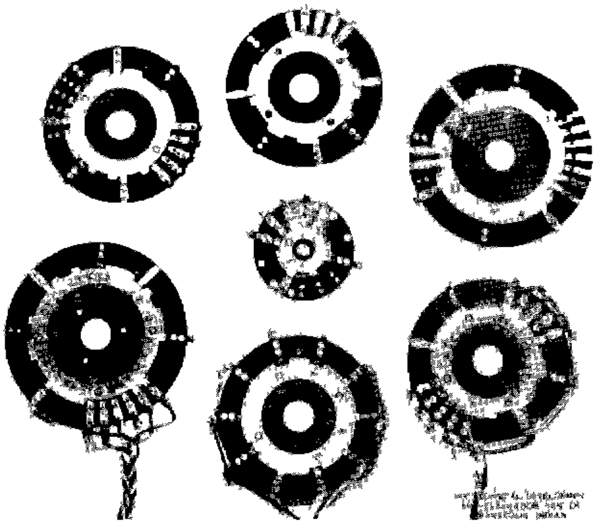


Fig. 13 Multiposition Wafers

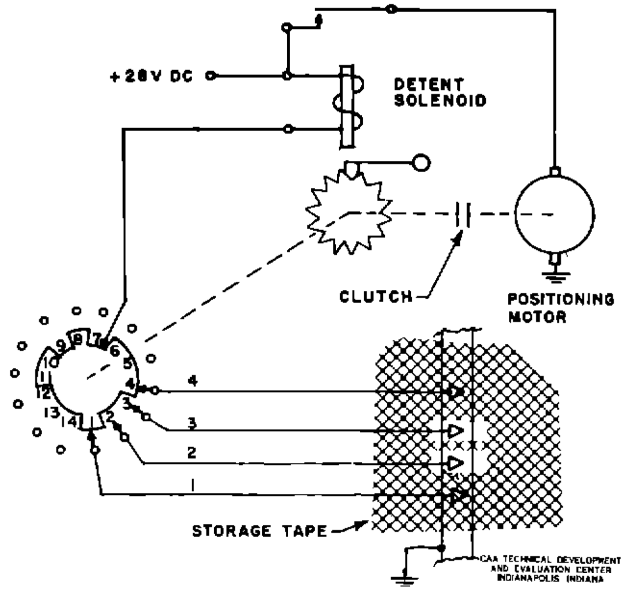


Fig. 14 Schematic Diagram of Simplified Four-Wire Position-Setting Switch and Mechanism

ten wires to be grounded to tune the responder and one of another group of ten wires to be grounded to tune the interrogator. Two devices for converting from the four-wire to the ten-wire system were built. The first uses a four-wire positioning switch to position a single-pole wafer as shown in Fig. 19. The second method uses four 4-pole relays in the circuit shown in Fig. 20.

The code for tuning the navigation receiver is the same as that used in the navigation-receiver control box. At first, the tuning control wires were connected directly to the storage unit. The current in the control wires was so heavy that the contacts on the storage unit were damaged. To correct this, buffer relays were installed between the storage unit and the navigation receiver.

The course control and the waypoint-azimuth co-ordinate control, shown schematically in Figs. 21 and 22, were identical and interchangeable units. The tens-of-degrees switch was a uniformly spaced, 36-position, 6-wire mechanism. The switch rotor was connected directly to the appropriate part of the course-line computer, and the stator was geared to the 1/2-degree control through a 20 1 reduction gear. In the equipment, the output shaft of the course control was hollow and the shaft of the waypoint-azimuth co-ordinate positioned the rotor of the waypoint resolver through the center of the course-control shaft. Thus, six spaces in the storage tape were used to set each of the controls to the nearest ten degrees of the desired value. The design of the switch blades was such that only 36 of the possible 62 positions for a 6-wire code were used. The one-half-degree setting switches were made up on the same rotor and stator parts as the tens-of-degrees units. Twenty positions, spaced ten degrees apart and using a five-wire code, were provided in these units. Two limit switches which reversed the positioning motor were mounted on the switch. The switch stator was mounted to the frame of the unit. The rotor was geared through a 20 1 reduction gear to the stator of the tens-of-degrees control. Thus, five spaces in the storage tape were used to set each of the controls to the nearest one-half degree over an arc of ten degrees.

The switches in the waypoint-distance co-ordinate control, shown schematically in Fig. 23, use the same type switch parts as those used in the route-selector switches. The tens-of-miles switch is a ten-position, four-wire unit on a wafer designed for 30 positions, while the half-mile switch is a 20-position, five-wire unit on the same type wafer but with the positions spaced 12 degrees apart and with reversing switches at the limits of travel. The stator of the half-mile switch is mounted to the frame of the unit, and the rotor drives the stator of the tens-of-miles switch through a 6 2/3 1 reduction gear. The rotor of the tens-of-miles switch drives the shaft of a dual 0.1-per cent linearity potentiometer which is part of the course-line computer.

TABLE IVa

COMPUTER DATA FOR FLIGHT IN INDIANAPOLIS AREA

Description of Course Line	Course Line	DME Channel	VOR Frequency (Mc)	Course (degrees)	Waypoint Azimuth Co-Ordinate (degrees)	Waypoint Distance Co-Ordinate (miles)	Miscellaneous
Brownsburg to Muncie	1	83	116 3	63 5	63 5	50 4	Sequence Begins clc*
Muncie to Kokomo	2	83		296 0	15 5	40 5	clc
Kokomo to Lafayette	3	83		266 5	324 5	44 5	clc
Lafayette to Brazil	4	83		190 0	243 5	40 0	clc
Brazil to Bloomington	5	83		125	189 0	39 0	clc
Bloomington to Greensburg	6	83		78 0	125 0	49 5	clc
Greensburg to Anderson	7	83		349 0	61 5	36 0	clc
Anderson to Frankfort	8	83		286 0	347 5	29 8	clc
Frankfort to Greencastle	9	83		203 0	246 0	25 0	clc
Greencastle to Franklin	10	83		104 5	144 5	25 0	clc
Franklin to Noblesville	11	83		4 0	52 0	21 6	clc
Noblesville to Lebanon	12	83		272 0	342 0	14 9	clc
Lebanon to Mooresville	13	83		117 5	181 5	12 5	clc
Mooresville to Airport	14	83		31 0	142 5	6 5	clc
Airport to Mooresville	15	83		211 0	181 5	12 3	clc Holding
Mooresville to Hall	16	83		244 0	206 0	17 8	clc
Hall to Airport	17	83		0 0	0 0	0 0	Sequence Ends ILS

TABLE IVb

COMPLETE DATA FOR FLIGHT FROM INDIANAPOLIS TO DAYTON AREA AND RETURN TO INDIANAPOLIS

Description of Course Line	Course Line	DME Channel	VOR Frequency (Mc)	Course (degrees)	Waypoint Azimuth Co-Ordinate (degrees)	Waypoint Distance Co-Ordinate (miles)	Miscellaneous
Indianapolis to Connersville	1	83	116 3	83 0	98 5	57 5	Sequence Begins clc*
Connersville to Liberty Inter	2	91	117 1	82 0	210 0	14 0	clc
Liberty Inter to Greenville	3	91	117 1	328 0	296 0	21 0	clc
Greenville to Muncie	4	91	117 1	279 0	284 5	55 5	clc
Muncie to Indianapolis	5	83	116 3	235 5	143 0	6 5	Sequence Ends

*course line computer

THE PUNCH

Data compiled for typical flights are shown in Tables IVa and IVb. These data are converted from decimal to binary form by the keyboard of the punch shown in Fig. 24. The keyboard has a column of keys for each group of spaces used in the storage tape. Each column has as many keys as there are different bits of data for that group. This corresponds to the number of positions used for each of the positioning switches and to the number of frequencies available in each of the tuning groups. Each column of keys has associated with it a group of bars and punches. The number and sequence of bars and punches correspond to the number and sequence of the spaces in the groups of the storage tape. The foot of each key reaches

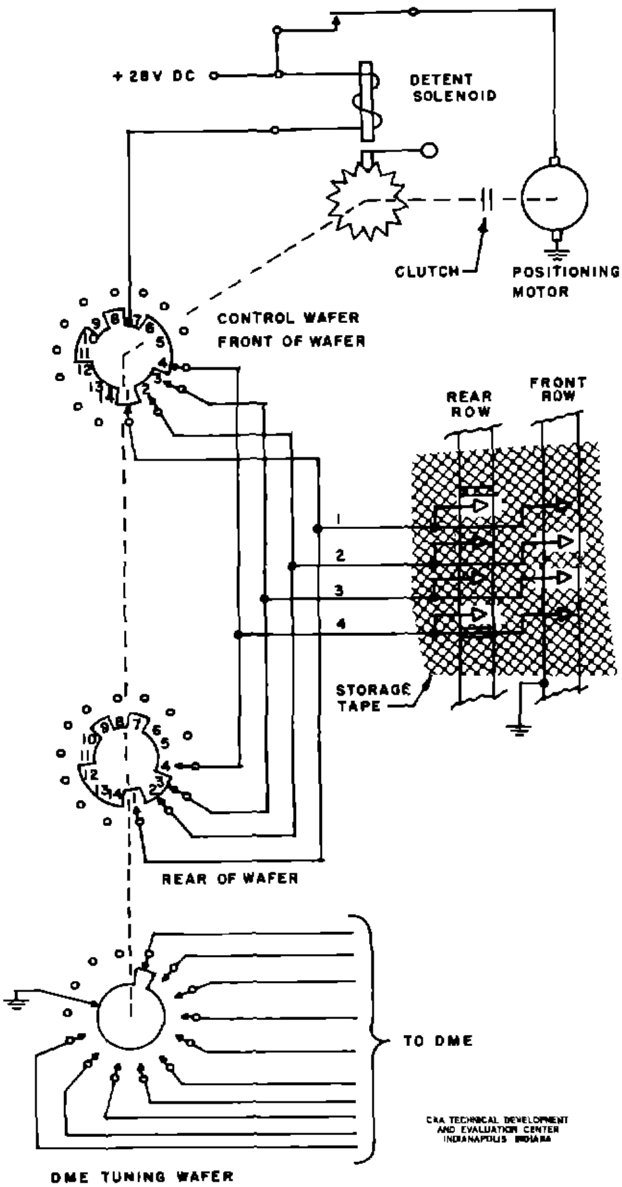


Fig. 15 Schematic Diagram of Simplified Four-Wire Position-Setting Switch and Mechanism Showing Wafers in Position Corresponding To Punching in Storage Tape

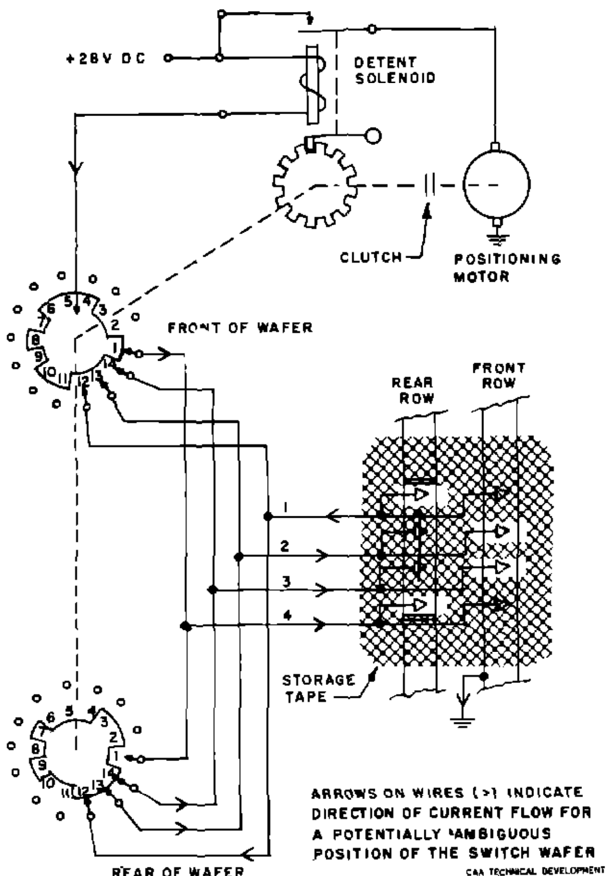
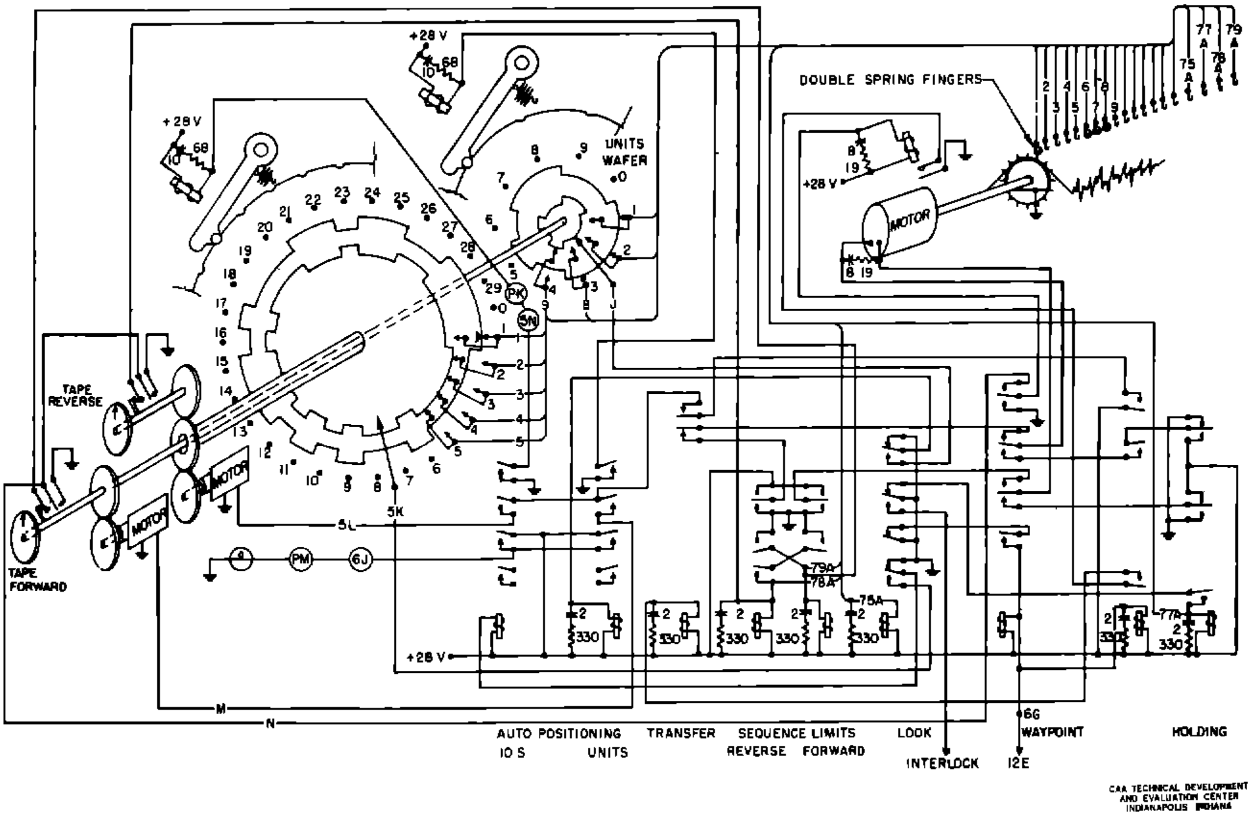


Fig. 16 Schematic Diagram of Simplified Four-Wire Position-Setting Switch and Mechanism Showing Method of Resolving Ambiguous Positions



WIRE	SEQUENCE CONTROL POSITION 10 S WAFER																													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
1	O	X	X	X	X	O	O	X	X	O	X	X	O	O	O	X	O	X	X	X	O	X	O	X	O	O	X	O	O	O
2	O	O	X	X	X	X	O	O	X	X	O	X	X	O	O	O	X	O	X	X	X	O	X	O	X	O	O	X	O	O
3	O	O	O	X	X	X	X	O	O	X	X	O	X	X	O	O	O	X	O	X	X	X	O	X	O	X	O	O	X	O
4	O	O	O	O	X	X	X	X	O	O	X	X	O	X	X	O	O	O	X	O	X	X	X	O	X	O	X	O	O	X
5	X	O	O	O	O	X	X	X	X	O	O	X	X	O	X	X	O	O	O	X	O	X	X	X	O	X	O	X	O	O

WIRE	UNITS WAFER									
	1	2	3	4	5	6	7	8	9	0
6	X	O	O	X	X	O	X	O	X	X
7	X	X	O	O	X	X	O	X	O	X
8	X	X	X	O	O	X	X	O	X	O
9	X	X	X	X	O	O	X	X	O	X

NOTE

SWITCH WAFERS SHOWN IN POSITION NO 1

X'S IN TABLE DESIGNATE PUNCHED HOLES IN STORAGE TAPE FOR GROUNDING WIRES INDICATED

O'S IN TABLE INDICATE LEADS CONNECTED TO J AND K RESPECTIVELY FOR A GIVEN POSITION

Fig. 17 Preliminary Schematic Wiring Diagram of Sequence-Control, Storage Selector, and Storage Unit

across all the bars in its column. The bars were prepared with a stop for each key. The decimal-to-binary code conversion was made by cutting off the stops on the bars that are to be grounded for a given switch position. The die used in punching the tape is equipped with two rows of holes. The first 75 holes are equipped with a punching blank that can be moved from one to the other of the rows. The operating steps in the preparation of a tape are as follows

1. With a blank tape in the punch, sprocket holes for a leader on the tape are punched. The punch handle is equipped with two locks. The releasing of the first lock permits the punching of sprocket holes in each edge of the tape on the forward stroke of the handle and advances the tape one position on the return stroke. About twenty spaces are sufficient for a leader.
2. With the handle in the ready position, data for the first course line are entered into the keyboard by pressing down the proper key in each column. The setting of the keys should be checked carefully, and any error should be corrected by pressing down the correct key. The sequence-begin key should be pressed for the first course.
3. The second lock on the operating handle is released.
4. The punch handle is operated. As the handle moves forward, the bars and punching blank are carried forward by spring pressure. Those bars with stops at the depressed key are stopped so that the holes are punched in the first row of the tape. Those bars without stops travel to the rear so that the holes are punched in the second row. In the miscellaneous group, one hole is punched for each key that is pressed. All bars and punches are

positioned, and all holes, including sprocket holes, are punched on the forward stroke of the handle. On the return stroke, the punching blanks are lifted out of the die and all bars are returned to the ready position. Also during the return stroke, the tape is advanced to the next punching position. At the end of the return stroke, the handle is locked into position.

5. The keyboard is cleared by operating the key-release levers. This returns the punch to its ready position.
6. Steps 2 to 5, inclusive, are repeated for each course to be set into the storage. Data for the last course must include the sequence-end punch.
7. An end leader is punched by making about 20 additional sets of sprocket holes. The tape is now ready to be removed from the punch and installed in the storage unit

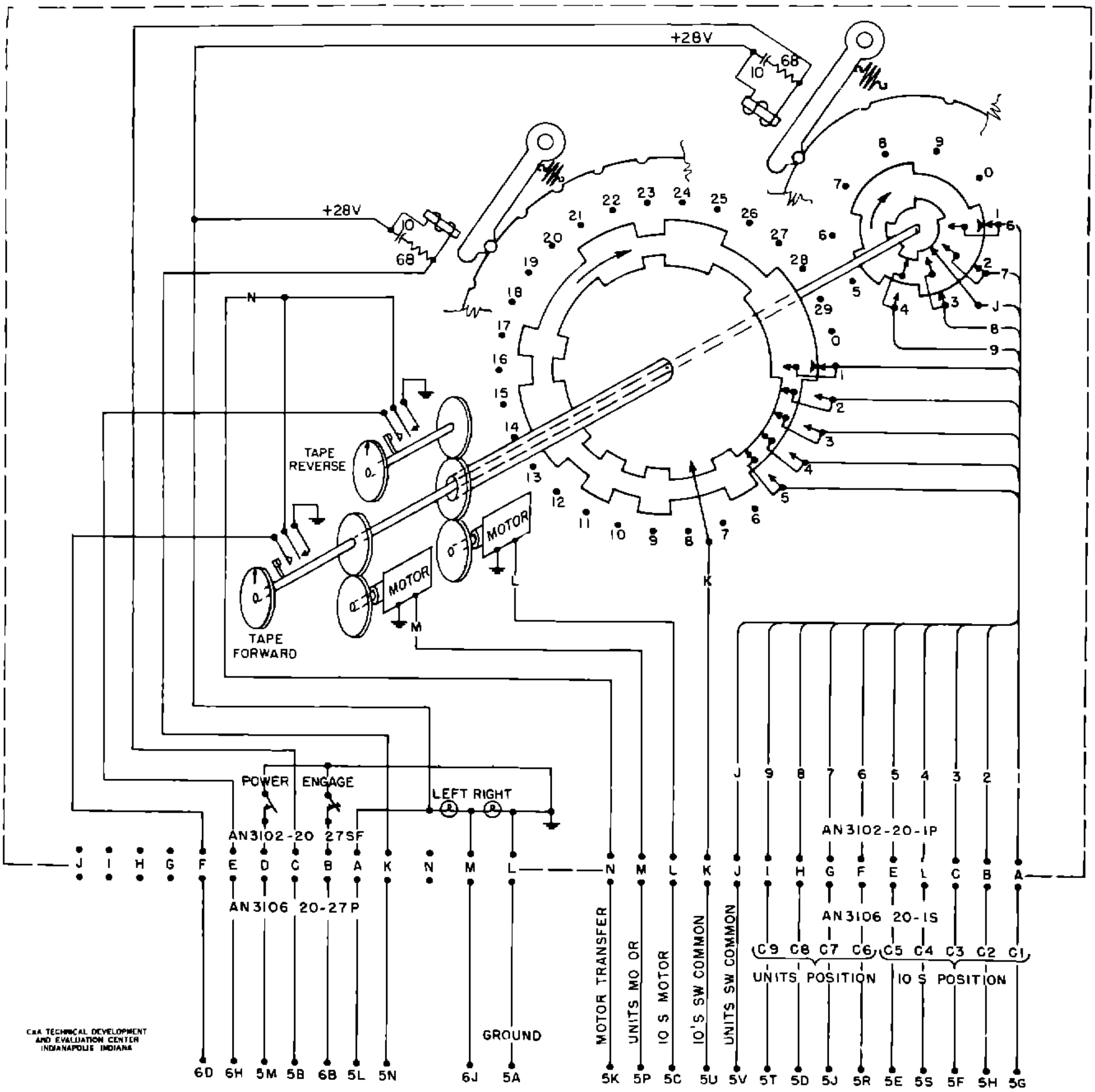


Fig. 18 Schematic Wiring Diagram of Control Box

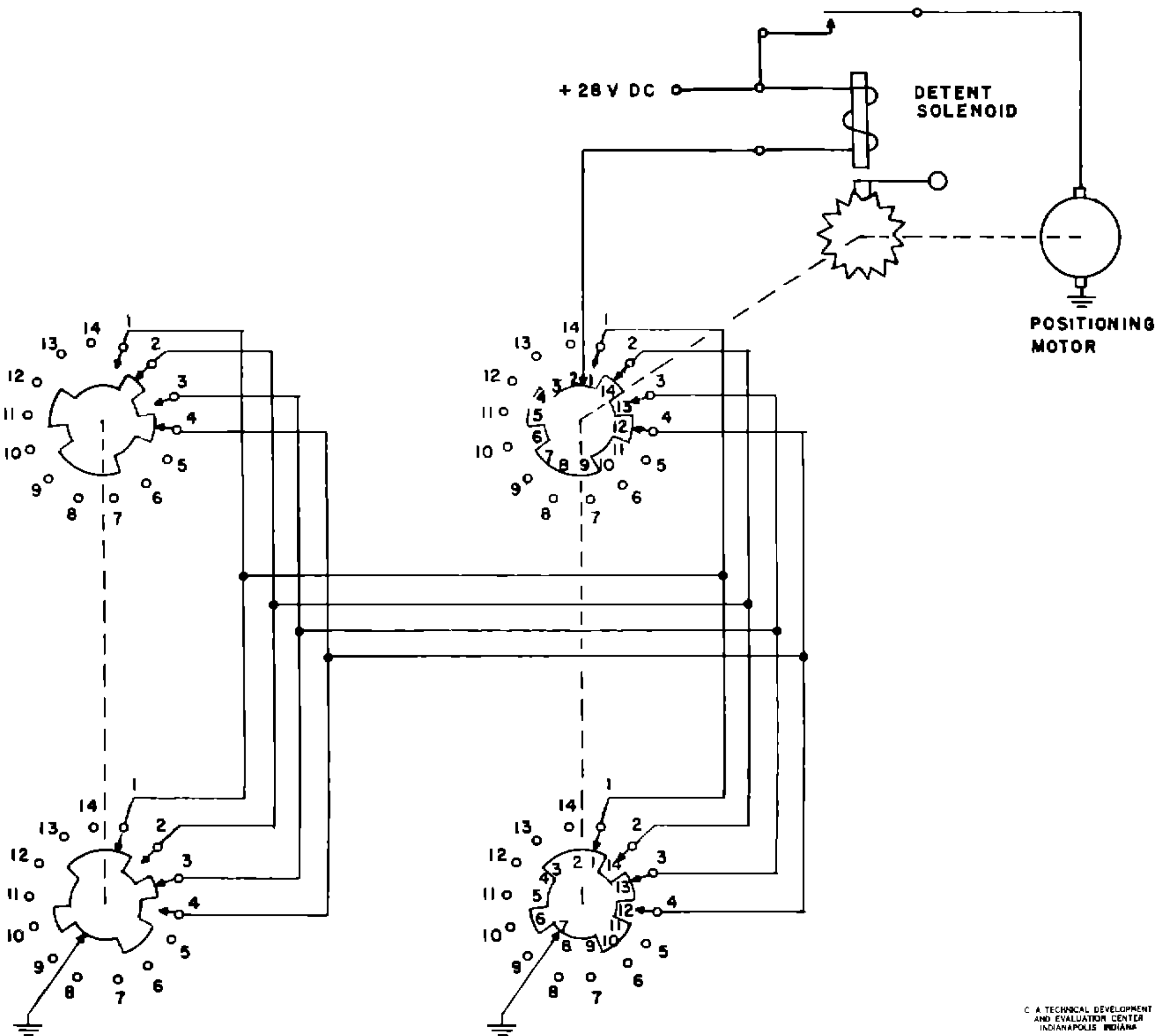


Fig. 19 14-Position, 4-Wire Autopositioner

TESTS AND RESULTS

Adjustment and Calibration.

After the computer was fully assembled and the co-ordinate dials and synchros were oriented as described in Technical Development Report No 152, the computer was fed simulated signals from a test set, Fig. 25, which furnished calibrated omnibearing-distance (OBD) and heading signals All functions were made to operate satisfactorily while this simulator was used Courses were followed on the simulator map, and the errors were corrected

Observed Computer Accuracy in Laboratory-Test Set-Up.

Maximum errors (most of the error was due to driving-gear backlash)

a Distance repeat-back ±0 25 mile
b Bearing repeat-back ±0.3°
c Heading repeat-back ±0 3°
d Distance to waypoint ±0 5 mile
e Course width (maximum sensitivity) +3 miles, -3 1/2 miles
f Airplane heading 15 miles off computer course +100°, -80°

Flight Tests.

The CAA Type II automatic flight and navigation equipment was installed in a DC-3 airplane, N-182, in May 1953. A change-over switch was installed to transfer control equipment and signal sources from the existing equipment to the storage unit in the computer.

The first flight was May 27, 1953. The flight was for calibration and had no favorable results. Three more calibration flights were made, one on June 1, another on June 10, and one on June 11. The fifth flight, made on June 15, completed a very successful test. The autopilot remained engaged during a complete circuit of four waypoints.

Fig. 26 is a reproduction of the flight path made during two round trips. The solid line represents one trip with approximately no magnetic-heading information up to ±30° of the desired course. The broken line represents a trip with approximately no magnetic-heading information up to ±10° of the desired course. As shown in these two flights, the addition of some heading signal even close to the computer course is desirable for improved stability in an automatic navigational flight. Fig. 27 is a reproduction of a flight path from Indianapolis to the vicinity of Dayton, Ohio and return.

CONCLUSIONS

1. The CAA Type II automatic flight and navigation equipment demonstrates conclusively the technical practicality of automatic flight along a sequence of preselected course-line-computer courses.
2. The use of stored data and of automatic sequencing reduces the pilot's workload when he is using a course-line computer and, thereby, extends the use of the computer to the terminal-area holding pattern or to the ILS approach. Pilot reaction to this feature was especially favorable.
3. The storage unit demonstrates the practicality of storing flight data in a unit suitable for use in DC-3 or larger airplanes.
4. The technique of determining a unique position by means of multiple grounds on a group of wires is well suited to the punched-tape data-storage method.
5. The punch, arranged with a data-conversion keyboard, provides an accurate and easily used method of converting data from decimal to binary form and of storing the data in a tape storage.
6. The accuracy that can be expected from a course-line computer is fairly well established. The Type II equipment provides an additional advantage in that the data are set in mechanically and, therefore, more accurately than can be done manually under

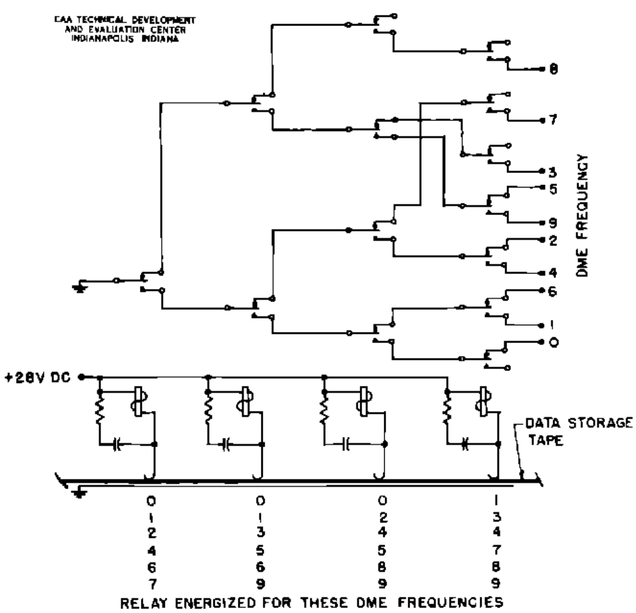


Fig. 20 Relay-Type DME Tuning Converter

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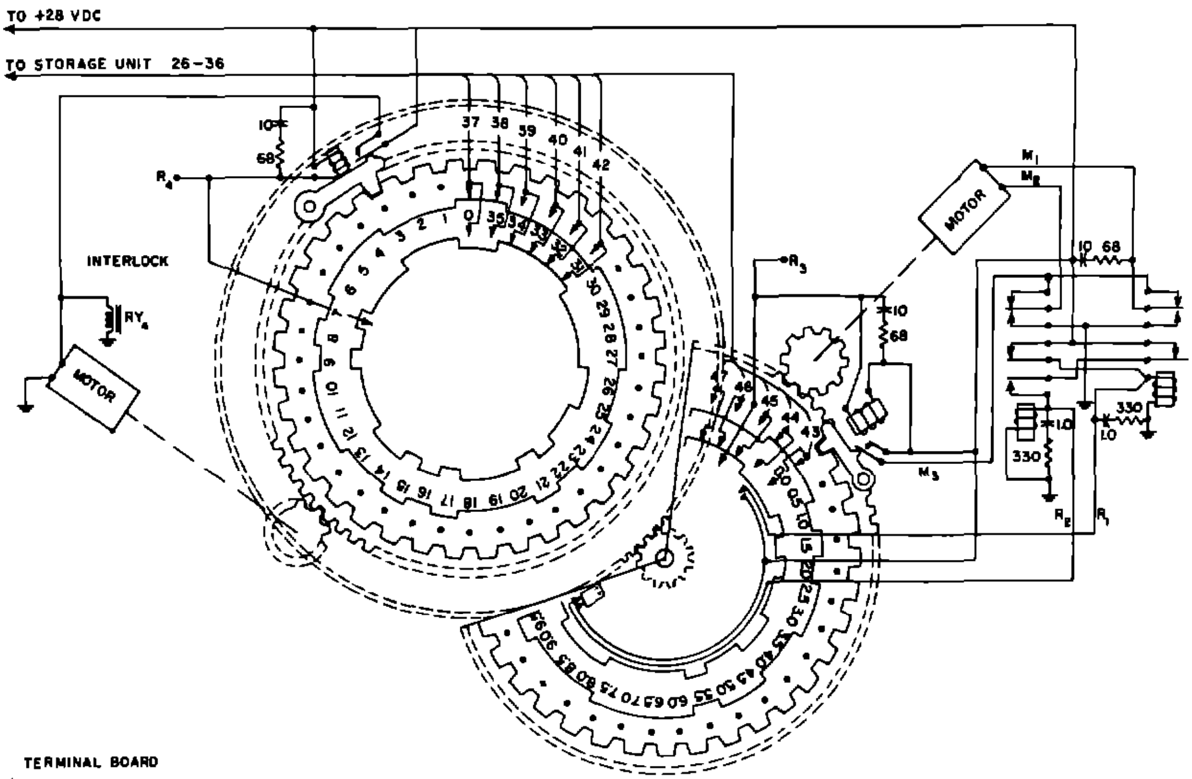
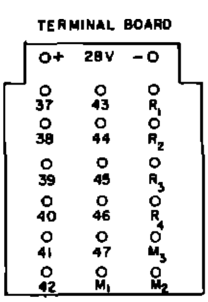
normal flight conditions.

7. Since the shafts of the computer are positioned by a pawl-and-rachet mechanism, the accuracy with which the data can be set into the computer depends upon the accuracy of the rachet and associated gearing. With present machine-shop techniques, accuracies of one minute of arc are easily obtained. Thus, the gearing error is small when compared with the electrical errors in the computing resolvers (about 15 minutes spread) or with the errors in the omnibearing data.
8. The combination of heading signal and rate signal provides a much better damping signal for automatic flight on wide courses than does the use of rate signal alone.





NOTE
WAFERS SHOWN IN POSITION 000
XS IN TABLE INDICATE STORAGE TAPE PUNCHED TO GROUND INDICATED WIRE
OS IN TABLE INDICATE WIRES CONNECTED TO POSITIONING RELAY

WIRE	10° WAFER POSITIONS																																			
	0	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
37	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X	O	O	O	O	X
38	X	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X	O	O	O	O
39	O	X	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X	O	O	O
40	O	O	X	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X	O	O
41	O	O	O	X	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X	O
42	O	O	O	O	X	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X

WIRE	0.5° WAFER POSITIONS																			
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
43	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O	O	O	X
44	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O	O	O
45	O	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O	O
46	O	O	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O
47	O	O	O	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X

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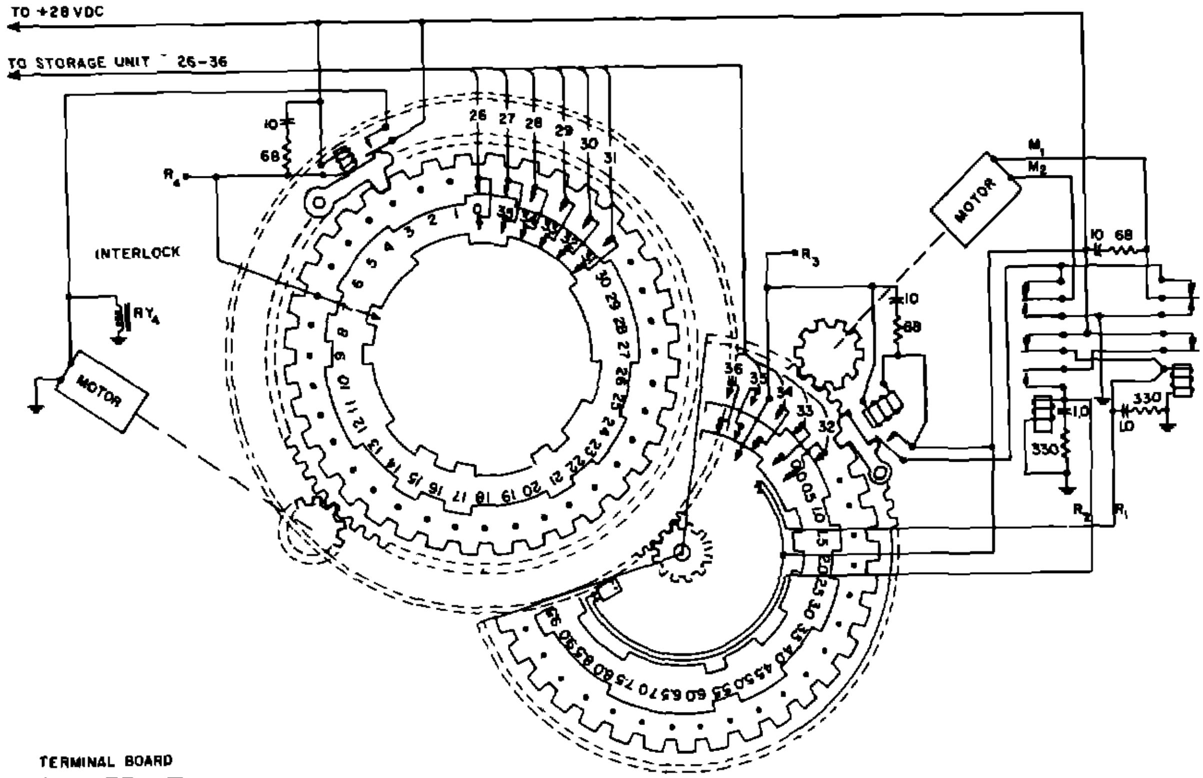
Fig. 21 Destination-Azimuth Co-Ordinate Selector



TERMINAL BOARD

O+	28V	-O
26	32	R_1
27	33	R_2
28	34	R_3
29	35	R_4
30	36	M_3
31	M_1	M_2

NOTE
WAFERS SHOWN IN POSITION 00.0
X S IN TABLE INDICATE STORAGE TAPE PUNCHED TO GROUND INDICATED WIRE
O'S IN TABLE INDICATE WIRES CONNECTED TO POSITIONING RELAY

10° WAFER POSITIONS

WIRE	0	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1
26	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X	O	O	O	O	X
27	X	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X	O	O	O	O
28	O	X	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X	O	O	O
29	O	O	X	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X	O	O
30	O	O	O	X	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X	O
31	O	O	O	O	X	X	O	O	O	X	X	X	O	X	O	X	X	X	O	O	X	O	X	O	O	O	X	O	X	X	O	O	X	X	X	X

0.5° WAFER POSITIONS

WIRE	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
32	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O	O	O	X
33	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O	O	O
34	O	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O	O
35	O	O	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O
36	O	O	O	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X

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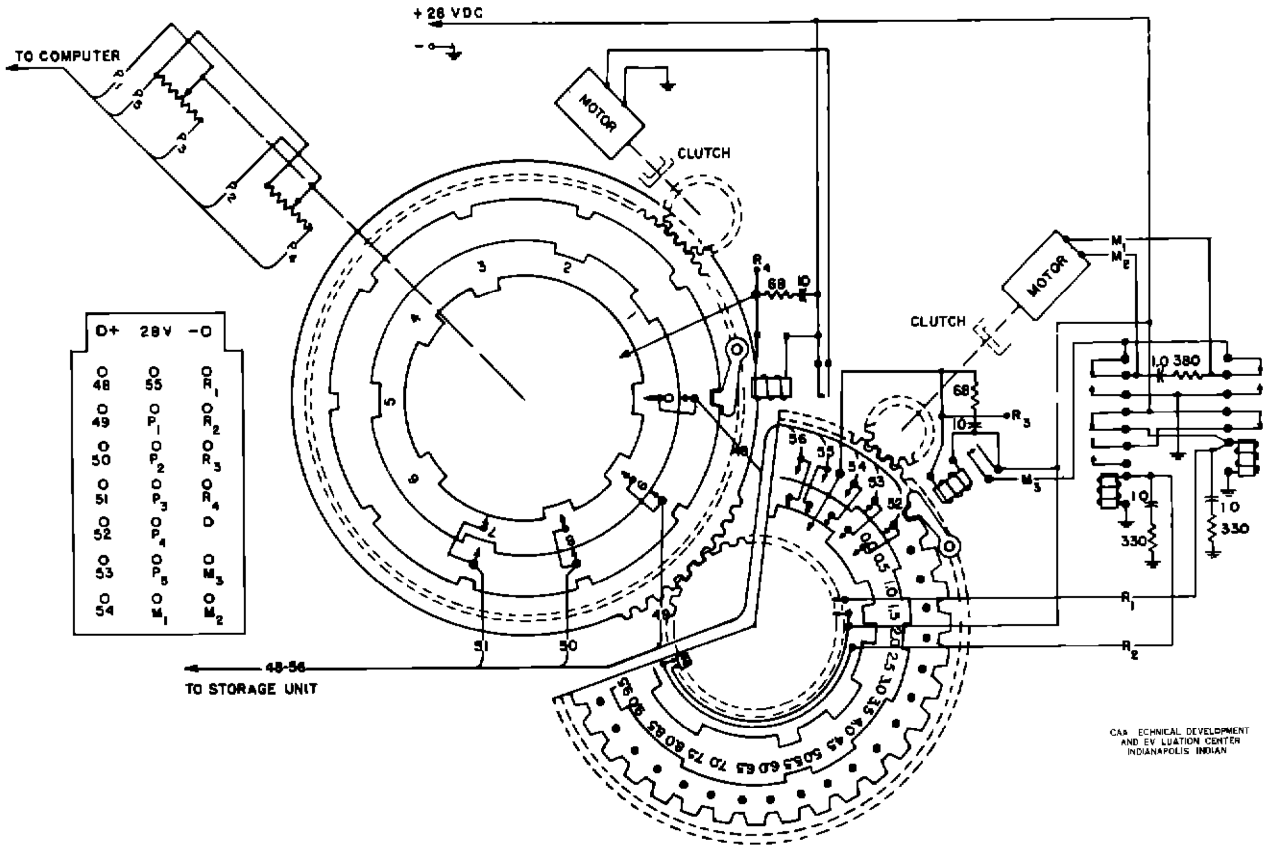
Fig 22 Preliminary Schematic Wiring Diagram, Course-Heading Selector



WIRE	10 MILE WAFER POSITIONS									
	0	1	2	3	4	5	6	7	8	9
48	X	O	O	X	X	O	X	O	X	X
49	X	X	O	O	X	X	O	X	O	X
50	X	X	X	O	O	X	X	O	X	O
51	O	X	X	X	O	O	X	X	O	X

WIRE	0.5 MILE WAFER POSITIONS																			
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5
52	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O	O	O	X
53	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O	O	O
54	O	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O	O
55	O	O	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X	O
56	O	O	O	X	X	X	O	X	O	X	X	O	O	X	X	O	X	X	X	X

NOTES

WAFERS SHOWN IN POSITION 00 0

XS IN TABLE INDICATE STORAGE TAPE PUNCHED TO GROUND INDICATED WIRE

O'S IN TABLE INDICATE WIRES CONNECTED TO POSITIONING RELAY

Fig. 23 Destination-Distance Co-Ordinate Selector

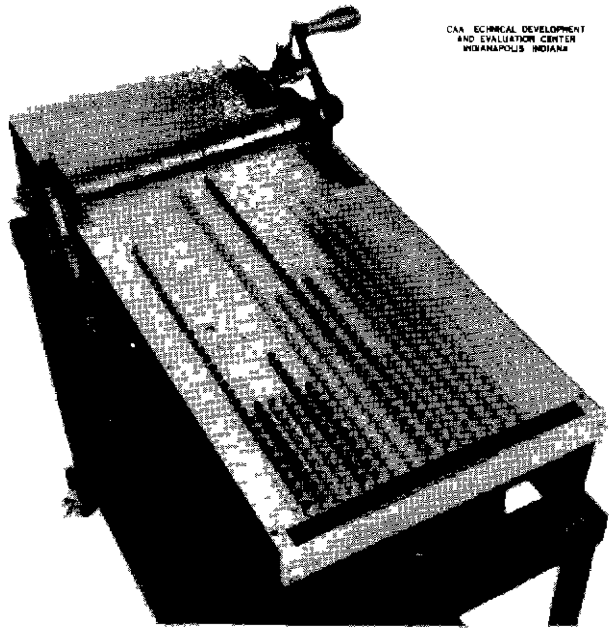


Fig. 24 Keyboard and Punch for Storing Computer Data in Tape, Top Oblique View

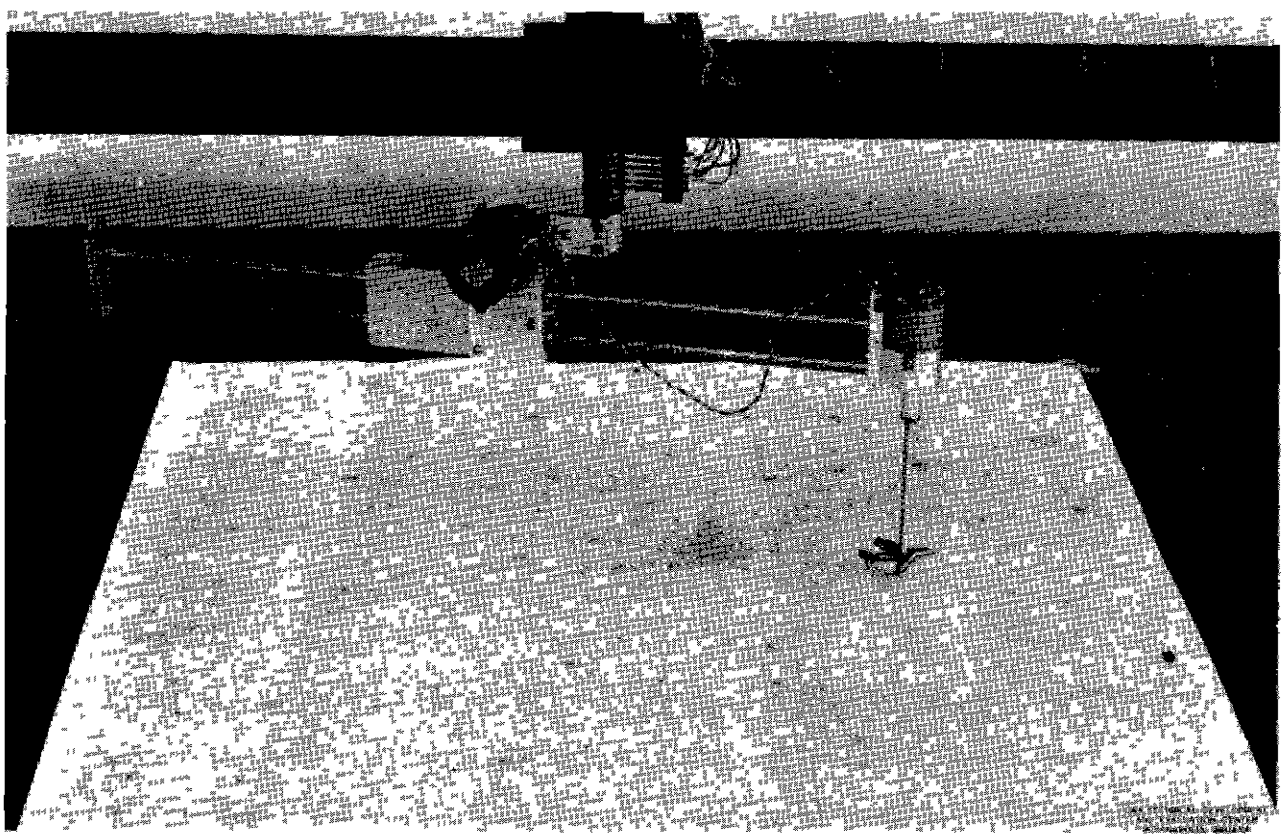


Fig. 25 Simulator Table for Omnibearing, Distance, and Heading

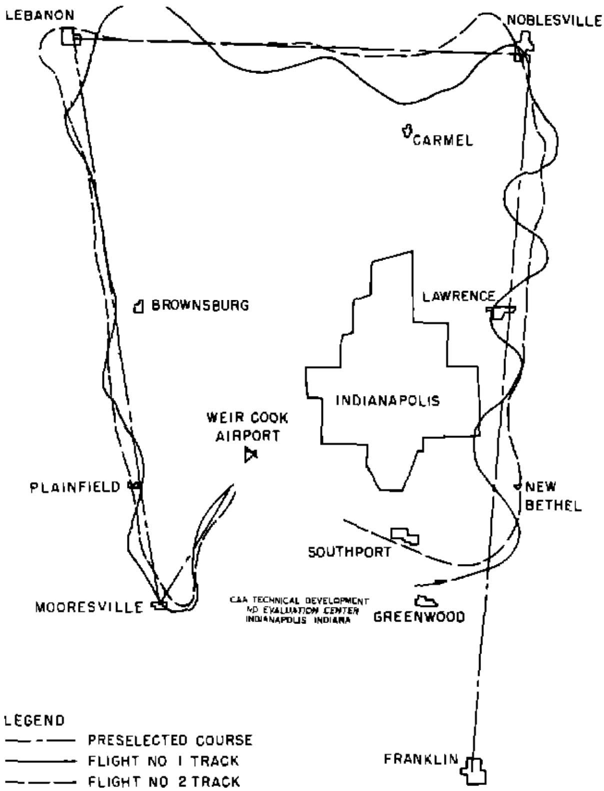


Fig. 26 Reproduction of Flight Path in Indianapolis Area

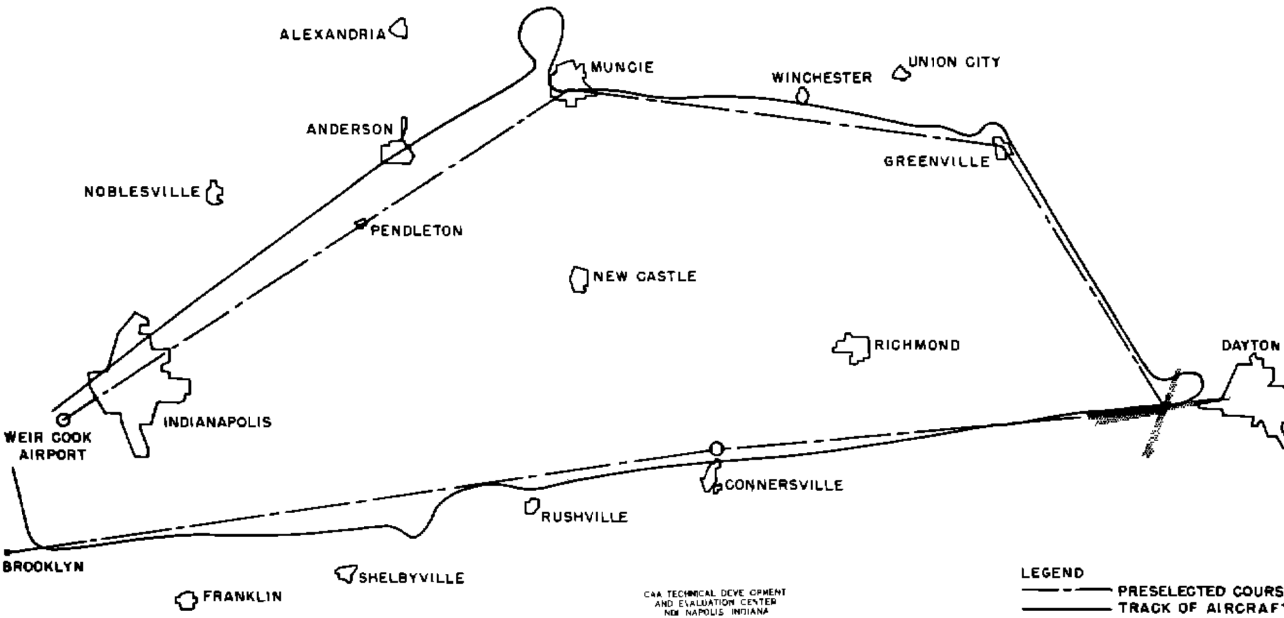


Fig. 27 Reproduction of Flight Path, Indianapolis-to-Dayton Area