INITIAL FLIGHT TESTS AND THEORY OF AN EXPERIMENTAL PARALLEL COURSE COMPUTER

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INITIAL FLIGHT TESTS AND THEORY OF AN EXPERIMENTAL PARALLEL COURSE COMPUTER

SUMMARY

This report presents the results of flight tests made with an experimental parallel course computer which was manufactured on contract for the CAA Office of Technical Development by the Minneapolis-Honeywell Regulator Company The maximum errors were found to be small enough to permit safe flight over parallel tracks of ten-mile separation Results of bench tests of the computer are also presented, and the theoretical relation between computer error and distance and bearing errors is explained

There will soon be available navigation receivers and distance measuring equipments built to more rigid specifications than those used in these tests, and as a consequence the errors of computer flying will be reduced to less than those shown in this report

INTRODUCTION

The parallel course computer is one type of course line computer Computers of this type are also known by the following names, course line computer, offset course computer, bearing distance computer, and R-θ computer The function of the computer which is discussed in this report is to accept bearing information from the omni range radio receiver and distance information from the airborne unit of the radar distance measuring equipment (DME) and to convert this information into simple track guidance directions for the pilot This computer also supplies a continuous indication of the distance along the track between the aircraft and a selected destination

Because there had been a great deal of theoretical and speculative discussion about computers, the CAA Office of Technical Development contracted with the Minneapolis-Honeywell Regulator Company to develop and construct an experimental computer suitable for making flight tests with the bearing distance facilities available at the Experimental Station at Indianapolis To expedite delivery, weight and space limitations were excluded from the specifications Also, the manufacturer was permitted to mount all but one of the indicator dials and controls in one unit which was to be mounted in the radio compartment of a DC-3 aircraft The exception was the course deviation indicator which was to be a standard Weston Model 888 Type 3 indicator mounted on the pilot's instrument panel. This is the standard cross-pointer instrument with flag alarm added The computer is illustrated in Fig 1 In future models all essential controls and indicators will be available to the pilot, and it is estimated that the amplifier unit will be compressed to the size of a standard one-half ATR.

OPERATION

The method of operating the computer can be best described with the aid of the trigonometric diagram of Fig 2. In setting the computer dials for a particular course the following operations are usually performed in the order listed

1 Draw the selected course line on the chart such as the heavy line through the destination in Fig 2

2. Measure the bearing of the course with respect to magnetic north. In Fig 2 this is the angle C which is 112 degrees for the direction of flight chosen in the example

3 Set the course angle into the computer by adjusting dial C in upper left center of Fig. 1

4 Locate the desired station on the chart and measure the course line offset distance which is the shortest distance between the station and the course

5 Adjust "offset dial" at the upper left of Fig. 1 Offset is to the left on the dial if station is to the left in passing as in Fig 2. If station is going to be to the right in passing, then the offset dial is set to the right.

6 On the chart locate the desired destination on the course and measure the "along track coordinate." This coordinate is the distance between the destination and the point nearest the omni station on the course which is also the foot of the perpendicular from station to course

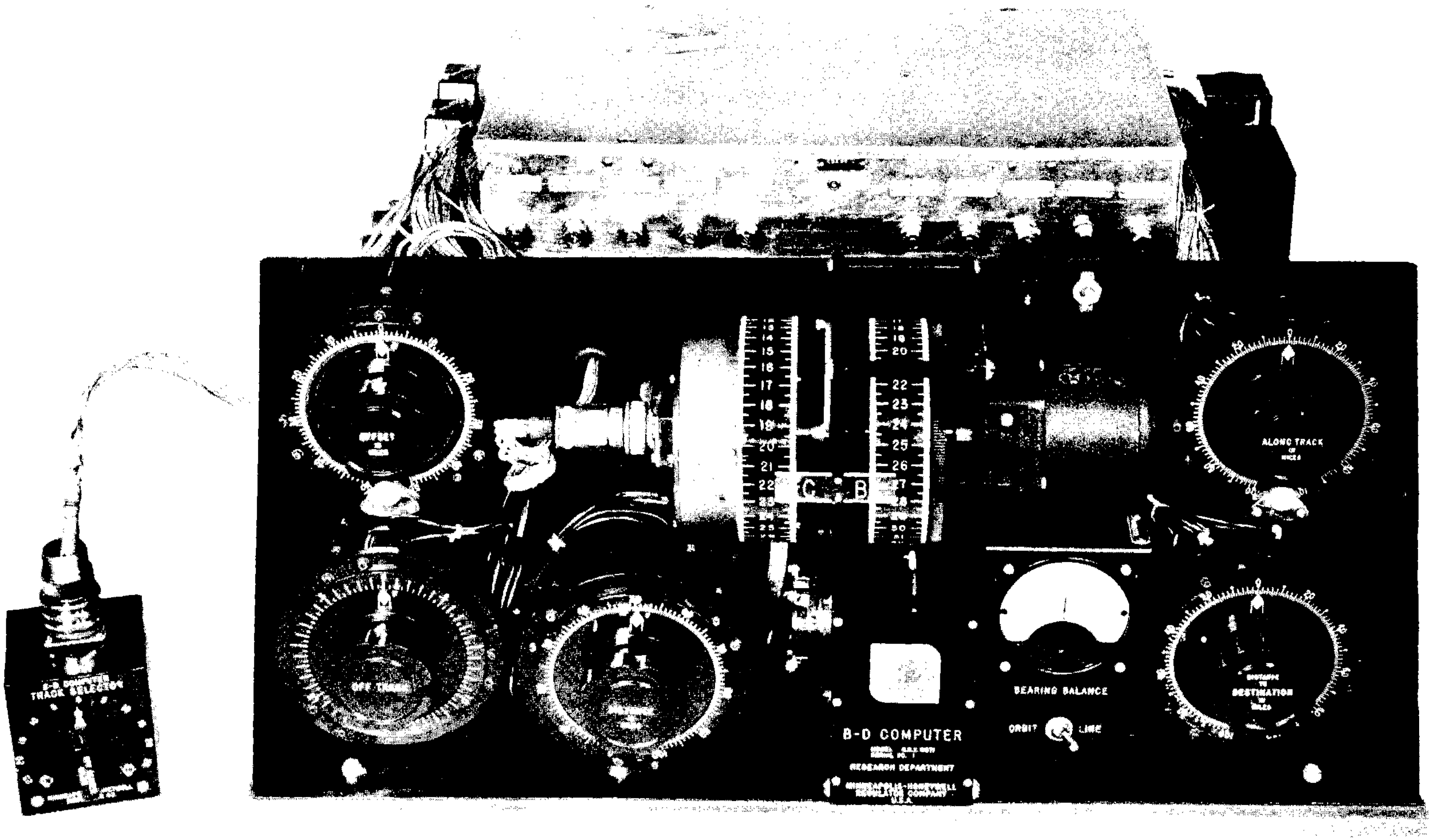

Fig. 1 Experimental Model of Parallel Course Computer

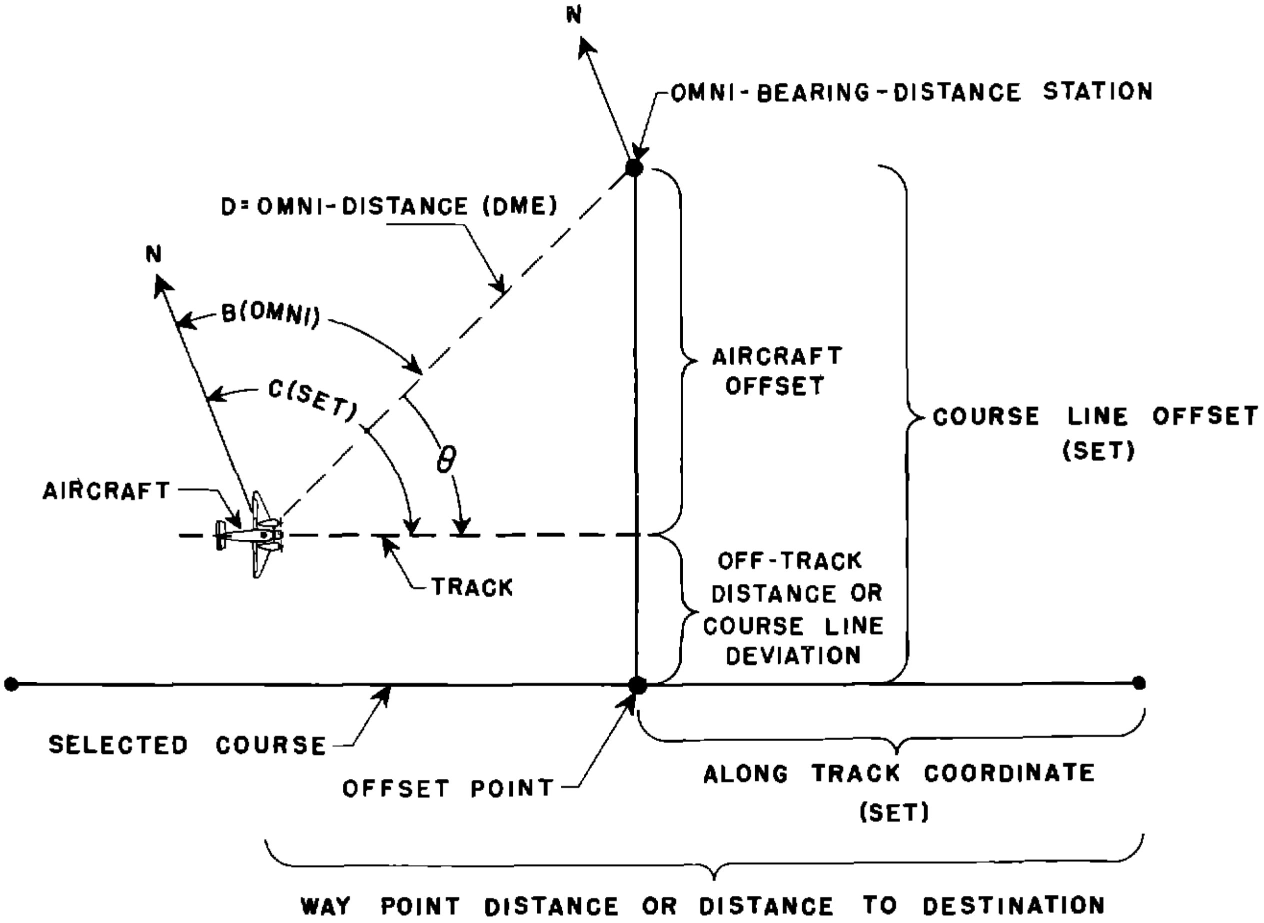

Fig 2 Trigonometry of Computer Operation

7. Adjust "along track" dial at upper right of Fig. 1. Along track coordinate is the distance from the foot of the perpendicular to the destination If the destination is beyond the offset point in Fig. 2, the dial is set to the left, and if the destination precedes the offset point, the dial is set to the right

8. Tune in the selected station and switch course deviation indicator to computer

9. Fly course deviation indicator (cross-pointer instrument) to place aircraft on course and keep it there.

The course deviation indicator has the same right or left sensing as when on the CAA localizer or omni range course. However, the deflection of the course deviation indicator is proportional to course line deviation in miles in the computer, whereas it is proportional to angular deviation in localizer and omni range equipments.

If the pilot wishes to fly another track parallel to the one which he has already set up on the computer, he may do so by setting the track selector either right or left the desired number of indicated miles For example, if he sets the track selector ten miles right and "flies the needle" the aircraft will travel a course ten miles to the right of the course set up but parallel to it. Also, as one would expect, the destination will be displaced ten miles right.

INSTALLATION

The panel of the computer is shown in Fig. 1. It was installed in CAA aircraft NC-182 and connected to the Aircraft Radio Corporation Model 15 variable tuned omni range receiver, shown in Fig. 3 and to a radar distance measuring equipment shown in Fig. 4, which was

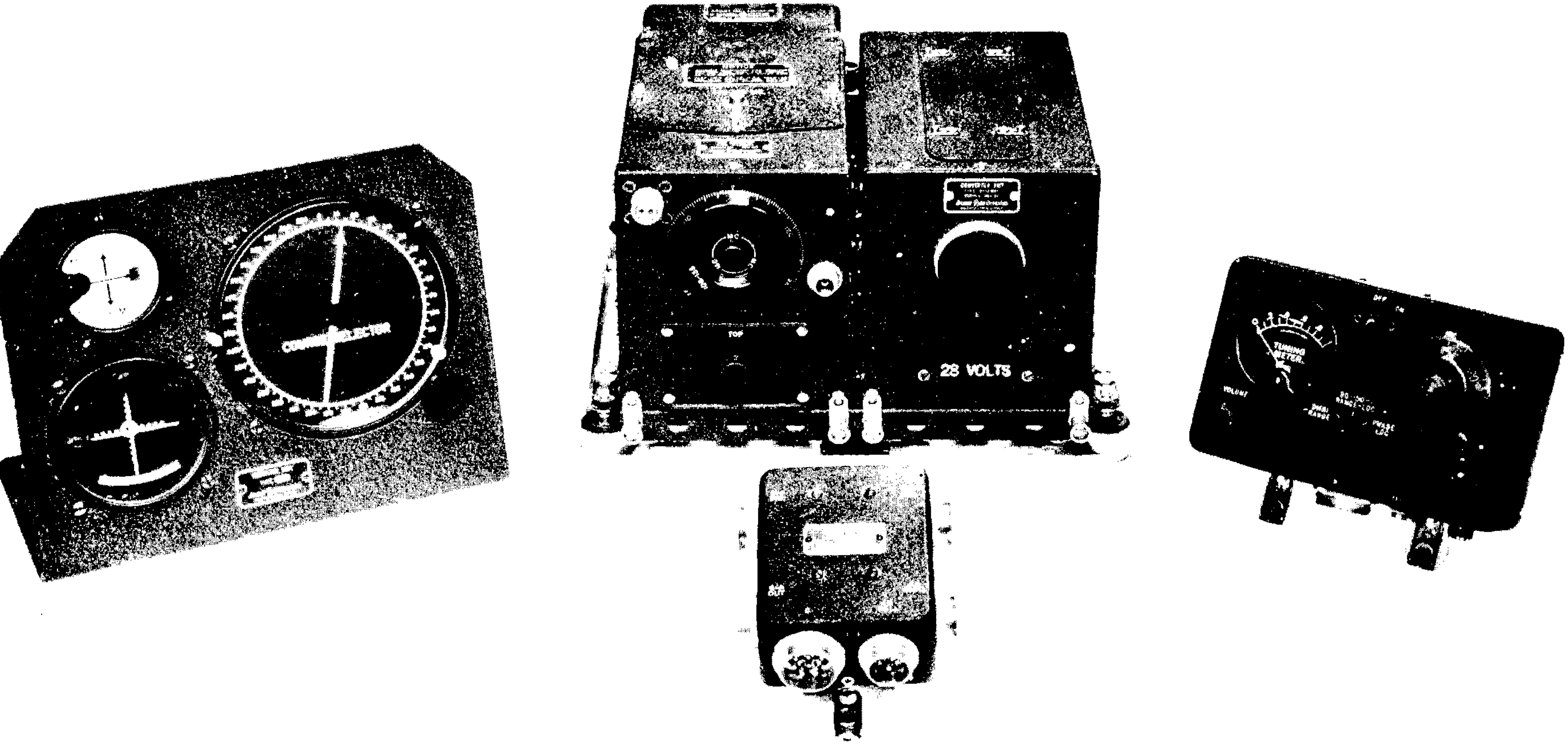

Fig. 3 The VHF Omni Range Receiver Used in the Computer Tests

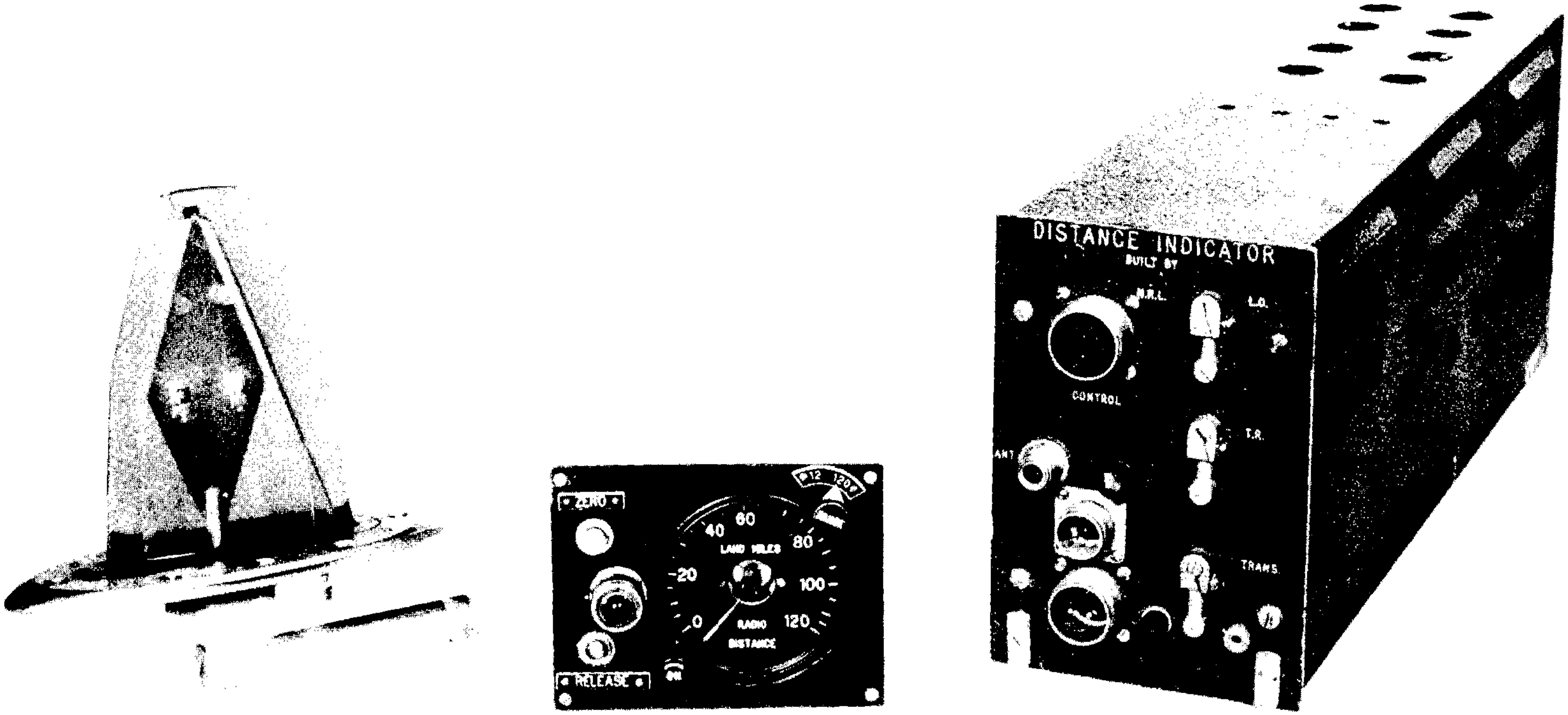

Fig. 4 The Experimental Airborne Distance Measuring Equipment Used in the Computer Tests

constructed at the U S Naval Research Laboratory. The connections to the omni receiver were such that a servo driven bearing selector in the computer was substituted electrically for the manual bearing selector, and the omni leads normally connected to the course deviation indicator were transferred to the input of the servo controlling the computer bearing dial. This servo positions the cylindrical dial B in Fig. 1 so that it indicates bearing from aircraft to the omni station The DME range voltage is supplied from a cathode follower tube in the DME. The plate voltage of the cathode follower tube, as well as the range voltage, is supplied to the computer The ratio of these two voltages actuates a servo motor so that it properly positions the dial labeled Distance in Miles at the lower left center of Fig 1.

CIRCUITRY OF EXPERIMENTAL COMPUTER

Fig 5 is a simplified schematic diagram of the computer Starting at the upper right the distance servo motor drives its shaft until the DME range volts are equal to the voltage picked off the potentiometer which is energized by the DME 210-volt supply In Fig 1 the dial labeled Distance in Miles is on this same shaft. Also, on the same shaft is the dual distance potentiometer whose output consists of two 400-cycle voltages of opposite polarity but each proportional to the distance D from the aircraft to the omni station. This voltage is applied to the resolver potentiometer The housing of the resolver potentiometer is fixed to the course dial C in Fig. 1, while the two wipers are mounted on a shaft which is connected to bearing dial B. It should be noted that the sine and cosine wipers have a fixed spacing of 90 degrees on the shaft and that the sine wiper, for example, will be positioned on either the +D or -D side of the resolver winding, depending on the algebraic sign of the sine (C-B) Because of this arrangement, the left hand resolver potentiometer wiper in Fig. 5 has a voltage output proportional to D sin (C-B), which is the same as D sin θ in Fig. 2 This voltage and the voltage from the offset potentiometer act through their respective series summing resistors to produce currents of opposite phase in the totalizing resistor. If these two currents are equal, then the off-track servo motor will center the off-track balance potentiometer D sin θ equals the offset distance only when the aircraft is on course, and hence when the course deviation is zero If D sin θ is not equal to the offset distance, then there is a residual current in the totalizing resistor. The servo motor positions the off-track balance potentiometer until the totalizing resistor current is zero. The resultant displacement of the off-track balance potentiometer shaft from the center position is proportional to the course line deviation in Fig. 2 The off-track dial at lower left in Fig. 1 is mounted on this same shaft Also, mounted on the off-track balance potentiometer shaft is the potentiometer supplying the course deviation indicator The magnitude of the 400-cycle output voltage from this latter potentiometer is proportional to course deviation and the phase for right deviation is the reverse of that for left deviation After this voltage passes through a phase sensitive rectifier, it is applied to the course deviation indicator on the pilot's instrument panel

The right-hand wiper of the resolver potentiometer in Fig. 5 has a voltage output proportional to D cos (C-B), which is the same as D cos θ in Fig. 2 This voltage and the voltage from the along-track coordinate potentiometer act through their respective series summing resistors to produce currents of opposite phase in the "along-track" totalizing resistor The Distance to Destination servo motor positions the Distance to Destination Potentiometer so as to reduce the totalizing resistor current to zero. This makes the displacement of that potentiometer shaft proportional to distance along the track between aircraft and destination. The dial marked Distance to Destination in the lower right-hand corner of Fig 1 is mounted on this same shaft.

The track selector potentiometer with fixed steps is shown on the left side of Fig. 5. It is so connected that it can either add to or subtract from the component of current from the offset potentiometer. By this means the offset can be changed in discreet steps to permit flying tracks parallel to but displaced from the track initially set up This circuit is actuated by the decade switch shown to the left of the computer in Fig 1.

In constructing this computer it was the original intention to add voltages by connecting them in series. However, the capacitance to ground of the various 400-cycle transformer

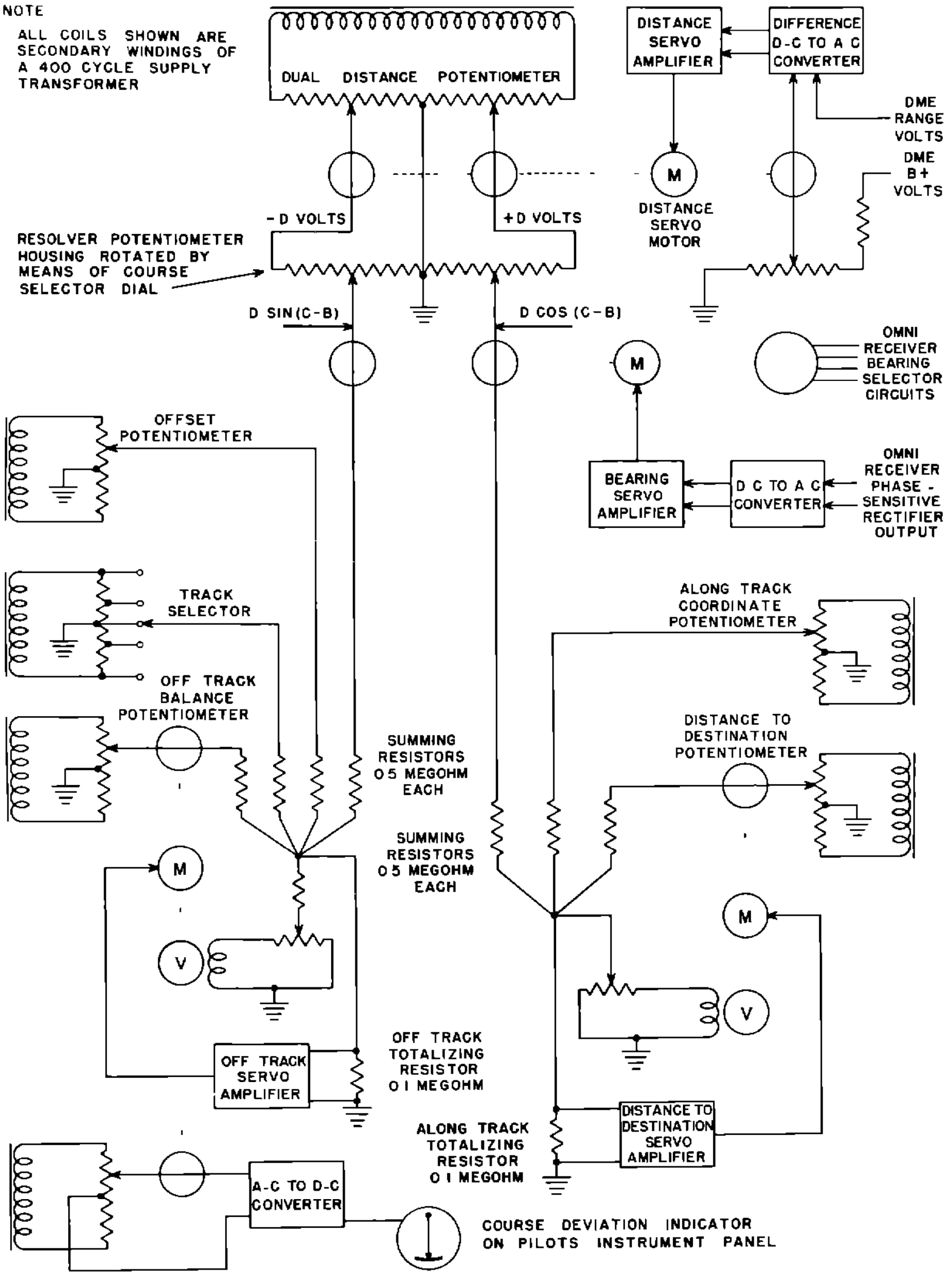

Fig 5 Simplified Schematic of Experimental Computer

windings introduced serious computer errors. The parallel arrangement using summing resistors was then devised to eliminate this error.

After the computer was delivered, flag alarm circuits were added The flag alarm of the course deviation indicator was actuated by the omni bearing receiver However, a relay was actuated from the DME warning light circuit so that the flag alarm current was interrupted whenever the DME signal was out of the gate.

Future development of more adequate flag alarm circuits is contemplated.

THEORY OF OFF-TRACK ERRORS

Since given errors in bearing and distance information produce errors of different magnitude at different points on a track, it is desirable to study the theoretical effect of such errors The following equation for the components of off-track error introduced by errors in the omni bearing information and the DME information is derived in Appendix I

$$\begin{bmatrix}\text{Off-track error}\\ \text{caused by bearing}\\ \text{and distance errors}\end{bmatrix} = 0.017\, b\, D \cos (C-B) - d \sin (C-B)$$

Where b is the omni bearing error in degrees (assumed less than four degrees), d is the DME distance error in miles (assumed less than three miles), D, B, and C are defined in Fig. 2

Note that in this equation the bearing error makes a negligible contribution to the off-track error when the cos (C-B) is zero, namely, when (C-B) is 90 degrees. This condition exists when the aircraft is at the offset point which is the point nearest the station for any track. Conversely, the bearing error has its greatest effect on the off-track error at the extremes of the track where the angle (C-B) is small and therefore cos (C-B) is very nearly unity As shown in Fig 6, the off-track error component for a given bearing error is proportional to the distance between the aircraft and the offset point.

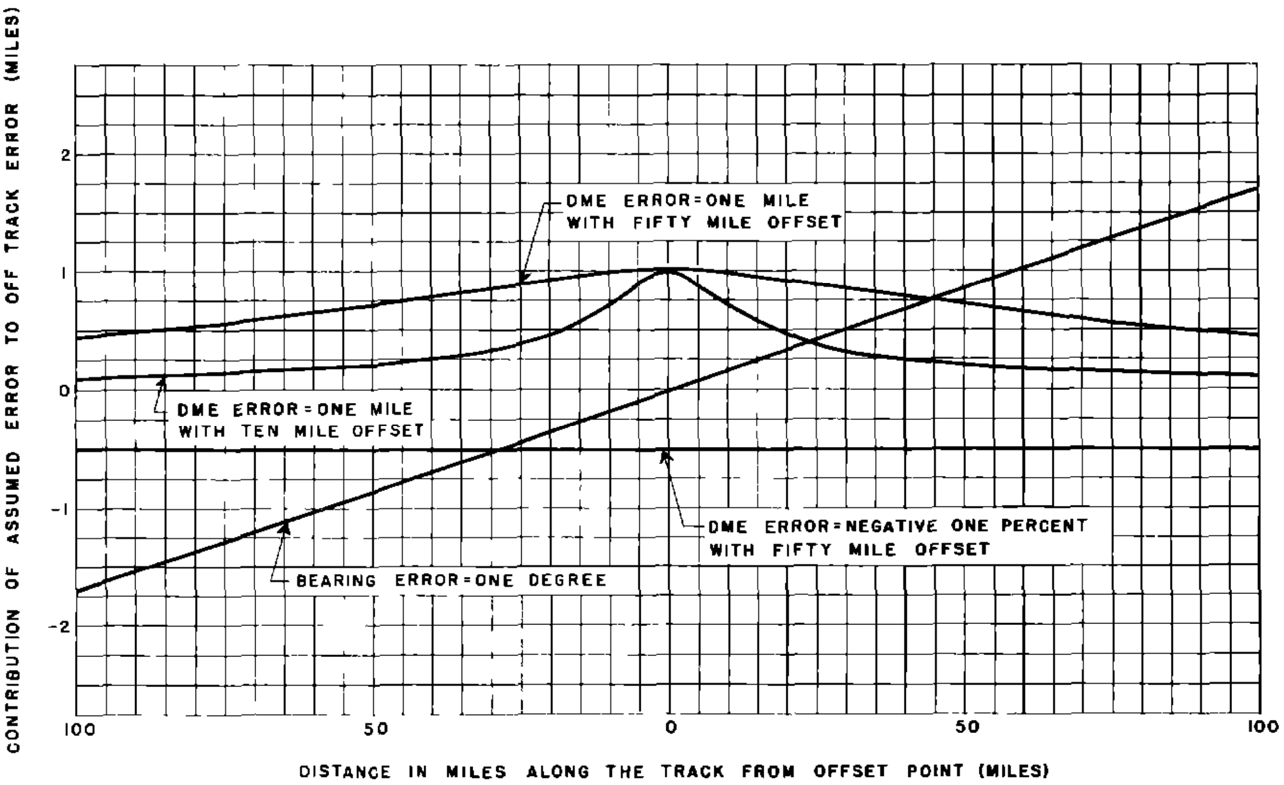

Fig. 6 Contributions to Off-Track Error of Different Assumed Bearing and Distance Errors

The off-track error caused by a given DME error in miles is proportional to the sin (C-B) and is therefore greatest at the offset point and negligible at the extreme ends of any track. When the component is plotted against distance along the track, as in Fig. 6, its effect is also a function of the offset distance

An interesting condition exists when the offset is zero, viz , when the track passes directly above the station. On this track for all points, except the one over the station, the angle (C-B) is zero, and hence the DME error does not contribute to the off-track error Directly over the station, however, the servo controlled bearing dial oscillates violently sometimes making a complete revolution At this time the maximum excursions of the course deviation indicator will be directly proportional to the DME error The DME indication is proportional to slant distance which the computer interprets as though it were horizontal distance and the difference between these two appears as an effective DME error in the computer for points very close to the station The practical result is that excursions of the deviation indicator will be directly proportional to altitudes above the ground when the aircraft is directly over the station on a computer track.

Another condition of interest is that in which the error in the DME distance information is a fixed percentage of the distance It is interesting to note that such a given fixed percent error produces a constant off-track error which is proportional to the offset distance for any track as is shown graphically in Fig 6

The errors introduced by the computer itself were determined by a bench test in the laboratory. The computer was energized but the DME and bearing servo mechanisms were disconnected The bearing and distance dials were positioned manually to the nearest even division for several calculated values on various tracks. The calculated off-track error was then subtracted from the observed off-track indication to obtain the computer error. The results are tabulated in Table I

One possible source of off-track error was discovered in a bench check for accuracy made after the off-track servo motor was changed It was found that the induction type velocity generator used for feed back in the servo mechanism had a voltage output at standstill which introduced a one mile off-track error. This was eliminated by carefully selecting another servo motor assembly

THEORY OF DISTANCE TO DESTINATION ERRORS

Components of the distance to destination errors can be separated in a manner similar to that used for the off-track errors

The following equation is also derived in Appendix I for the components of error introduced by errors in the bearing and distance information

$$\left[\begin{array}{l}\text{Distance to destination}\\ \text{error caused by bearing}\\ \text{and distance errors}\end{array}\right] = d\cos(C-B) - 0\ 017\, b\, D\sin(C-B)$$

In this case the DME errors have the greatest effect at the extremes of the track, while the effect of a given bearing error is the same along any one track but is proportional to the offset distance D sin (C-B) which is practically constant for a given track.

Distance to destination errors introduced by the computer were determined by bench test and are given in Table I

RESULTS OF FLIGHT TESTS OVER PARALLEL COURSES

In Fig 7 is reproduced a simplified map of test flights on this computer. The triangular symbol in the center represents the station. The number near the center of each track represents the offset in miles, for example, the track numbered N10 is offset ten miles to the north of the station The straight lines represent the intended courses and the lines with arrowheads represent the actual tracks of the aircraft, the arrowhead indicating the direction of flight The deviation in miles of the aircraft track from the intended course can be readily estimated by noting the proportion between deviation and course spacing Spacing for two courses is, of course, the difference between offset distances.

The average observed off-track error without regard to algebraic sign was 3/4 mile The service area of the station is expected to

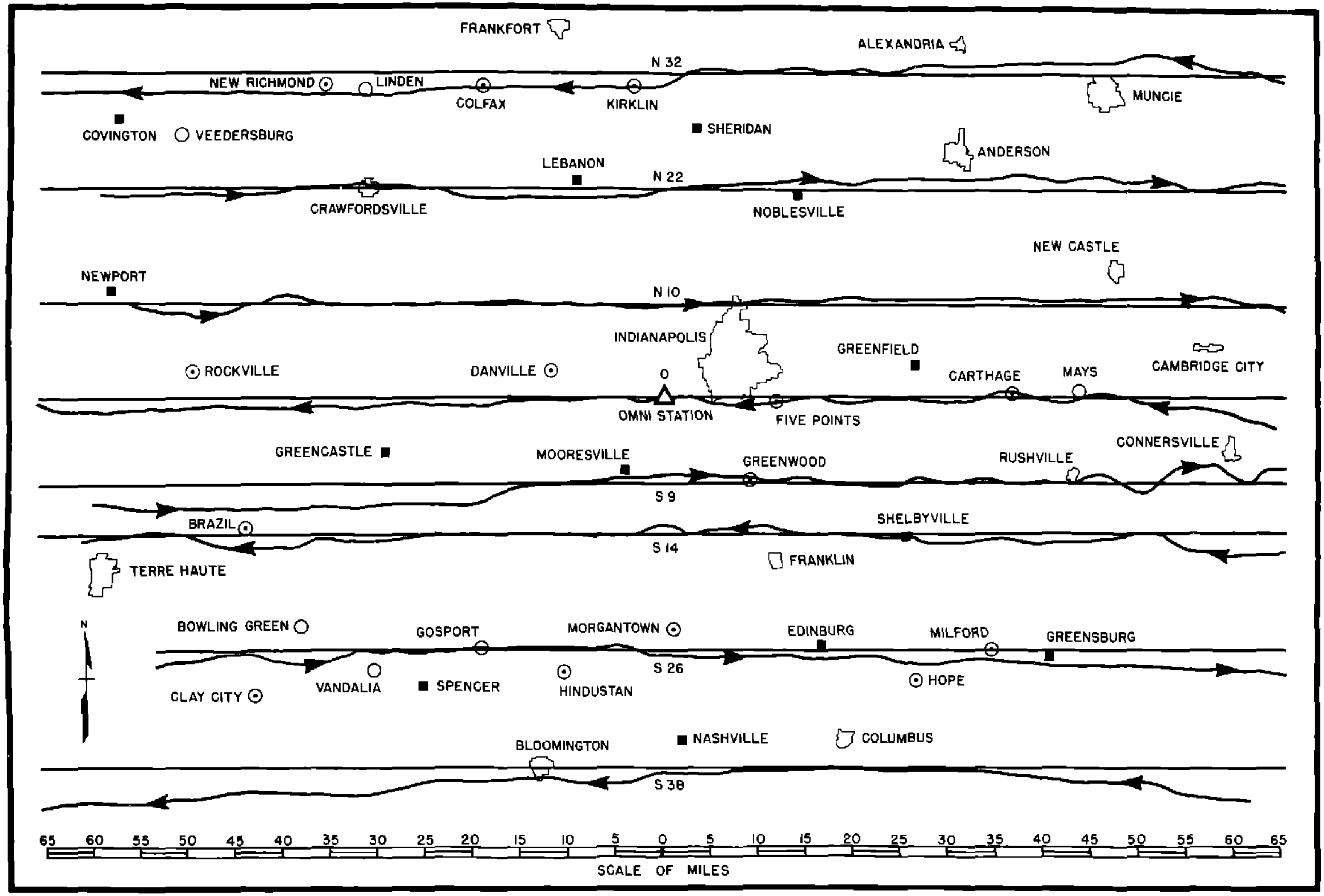

Fig. 7 Simplified Map Presentation of the Data From Tests Over Parallel Courses

be within 45 miles of the offset point. The greatest single observed error within that service area was 2 1/2 miles. The greatest single error observed in these tests was three miles at the extreme ends of track S38 A portion of this latter error is known to have been caused by a percentage change in the calibration of the distance measuring equipment during this series of tests.

The method of plotting these computer tracks may be of interest.

During the flights, the pilot endeavored to keep the needle centered while either the copilot or an engineer sat in the copilot's seat and plotted the path of the aircraft on detailed county maps having a scale of 1/2 inch per mile At the beginning of these tests, the observer's accuracy was tested by comparing his observation of the aircraft's position with that observed through an Army Type B-3 gyro-stabilized drift sight The two observations were found to agree to better than 0.2 mile up to an altitude of 5000 feet

The maps used were also compared with the sectional aeronautical charts and found to be in excellent agreement.

Fig. 8 is a reproduction of the recordings of the course deviation indicator for three of the tracks shown in Fig 7.

The heavily inked symbol represents the course deviation indicator, although only three of the five dots are shown here. It will be noted that the sensitivity of the pointer is 1/2 mile per dot Experience gained during these tests indicate that the pilot can fly computer courses with satisfactory precision if the sensitivity is as low as two miles per dot However, if ten-mile track separation is used, it seems advisable that the ultimate sensitivity of the deviation indicator should be one mile per dot which would make the course width of the deviation indicator ten miles.

In Fig 8 the term "offset point' is used on the upper and lower recordings to indicate the foot of the perpendicular from the station, which is also that point on the track that is nearest the station It will be noted that the recording is smooth near the offset point but that elsewhere the record suffers from a periodic disturbance whose magnitude is roughly proportional to the distance between the aircraft and the offset point It has been determined that this disturbance is caused by a variation of plus or minus one degree in the omni bearing information, which is negligible in the omni range receiver presentation, but shows up here because of the greater sensitivity of the computer to bearing error The period of the disturbance can be estimated from these recordings, since each time division represents 45 seconds, for example, the four divisions between eight and noon represent three minutes It is planned to minimize this oscillation by reducing the sensitivity by two as previously mentioned, and also by adding in a small amount of integration In making the flights illustrated in Fig 7 the pilot mentally integrated the pointer swing

Although distance to destination readings were made during the flights illustrated in Fig 7, it was not practical to precisely correlate these readings with the map. All that was done on these flights was to determine that distance to destination indications were reasonably accurate However, one flight was repeated over tract N10 of Fig. 7 in an east to west direction taking the data in a different manner Some of the tracks, such as N10, are township lines of the U S Land Survey and are visible from the air as straight continuous lines clearly marked by roads and farm boundaries. In making this flight over track N10 the pilot ignored the course deviation indicator and flew the aircraft on a straight track along this township line. Check points were selected in advance at intervals of approximately five miles All the computer dials were read whenever the aircraft passed over one of these check points True bearings and true distances for each check point were determined from the detailed county maps having a scale of 1/2 inch per mile The resulting data is contained in Table II

RESULTS OF FLIGHT TESTS OVER CIRCULAR ORBITS AROUND THE STATION

In the lower right center of Fig 1 is a switch labeled "orbit or line " If this switch is thrown to the "orbit" position, and the offset dial is set to a distance such as 20 miles to the left, then the pilot can fly a left hand circular pattern about the station by flying the deviation indicator with normal sensing The flight paths shown in Fig. 9 were made in a manner similar to those of Fig 7, except that the orbiting function of the computer was used

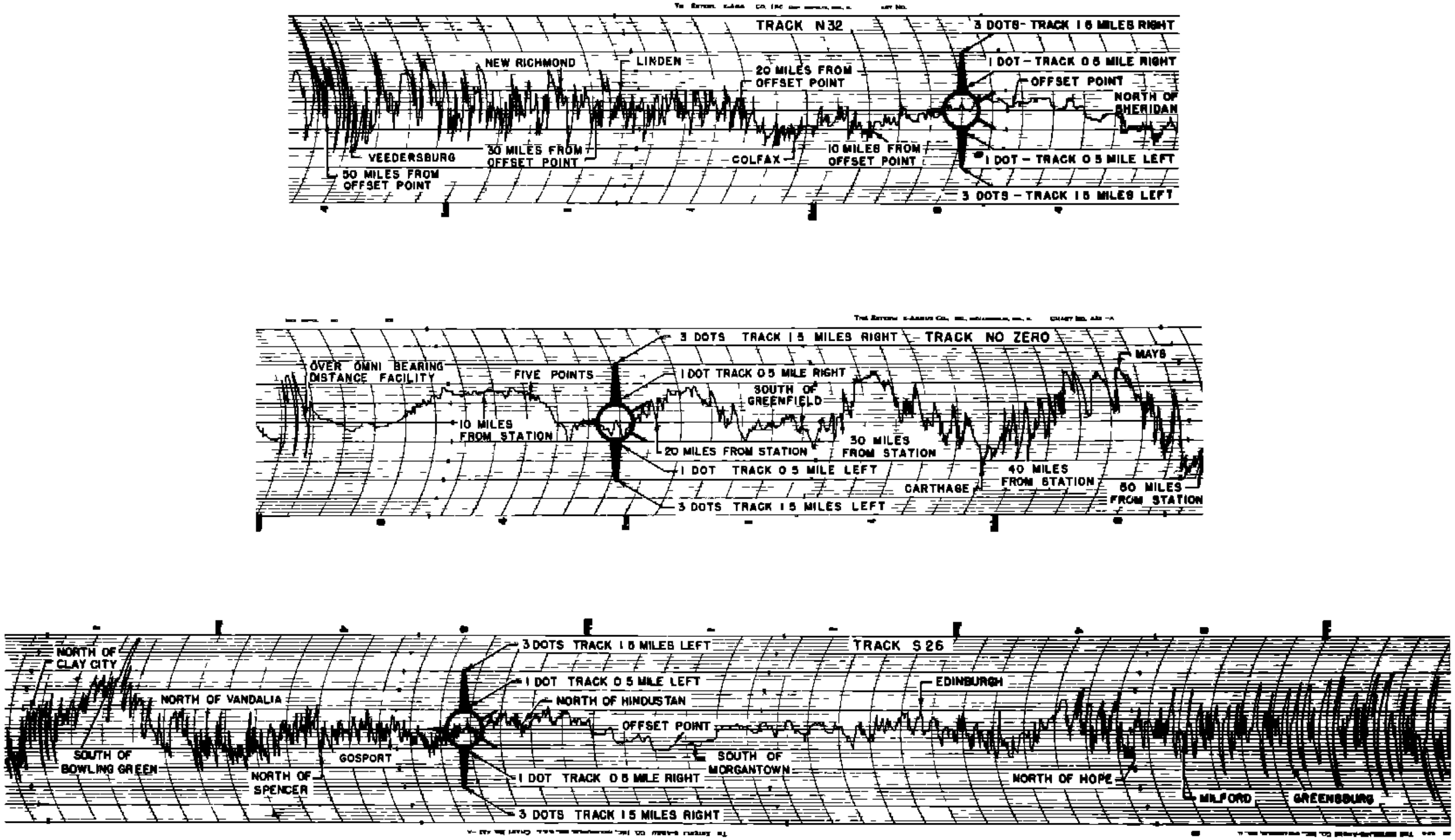

Fig 8 Recordings of the Course Deviation Indicator Made During Flights Over Tracks N32, zero, and S26 of Fig 7

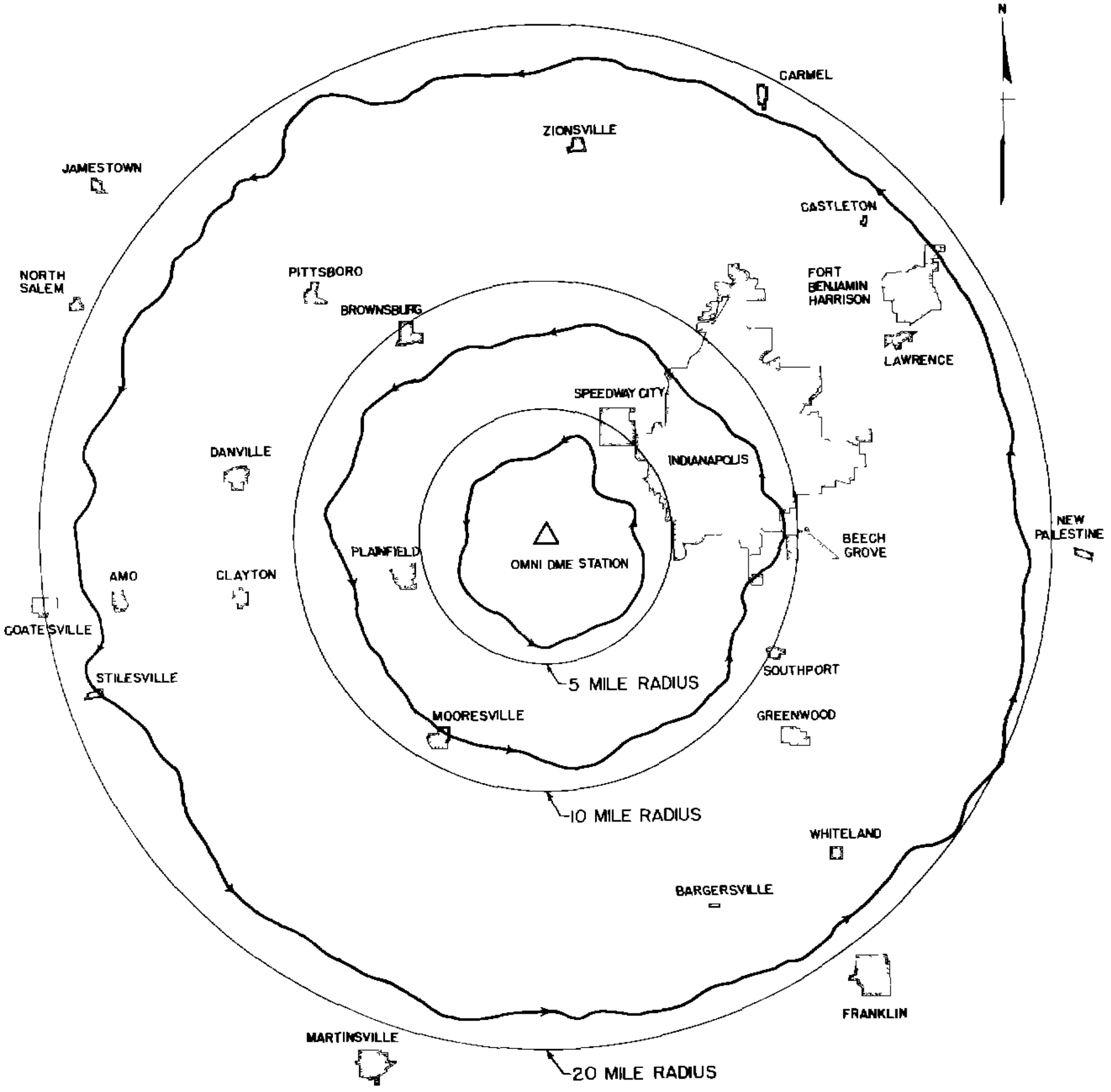

Fig 9 Simplified Map Presentation of the Data From Flight Tests Over Circular Orbits About the Station

The perfect circles are the intended orbital tracks, and the adjacent tracks are those made by the aircraft. Bench tests of the computer indicated that of the errors shown in Fig 9, one mile was contributed by the computer at a 20-mile radius, 0.6 mile at a 10-mile radius, and 0.5 mile at a 5-mile radius.

CONCLUSIONS

Flight tests of the experimental computer show that it has an average off-track error of 3/4 mile and a maximum error of 2 1/2 miles within the expected service range of the station. Errors in the distance to destination or waypoint are found to be of the same order of magnitude. These errors are well within the limits recommended by the January, 1947, Report of the Special Radio Technical Division of ICAO. Soon there will be available navigation receivers and distance measuring equipments built to more rigid specifications than those used in these tests, and as a consequence the errors of computer flying will be reduced to less than those shown in this report.

In procuring the experimental computer, size and weight limitations were waived to obtain prompt delivery. With the precision potentiometers and autosyn units of compact design now available, it is believed that the size can be reduced to that of a one-half ATR and the weight to approximately 20 pounds

Off-track errors of the magnitude found in these tests would permit the use of ten-mile track separation with safety It may be noted that the portion of the errors introduced by the transmitting station does not affect the track separation because such errors affect all receiving equipments alike

APPENDIX I

Analysis of the Computer Equation for Error Relationships

The following computer equation for the parallel course computer is readily derived from the diagram of Fig. 2

$$\left[\begin{array}{l}\text{Off}\\ \text{Track}\\ \text{Distance}\end{array}\right] = \left[\begin{array}{l}\text{Course Line}\\ \text{Offset}\\ \text{Distance}\end{array}\right] - D \sin (C-B) \qquad (1)$$

Bearing and distance errors may be taken account of by rewriting the computer equation as follows

$$\left[\begin{array}{l}\text{Off}\\ \text{Track}\\ \text{Distance}\end{array}\right] + \left[\begin{array}{l}\text{Off}\\ \text{Track}\\ \text{Errors}\end{array}\right] = \left[\begin{array}{l}\text{Course Line}\\ \text{Offset}\\ \text{Distance}\end{array}\right] - (D+d) \sin (C-B-b) \qquad (2)$$

where

b = bearing error in degrees
d = distance error in miles.

Expanding equation (2) gives

$$\left[\begin{array}{l}\text{Off}\\ \text{Track}\\ \text{Distance}\end{array}\right] + \left[\begin{array}{l}\text{Off}\\ \text{Track}\\ \text{Error}\end{array}\right] = \left[\begin{array}{l}\text{Course Line}\\ \text{Offset}\\ \text{Distance}\end{array}\right] - D \sin (C-B) \cos b + D \cos (C-B) \sin b - d \sin (C-B) \cos b + d \cos (C-B) \sin b \qquad (3)$$

Subtracting equation (1) from (3) leaves

$$\left[\begin{array}{l}\text{Off}\\ \text{Track}\\ \text{Error}\end{array}\right] = (1-\cos b)\, D \sin (C-B) + D \sin b \cos (C-B) - d \cos b \sin (C-B) + d \sin b \cos (C-B) \qquad (4)$$

If b is assumed to be three degrees or less and d is assumed four miles or less, then the first and last terms on the right-hand side of equation (4) become less than 0.2 mile and therefore negligible This assumption also makes sin b equal to b in radians and cos b equal to one.

With these approximations, equation (4) can be rewritten as follows

$$\left[\begin{array}{l}\text{Off}\\ \text{Track}\\ \text{Error}\end{array}\right] = 0.17\, b\, D \cos (C-B) - d \sin (C-B) \qquad (5)$$

Similarly, the following equation can be set up for distance to destination error relations

$$\left[\begin{array}{l}\text{Distance to}\\ \text{Destination}\\ \text{or Waypoint}\end{array}\right] = \left[\begin{array}{l}\text{Along}\\ \text{Track}\\ \text{Coordinate}\end{array}\right] + D \cos (C-B) \qquad (6)$$

Introducing b and d and expanding gives

$$\left[\begin{array}{l}\text{Distance to}\\ \text{Destination}\\ \text{or Waypoint}\end{array}\right] + \left[\begin{array}{l}\text{Distance to}\\ \text{Destination}\\ \text{Error}\end{array}\right] = \left[\begin{array}{l}\text{Along}\\ \text{Track}\\ \text{Coordinate}\end{array}\right] + D \cos b \cos (C-B) - D \sin b \sin (C-B) + d \cos b \cos (C-B) - d \sin b \sin (C-B) \qquad (7)$$

Subtracting (6) from (7)

$$\left[\begin{array}{l}\text{Distance to}\\ \text{Destination}\\ \text{Errors}\end{array}\right] = (\cos b-1)\, D \cos (C-B) - D \sin b \sin (C-B) + d \cos b \cos (C-B) - d \sin b \sin (C-B) \qquad (8)$$

Assuming b and d small as before and approximating

$$\left[\begin{array}{l}\text{Distance to}\\ \text{Destination}\\ \text{Errors}\end{array}\right] = d \cos (C-B) - 0.017\, b\, D \sin (C-B) \qquad (9)$$

TABLE I

Bench Test Errors of Experimental Course Line Computer

When the following data were recorded, the course angle dial was set at zero, and along-track dial was also set at zero

Offset (Miles)**	Omni-Bearing (deg)	Omni-Distance (miles)	Calculated Off-track (miles)	Observed Off-track (miles)	Off-track Error (miles)*	Calculated Distance to Destination (miles)	Observed Distance to Destination (miles)	Distance to Destination Correction (miles)***
Right 50	30	100.0	0.0	L 1.0	L 1.7	86	L 87	-1.0
	38	81.0	L 0.1	L 1.7	L 1.6	64	L 63	+1.0
	51	64.5	R 0.1	L 0.8	L 0.9	41	L 39	+2.0
	68	54.0	R 0.1	L 0.2	L 0.3	22	L 19	+3.0
	90	50.0	0.0	R 0.2	R 0.2	0	R 2	+2.0
	112	54.0	R 0.1	R 0.3	R 0.2	22	R 22	0.0
	129	64.5	R 0.1	R 0.1	0.0	41	R 41	0.0
	142	81.0	L 0.1	L 0.4	L 0.3	64	R 64	0.0
	150	100.0	0.0	L 0.2	L 0.2	86	R 87	-1.0
Right 40	24	98.5	L 0.1	L 1.0	L 0.9	90	L 91	-1.0
	30	80.0	0.0	L 1.7	L 1.7	69	L 69	0.0
	39	63.5	0.0	L 1.4	L 1.4	49	L 48	+1.0
	54	49.5	0.0	L 0.6	L 0.6	29	L 28	+1.0
	76	41.5	R 0.3	0.0	L 0.3	10	L 9	+1.0
	90	40.0	0.0	0.0	0.0	0	R 2	+2.0
	104	41.5	R 0.3	R 0.5	R 0.2	10	R 12	-2.0
	126	49.5	0.0	R 0.3	R 0.3	29	R 30	-1.0
	141	63.5	0.0	L 0.1	L 0.1	49	R 50	-1.0
	150	80.0	0.0	L 0.3	L 0.3	69	R 69	0.0
	156	98.5	R 0.1	L 0.3	L 0.4	90	R 91	-1.0
Right 30	18	97.5	R 0.1	L 0.6	L 0.7	93	L 94	-1.0
	23	76.5	L 0.1	L 0.8	L 0.7	70	L 70	0.0
	31	58.5	R 0.1	L 0.6	L 0.7	50	L 50	0.0
	45	42.5	0.0	L 0.6	L 0.6	30	L 29	+1.0
	72	31.5	0.0	R 0.2	R 0.2	10	L 9	+1.0
	90	30.0	0.0	R 0.3	R 0.3	0	R 1	+1.0
	108	31.5	0.0	R 0.4	R 0.4	10	R 12	-2.0
	135	42.5	0.0	R 0.2	R 0.2	30	R 31	-1.0
	149	58.5	R 0.1	R 0.4	R 0.3	50	R 51	-1.0
	157	76.5	L 0.1	R 0.2	R 0.3	70	R 70	0.0
	162	97.5	R 0.1	0.0	L 0.1	93	R 93	0.0
Right 20	12	97.0	R 0.2	R 0.2	0.0	95	L 96	-1.0
	16	72.5	0.0	0.0	0.0	70	L 70	0.0
	22	53.5	0.0	L 0.1	L 0.1	50	L 50	0.0
	34	36.0	R 0.1	0.0	L 0.1	30	L 29	+1.0
	64	22.5	R 0.2	R 0.7	R 0.5	10	L 9	+1.0
	90	20.0	0.0	R 0.8	R 0.8	0	R 1	+1.0
	116	22.5	R 0.2	R 1.0	R 0.8	10	R 11	-1.0
	146	36.0	R 0.1	R 0.6	R 0.5	30	R 30	0.0
	158	53.5	0.0	R 0.6	R 0.6	50	R 50	0.0
	164	72.5	0.0	R 0.4	R 0.4	70	R 69	+1.0
	168	97.0	R 0.2	R 0.4	R 0.2	95	R 95	0.0

TABLE I (Continued)

Offset (miles)*	Omni-Bearing (deg)	Omni-Distance (miles)	Calculated Off-track (miles)	Observed Off-track (miles)	Off-track Error (miles)**	Calculated Distance to Destination (miles)	Observed Distance to Destination (miles)	Distance to Destination Correction (miles)***
Right 10	6	95.5	0.0	R 0.2	R 0.2	95	L 97	-2.0
	8	72.0	0.0	R 0.1	R 0.1	71	L 72	-1.0
	11	52.5	0.0	R 0.1	R 0.1	52	L 52	0.0
	18	32.5	0.0	R 0.2	R 0.2	31	L 30	+1.0
	45	14.0	L 0.1	L 0.3	L 0.2	10	L 10	0.0
	90	10.0	0.0	R 0.1	R 0.1	0	0	0.0
	135	14.0	L 0.1	0.0	R 0.1	10	R 11	-1.0
	162	32.5	0.0	R 0.1	R 0.1	31	R 31	0.0
	169	52.5	0.0	R 0.2	R 0.2	52	R 52	0.0
	172	72.0	0.0	R 0.1	R 0.1	71	R 70	+1.0
	174	95.5	0.0	R 0.1	R 0.1	95	R 95	0.0
0	0	100.0	0.0	0.0	0.0	100	L 99	+1.0
	0	80.0	0.0	0.0	0.0	80	L 81	-1.0
	0	60.0	0.0	0.0	0.0	60	L 61	-1.0
	0	40.0	0.0	0.0	0.0	40	L 40	0.0
	0	20.0	0.0	0.0	0.0	20	L 20	0.0
	0	0.0	0.0	0.0	0.0	0	0	0.0
	180	20.0	0.0	0.0	0.0	20	R 21	-1.0
	180	40.0	0.0	0.0	0.0	40	R 40	0.0
	180	60.0	0.0	0.0	0.0	60	R 61	-1.0
	180	80.0	0.0	0.0	0.0	80	R 80	0.0
	180	100.0	0.0	0.0	0.0	100	R 100	0.0
Left 10	354	95.5	0.0	L 0.1	L 0.1	95	L 97	-2.0
	352	72.0	0.0	0.0	0.0	71	L 72	-1.0
	349	52.5	0.0	L 0.1	L 0.1	52	L 52	0.0
	342	32.5	0.0	0.0	0.0	31	L 31	0.0
	315	14.0	R 0.1	L 0.1	L 0.2	10	L 10	0.0
	270	10.0	0.0	L 0.3	L 0.3	0	0	0.0
	225	14.0	R 0.1	R 0.2	R 0.1	10	R 11	-1.0
	198	32.5	0.0	R 0.2	R 0.2	31	R 31	0.0
	191	52.5	0.0	R 0.3	R 0.3	52	R 52	0.0
	188	72.0	0.0	R 0.4	R 0.4	71	R 70	+1.0
	186	95.5	0.0	R 0.5	R 0.5	95	R 95	0.0
Left 20	348	97.0	L 0.2	R 0.2	R 0.4	95	L 98	-3.0
	344	72.5	0.0	R 0.6	R 0.6	70	L 71	-1.0
	338	53.5	0.0	R 0.3	R 0.3	50	L 50	0.0
	326	36.0	L 0.1	0.0	R 0.1	30	L 29	+1.0
	296	22.5	L 0.2	L 0.5	L 0.3	10	L 10	0.0
	270	20.0	0.0	L 0.3	L 0.3	0	0	0.0
	244	22.5	L 0.2	L 0.3	L 0.1	10	R 11	-1.0
	214	36.0	L 0.1	R 0.2	R 0.3	30	R 30	0.0
	202	53.5	0.0	R 0.2	R 0.2	50	R 50	0.0
	196	72.5	0.0	R 0.3	R 0.3	70	R 69	+1.0
	192	97.0	L 0.2	R 0.2	R 0.4	95	R 95	0.0

TABLE I (Continued)

Offset (miles)*	Omni-Bearing (deg)	Omni-Distance (miles)	Calculated Off-track (miles)	Observed Off-track (miles)	Off-track Error (miles)**	Calculated Distance to Destination (miles)	Observed Distance to Destination (miles)	Distance to Destination Correction (miles)***
Left 30	342	97.5	L 0.1	R 0 4	R 0 5	93	L 94	-1 0
	337	76.5	R 0.1	R 0 4	R 0 3	70	L 71	-1 0
	329	58.5	L 0 1	R 0 5	R 0 6	50	L 51	-1 0
	315	42.5	0 0	R 0.4	R 0 4	30	L 30	0 0
	288	31.5	0 0	R 0 2	R 0.2	10	L 10	0 0
	270	30.0	0.0	0.0	0.0	0	0	0.0
	252	31.5	0 0	R 0 7	R 0 7	10	R 10	0.0
	225	42.5	0 0	R 0 9	R 0.9	30	R 30	0 0
	211	58 5	L 0.1	L 1 0	R 1 1	50	R 50	0 0
	203	76 5	R 0 1	R 1 0	R 1 1	70	R 69	+1 0
	198	97 5	L 0 1	R 0 8	R 0 9	93	R 93	0.0
Left 40	336	98 5	L 0 1	R 1 0	R 1 1	90	L 92	-2 0
	330	80 0	0 0	R 1 4	R 1 4	69	L 70	-1 0
	321	63 5	0 0	R 0 8	R 0.8	49	L 50	-1 0
	306	49 5	0 0	R 0 4	R 0 4	29	L 29	0 0
	284	41 5	L 0 3	0 0	R 0 3	10	L 10	0.0
	270	40 0	0 0	R 0 4	R 0 4	0	L 1	-1 0
	256	41 5	L 0 3	R 0 4	R 0 7	10	R 11	-1.0
	235	49 5	0 0	R 0 4	R 0 4	29	R 28	+1.0
	219	63 5	0.0	R 1.5	R 1 5	49	R 49	0 0
	210	80.0	0.0	R 1 6	R 1 6	69	R 68	+1 0
	204	98 5	L 0.1	R 1 3	R 1 4	90	R 89	+1 0
Left 50	330	100 0	0.0	R 1 0	R 1 0	86	L 88	-2.0
	322	81 0	R 0 1	R 1 7	R 1.6	64	L 64	0 0
	309	64 5	L 0 1	R 0 7	R 0.8	41	L 41	0.0
	292	54 0	L 0 1	R 0 3	R 0.4	22	L 21	+1 0
	270	50.0	0 0	R 0 1	R 0 1	0	L 1	-1 0
	248	54.0	L 0 1	R 0 8	R 0 9	22	R 20	+2 0
	231	64 5	L 0.1	R 1 5	R 1 6	41	R 39	+2 0
	218	81 0	R 0 1	R 2 2	R 2 1	64	R 63	+1 0
	210	100 0	0.0	R 2 0	R 2.0	86	R 85	+1.0

*Note - In each of these bench tests the course angle was zero, and the along-track coordinate was zero.

**Note - The L (left) and R (right) symbols in the off-track error column refer to the direction in which the course deviation indicator deflects

***Note - This correction is to be added algebraically to the reading of the distance to destination dial

TABLE II

Results of Straight Line Computer Flight Over Course N 10

Computer settings Offset - Left 9.7 Miles
Course - 268.5 degrees
Along track coordinate - 0 Miles

Check Point	Omni-Distance Dial (miles)	Omni-Distance From Map (miles)	Omni-Bearing Dial (degrees)	Omni-Bearing From Map (degrees)	Off-track Indication (miles)*	Distance to Destination Dial (miles)	Distance to Offset Point From Map (miles)	Distance to Destination Correction (miles)**
80	62.5	62.6	259.0	259.6	0.8 L	L 62.0	61.8	-0.2
79	57.4	56.7	258.0	258.7	0.6 L	L 56.5	55.9	-0.6
78	53.3	52.3	258.0	257.8	0.6 L	L 52.8	51.4	-1.4
65	51.5	49.4	257.5	257.2	0.4 L	L 50.5	48.4	-2.1
64	43.5	42.6	255.0	254.7	0.1 L	L 42.3	41.5	-0.8
63	37.1	36.4	252.0	253.1	0.7 L	L 35.5	35.1	-0.4
62	33.0	32.1	253.0	250.5	1.2 R	L 31.3	30.4	-0.9
61	27.1	26.2	249.0	247.2	1.1 R	L 25.0	24.4	-0.6
60	23.4	23.0	246.0	243.8	0.8 R	L 22.0	21.0	-1.0
59	19.6	18.9	240.0	238.0	0.3 R	L 17.0	16.3	-0.7
58	14.3	13.8	226.5	224.6	0.3 L	L 9.5	10.1	+0.6
57	12.5	11.8	216.0	215.0	0.3 L	L 8.0	10.0	+2.0
56	10.3	9.6	186.0	183.0	1.0 L	L 1.5	0.9	-0.6
55	10.2	9.6	172.5	168.3	1.0 L	R 2.0	1.5	-0.5
53	13.5	13.0	138.5	135.3	0.8 L	R 10.0	8.8	-1.2
52	18.5	18.0	121.5	120.6	0.6 L	R 17.0	15.2	-1.8
51	20.5	20.3	118.0	117.0	0.6 L	R 19.0	17.6	-1.4
49	27.8	27.3	110.5	109.4	0.7 L	R 26.0	25.5	-0.5
48	32.7	32.2	106.0	106.1	0.4 L	R 32.0	30.7	-1.3
47	36.4	36.2	104.5	104.1	0.6 L	R 36.0	34.9	-1.1
46	44.1	45.9	103.0	100.5	2.2 L	R 44.0	44.9	+0.9
84	49.4	50.5	99.0	99.7	0.6 R	R 49.0	49.6	+0.6
85	55.0	57.3	99.0	98.3	0.5 R	R 55.0	56.5	+1.5

* Note - Right and left deflection of course deviation indicator is indicated by R and L, respectively.

** Note - Correction is to be added algebraically to Distance to Destination dial reading