A VOR-DME SIMULATOR FOR LINK TRAINERS

By
Edward M. Blount, Hugh A. Kay
and Raymond E. McCormick
Navigation Aids Evaluation Division

Technical Development Report No. 193

CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT AND
EVALUATION CENTER
INDIANAPOLIS, INDIANA
March 1953

TABLE OF CONTENTS

Manuscript received September 1952

A VOR-DME SIMULATOR FOR LINK TRAINERS

SUMMARY

This report describes a VOR-DME simulator which may be used with a Link trainer either to provide basic omnirange and distance measurement instrumentation or to supply information for the operation of various types of navigation computers Errors in the simulator are less than one degree in bearing and less than one-half mile in distance Suggestions are included for aligning the equipment and for setting up navigational problems

INTRODUCTION

The Technical Development and Evaluation Center of the Civil Aeronautics Administration is conducting an evaluation program on the CAA Type III portable pictorial computer One of the phases of this program required a series of simulated flights in a Link trainer Although recent models of this trainer are equipped with modern navigational aids, many earlier types (including the installation at TDEC) have no provisions for such facilities As a result, it was necessary to design equipment to provide simulated bearing and distance information This equipment can be used to actuate one or more types of computers in the Link cockpit

Since the VOR-DME simulator developed for this purpose displayed a high degree of accuracy, a description of its construction was considered desirable in case other groups contemplate the assembly of a similar unit

MECHANICAL DESCRIPTION

The Model ANT-18 Link trainer uses an automatic recorder, commonly known as a crab, which is driven over a map on the instructor's desk to record the ground path "made good" Pulses of power from the trainer impart forward motion to the crab Turning is accomplished by a teletorque crab motor which is synchronized with a teletorque transmitter geared directly to the vertical shaft support of the trainer The recording wheel and the two drive wheels of the crab thus turn in synchronism with the trainer, while the crab frame retains any preset orientation with respect to the instructor's desk

To provide VOR information, a transmitting Autosyn was placed on a tripod on the crab as shown in Fig 1 The Autosyn stator was rigidly attached to the crab The rotor is turned by a cable which rotates about an axis perpendicular to the station Thus, crab movement about a radius produces mechanical rotation of the shaft of the crab Autosyn equal to the change in bearing to the station The cable was attached to the Autosyn shaft extension, passed through the cable guide over two pulleys, and attached to a weight which maintains constant cable tension The cable guide is supported by the omnibearing distance (OBD) positioning arm and extension attached to a vertical pipe secured to the back of the instructor's desk The arm and extension are adjustable so that the cable guide can be placed over the center of the desk An eccentric shaft extension was used on the Autosyn to effect a more rapid response to small changes in bearing

To obtain DME information, a distance potentiometer was mounted on insulators between the pulleys on the OBD positioning arm A wiper and a wiper holder were attached to the cable in such a manner that the wiper could make electrical contact with the potentiometer The portion of the cable extending from the crab to the wiper was made of 12-pound test, silk-covered flax cord while the remainder of the cable was a No 22, 12-strand, plastic-covered copper wire A worm gear at the top of the vertical support raises the OBD simulator arm assembly to provide slant range distances at various altitudes up to 40,000 feet This worm gear is turned by an altitude control knob All leads were fed through the pipe support to a junction box under the trainer desk OBD information and the direct current (dc) supply were transferred to the trainer through slip rings mounted on top of the fuselage The 115-volt, 400-cycle per second (cps) conductors were brought to the Link trainer through the base in order to prevent voltage from being induced into the Autosyn leads Fig. 2 shows a close-up view of the several components of the simulator.

THEORY OF OPERATION

System I.

Basic omni-instrumentation includes an omnibearing selector (OBS), a deviation indicator with flag alarm, and a TO-FROM indicator For this, the circuitry shown in Fig 3 will suffice When a preselected

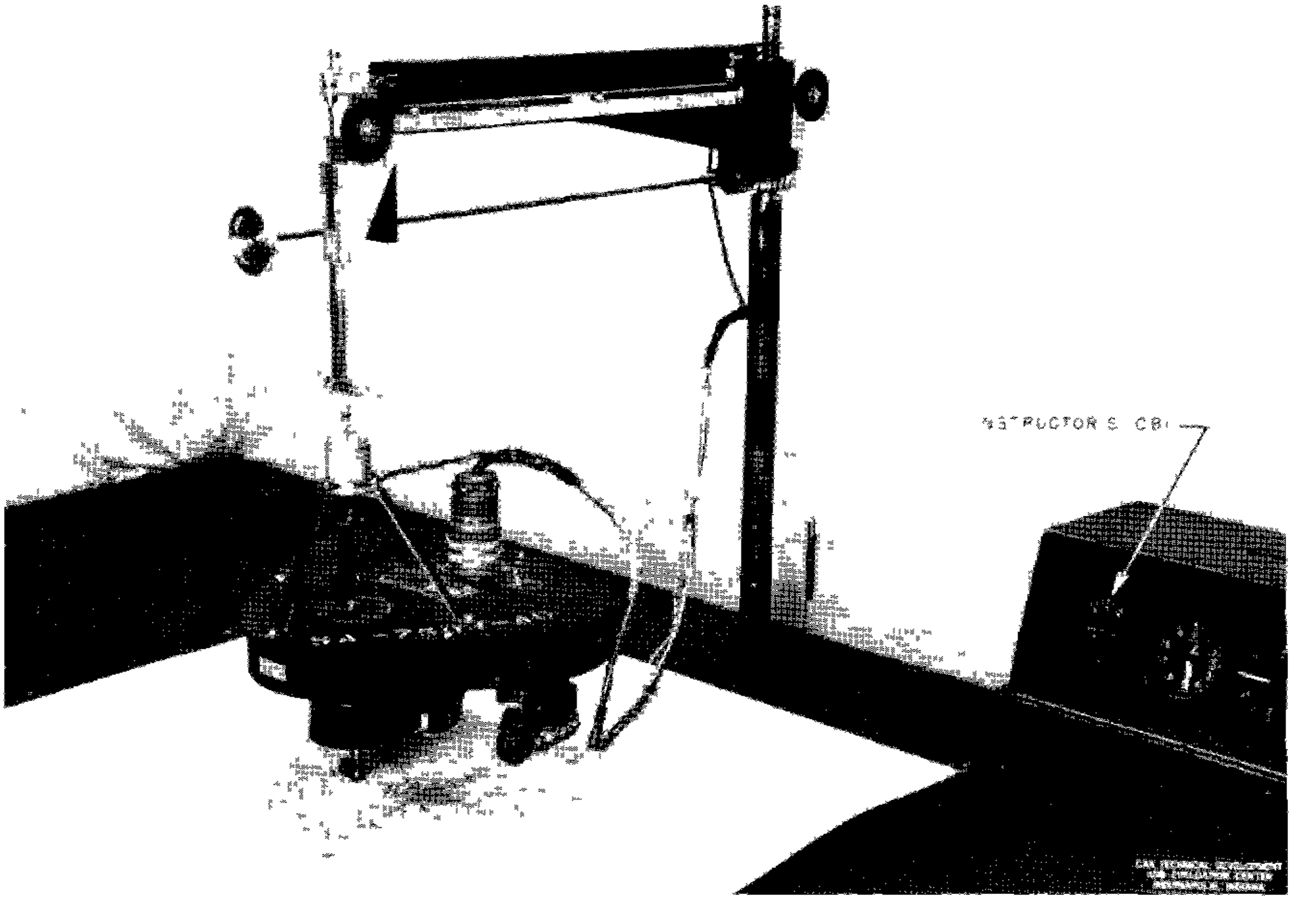

Fig 1 View of Instructor's Desk Showing VOR-DME Simulator

bearing is set into the OBS, the error voltage will be zero if the crab Autosyn and the OBS Autosyn are electrically aligned or are 180° out of alignment Under all other conditions, there will be induced in the rotor of the OBS Autosyn a voltage proportional in magnitude to the angular displacement of this shaft with respect to the Autosyn rotor of the crab The phase of this voltage in the OBS Autosyn rotor varies directly with the sine of the angle of displacement between the two shafts

This error voltage is fed through a two-stage amplifier to a phase-sensitive detector and is applied to the vertical needle of the deviation indicator Vacuum tube V-1A is coupled to tube V-1B, which in turn has the primary winding of transformer T-1 as a plate load The two secondary windings are connected through the 3 15-volt windings of transformer T-2 and through resistors R-6 and R-7 to rectifiers CR-1 The third secondary winding of T-1 provides feedback to the cathode of tube V-1A to stabilize the gain of the amplifier The two power supplies of 3 15 volts obtained from T-2 and applied to the secondary windings of T-1 are of equal magnitude but of opposite phase They are added individually to the error voltage introduced in the secondary windings of T-1, and the combinations are applied to the two bridge rectifiers CR-1 Since the error voltage and one of the 3 15 voltages are in phase, the error voltage will add to the inphase 3 15 voltage and will subtract from the out-of-phase 3 15 voltage The rectifiers are connected so that the difference of these two voltage sums will be applied to the vertical movement of the deviation indicator Resistors R-6 and R-7 cancel effects of variations in the forward resistance of the rectifiers, while R-9 is a potentiometer adjusted to eliminate any unbalance in the circuit R-1 provides a course width adjustment

The sensing amplifier which provides TO-FROM information receives its signal

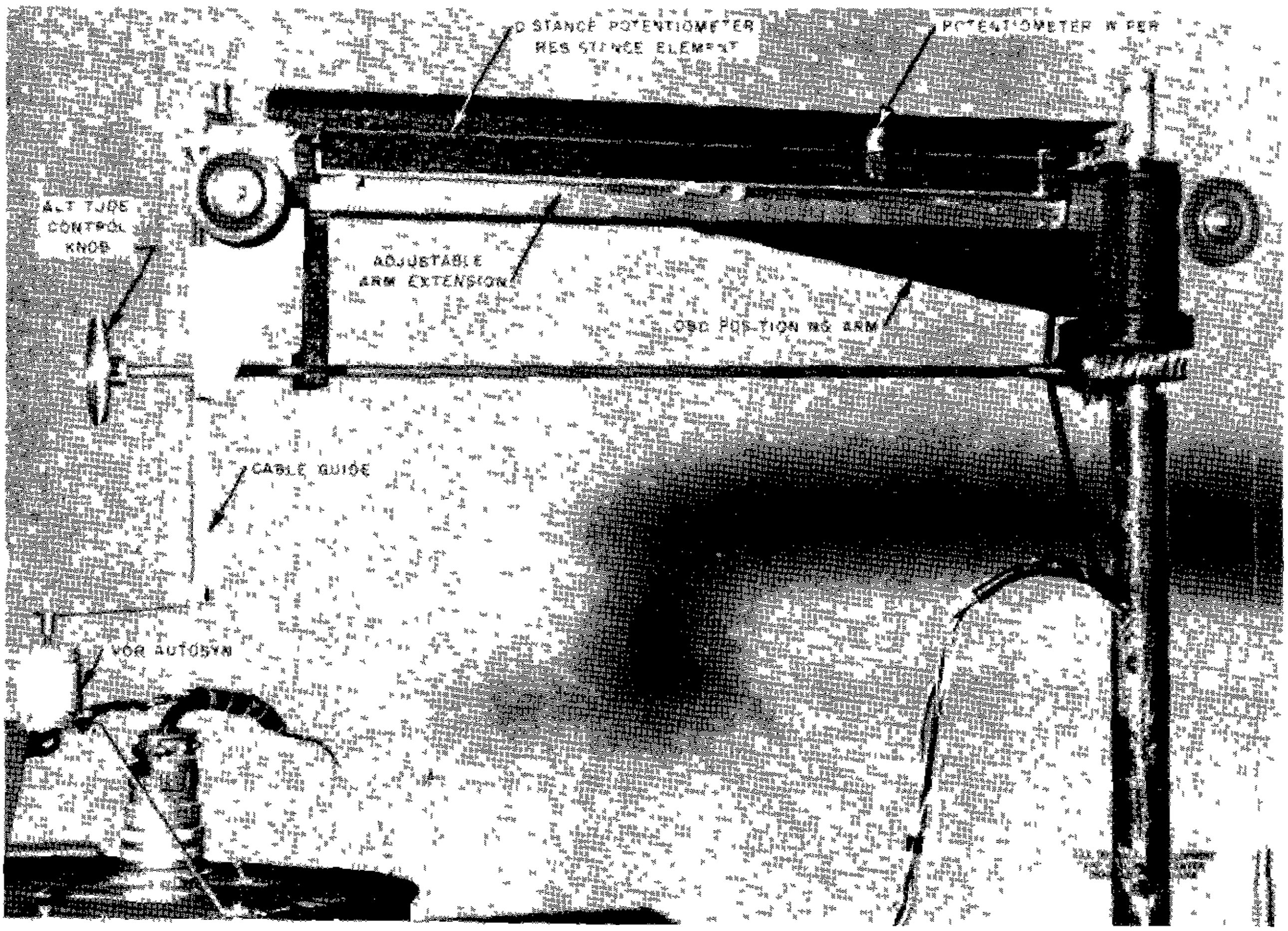

Fig 2 Arrangement of VOR-DME Simulator Components

voltage from a second OBS Autosyn rotor winding which is displaced 90° from that which feeds the deviation indicator amplifier This displacement produces a voltage proportional to the cosine of the angle of displacement between the Autosyn rotors and provides a maximum TO-FROM signal when the deviation signal is zero Since the 30-cps phase shifter in the OBS would provide only one of these voltages, it was necessary to substitute a 400-cps resolver in its place

To align the Autosyns of the crab and OBS set the crab at any known bearing TO the OBD station, then set this same bearing on the OBS Turn the resolver in the OBS until the deviation indicator is centered and the TO-FROM meter reads TO In the sensing amplifier, R-12 is a grid current limiting resistor and V-2A is a voltage amplifier resistor-capacitor (RC) coupled to V-2B The latter tube has relay K-1 as a plate load A 60-cps reference voltage is applied to the plate of V-2B through K-1 and filter capacitor C-3 If the crab is moving TO the station the reference voltage on the plate and the signal voltage on the grid are in phase, and the tube will conduct during positive half cycles causing K-1 to close If the reference and signal voltages are out of phase, the signal voltage will cut off plate current during positive half cycles of plate voltage and K-1 will open to indicate FROM the station To the two contacts of K-1, 3 15 volts at 60 cps of opposite phase are applied Rectifiers CR-2 and CR-3 are connected in such a manner that operation of K-1 reverses the rectified current to the TO-FROM indicator movement

The flag-alarm meter movement is energized by rectifying 3 15 volts from one winding of transformer T-2 through crystal diode CR-4 The flag is thereby held down whenever the equipment is operating

The distance measuring portion of this system utilizes the distance potentiometer as a voltage divider fed from a low voltage dc source The equipment is so connected

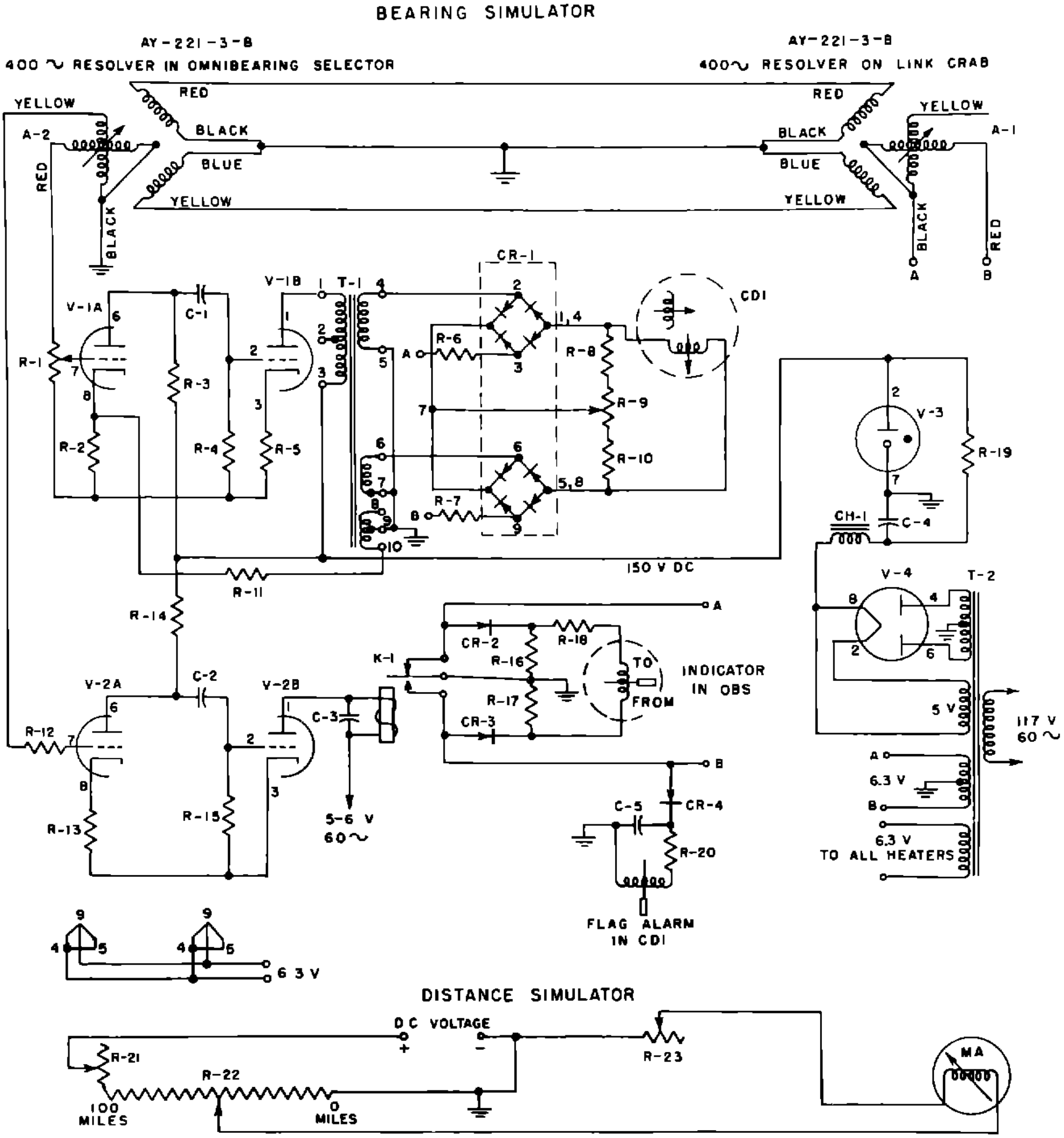

Fig. 3 Schematic Diagram System I

PARTS LIST FOR SYSTEM I (FIG 3)

A-1, A-2	Type A4-221-3-B 400-cps resolvers, Eclipse-Pioneer Division of Bendix Aviation Corp	
C-1	Paper condenser	0 01 mfd
C-2	Paper condenser	0 1 mfd
C-3	Paper condenser	0 1 mfd
C-4	Electrolytic condenser	24 0 mfd
C-5	Electrolytic condenser	10 0 mfd
R-1	Potentiometer	500,000 ohms
R-2	Fixed resistor	2,700 ohms
R-3	Fixed resistor	100,000 ohms
R-4	Fixed resistor	470,000 ohms
R-5	Fixed resistor	1,000 ohms
R-6	Fixed resistor	470 ohms
R-7	Fixed resistor	470 ohms
R-8	Fixed resistor	470 ohms
R-9	Potentiometer	100 ohms
R-10	Fixed resistor	470 ohms
R-11	Fixed resistor	39,000 ohms
R-12	Fixed resistor	1 megohm
R-13	Fixed resistor	3,900 ohms
R-14	Fixed resistor	220,000 ohms
R-15	Fixed resistor	1 megohm
R-16	Fixed resistor	2,700 ohms
R-17	Fixed resistor	2,700 ohms
R-18	Fixed resistor	22,000 ohms
R-19	Fixed resistor	2,500 ohms (10 w)
R-20	Fixed resistor	3,000 ohms
R-21	Potentiometer	500 ohms
R-22	Potentiometer (See text)	Type 1K-L1B precision potentiometer
R-23	Potentiometer	Value selected to give full-scale meter deflection with R-22 at minimum resistance
CR-1	Rectifier	Copper oxide, double bridge
CR-2	Rectifier	Selenium, Type 1N34
CR-3	Rectifier	Selenium, Type 1N34
CR-4	Rectifier	Germanium, Type 1N38
MA	Milliammeter	0-1 range
CH-1	Filter reactor	4 henrys
V-1	Vacuum tube	Type 12AU7
V-2	Vacuum tube	Type 12AX7
V-3	Voltage regulator tube	Type OA2
V-4	Vacuum tube	Type 5Y3

K-1 Relay, single-pole, double-throw, one contact normally closed, operating current 1 0 milliampere (ma)

T-1 Transformer, AF, United Transformer Company (Collins part No 677 019900) primary, 25,000 ohms center tap (c t), secondary No 1, 1000 ohms, secondary No 2, 1000 ohms, secondary No 3, 20,000 ohms c t

T-2 Transformer, power primary, 117 volts, 60 cps, secondary No 1, 520 volts c t at 50 to 90 ma, secondary No 2, 5 volts at 2 0 amps, secondary No 3, 6 3 volts c t at 3 0 amps, secondary No 4 (or additional heater transformer), 6 3 volts c t at 1 0 amp

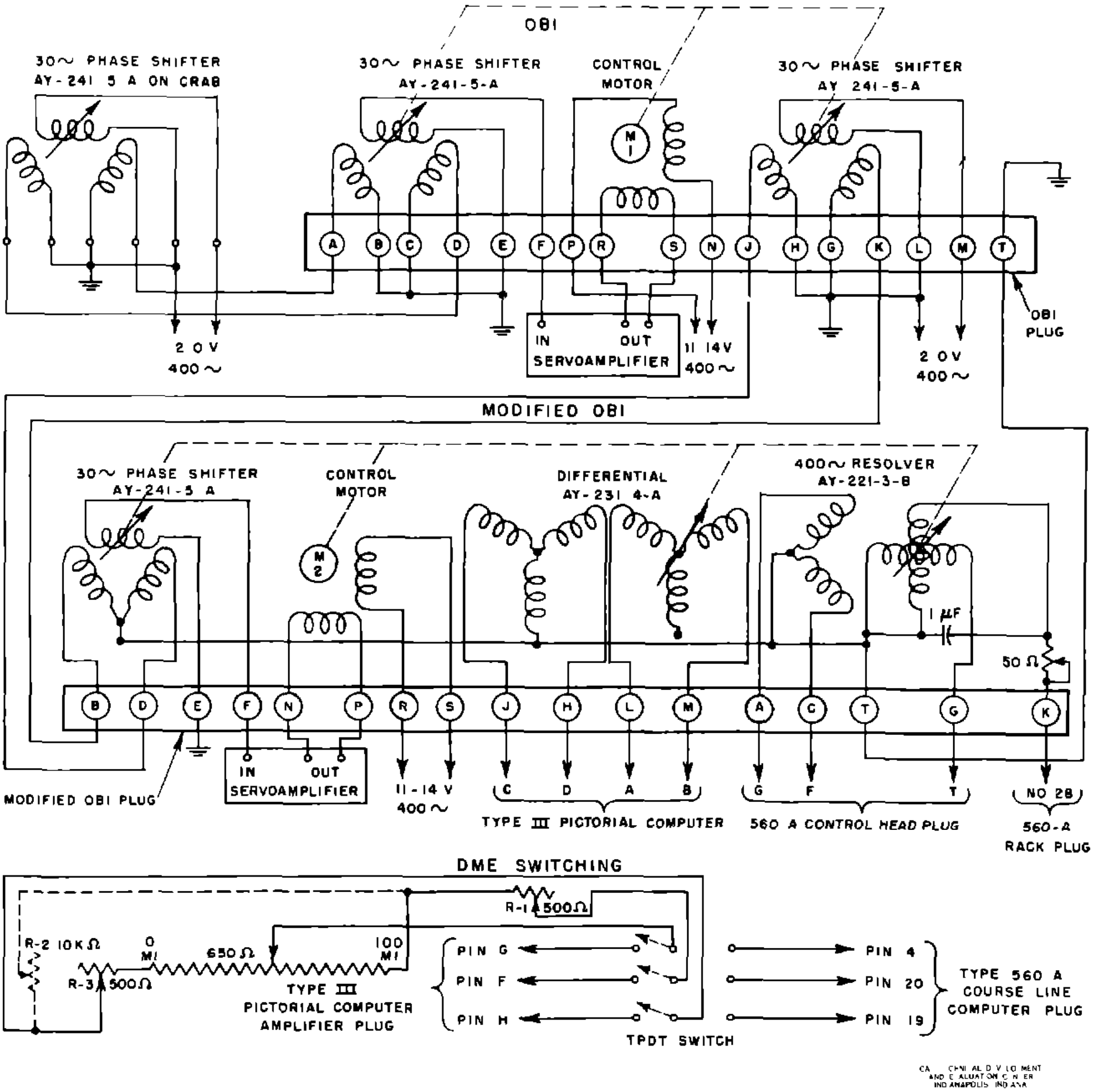

Fig 4 Diagram of System II

that at zero miles from the OBD station the sliding contact is at the ground end of the potentiometer, and no current flows through the distance indicator meter movement Voltage is proportional to range for other distances up to 100 miles, at which point full-scale deflection is obtained on the meter The indicator can be any available meter movement, preferably an 0-1 milliammeter with a suitable series resistor added to adjust for full-scale deflection A dial calibrated from 0 to 100 miles may be secured over the original meter scale

System II

This system which provides bearing and range information in suitable form for operation of course-line and pictorial computers in the Link cockpit presents a more complex problem than one supplying only basic omnirange and DME indications Accordingly the circuits are more involved and additional components are necessary

Fig 4 shows the circuits used to feed pictorial and course-line computers The rotor of the crab transmitting Autosyn, a 30-cps phase shifter, is energized with

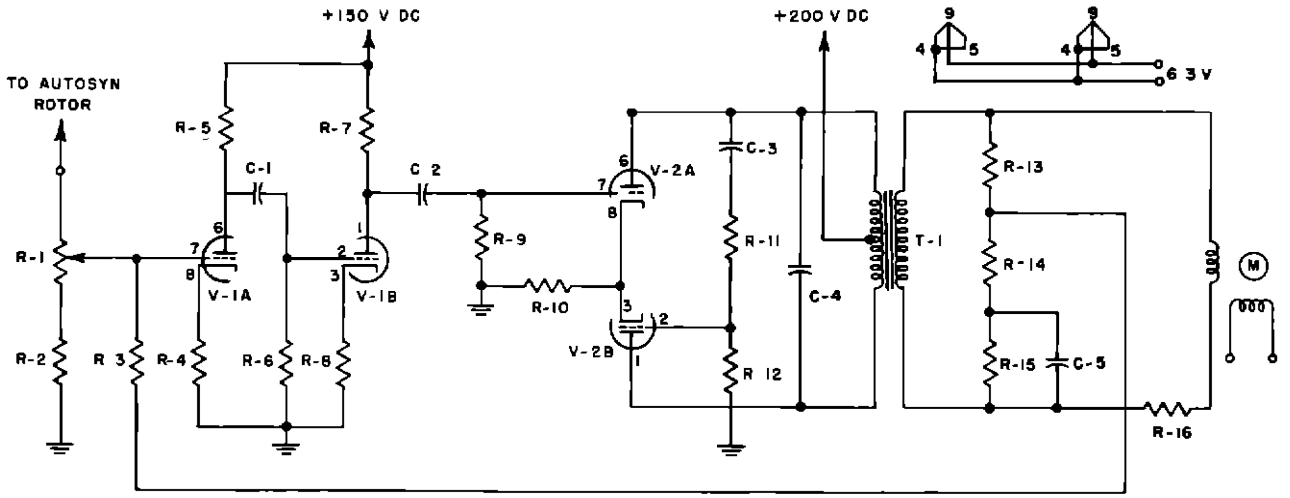

Fig 5 Schematic Diagram Servoamplifier

PARTS LIST
FOR SERVOAMPLIFIER (FIG 5)

C-1	Paper condenser	0 05 mfd
C-2	Paper condenser	0 05 mfd
C-3	Paper condenser	0 01 mfd
C-4	Paper condenser	0 1 mfd
R-1	Potentiometer	250,000 ohms
R-2	Fixed resistor	100,000 ohms
R-3	Fixed resistor	220,000 ohms
R-4	Fixed resistor	1,000 ohms
R-5	Fixed resistor	100,000 ohms
R-6	Fixed resistor	470,000 ohms
R-7	Fixed resistor	100,000 ohms
R-8	Fixed resistor	1,000 ohms
R-9	Fixed resistor	470,000 ohms
R-10	Fixed resistor	1,000 ohms
R-11	Fixed resistor	1 megohm
R-12	Fixed resistor	150,000 ohms
R-13	Fixed resistor	68,000 ohms
R-14	Fixed resistor	68,000 ohms
R-15	Fixed resistor	8,200 ohms
R-16	Fixed resistor	10 ohms
T-1	Output transformer Collins Part No 044 4033 01	15,000 ohms to 150 ohms
V-1	12AU7	
V-2	12AU7	
M	Servomotor in OBI	

2 5 volts at 400 cps, and the stators are connected to the stators of a receiving Autosyn in the omnibearing indicator (OBI) on the instructor's desk Error voltage obtained from the rotor of the OBI Autosyn is amplified and used to run the differential Autosyn in the desk OBI The rotor of this transmitter is energized and its stators are connected to a receiving Autosyn in the modified OBI on the instrument panel of the trainer A voltage taken from the rotor of the Autosyn of the modified OBI receiver is fed to a second servoamplifier which actuates servomotor M-2 A differential Autosyn and a 400-cps resolver coupled to this shaft supply bearing information to the pictorial and course-line computers, respectively

The several Autosyns used in this installation must be aligned for proper operation To accomplish this the stators of the 30-cps phase shifter, which was substituted for the differential Autosyn in the OBI on the instructor's desk, were rotated until the modified OBI read the same The crab was aligned with the trainer heading at 0°, and the stators of the crab Autosyn were rotated until the OBI indicated zero The computers used in the Link trainer were aligned with the modified OBI, in accordance with their instruction manuals

Each OBI requires a servoamplifier and a source of 10 to 15 volts at 400 cps to drive its control motor A schematic diagram of a suitable amplifier, which was used with the equipment at this Center, is shown in Fig 5 An error voltage from the rotor of the receiving Autosyn is applied to the grid of tube V-1A through the voltage divider formed by potentiometer R-1 and resistor R-2 Tubes V-1A and V-1B form a two-stage RC-coupled amplifier feeding output amplifier V-2 The grid of V-2B is connected to

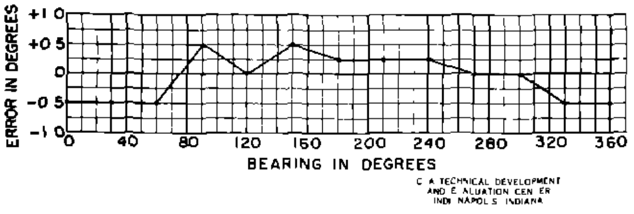

Fig 6 Error Curve, System I

voltage divider R-11, and R-12 is fed from the output of V-2A, thus providing phase inversion for a balanced output Output transformer T-1 is connected to a feedback bridge consisting of resistors R-13, R-14, R-15, condenser C-4, and the motor winding When there is a phase difference between the transmitting and receiving Autosyns, error voltage is applied to the grid of V-1A to operate the motor The feedback bridge is balanced when the motor is not running, but due to back electromotive force (emf) in the motor winding, this bridge is unbalanced when the motor is rotating The back emf is proportional to motor speed, and a portion of it is fed back to the grid of tube V-1A through resistor R-3 as a degenerative voltage to reduce hunting in the system

DME information is furnished to the computers by the same type of distance potentiometer previously described Since the distance potentiometer is used both by the pictorial computer in a bridge circuit and by the course-line computer as a voltage divider, the two types of equipment cannot be operated simultaneously from the same source

The necessary resistance per unit length of the distance potentiometer is determined by the scale of the map used and by computer requirements At this Center a map having a scale of 1 250,000 was selected to conform to the rate of travel of the crab

The computers require a resistance varying from 0 to 1000 ohms to cover a distance from 0 to 120 miles Since 60 miles is the maximum range of this CAA Type III pictorial computer, the resistance need vary only from 0 to 575 ohms This resistance must be distributed over 18 inches corresponding to 60 miles on the map The remaining 425 ohms are obtained by the use of a variable resistor R-1, Fig 4, placed in series with the distance potentiometer The 10,000-ohm variable resistor R-2, shown in dotted lines, will be needed if the computer used with the simulator does not provide sufficient range adjustment for calibration The distributed linear resistance used for the distance potentiometer in this installation is the resistance element removed from a Type 1K-L1B precision potentiometer obtained from the Ford Engineering Company

The initial adjustment of the DME simulator consisted first of setting the resistance of the parallel combination R-2 and the distance potentiometer to 575 ohms and then of setting R-1 to a value which would cause the computer in use to indicate 60 miles when the crab is 17 5 inches from the OBD station The computer was then calibrated according to the manufacturer's instructions The variable resistor R-3 simplifies the final calibration

TEST PROCEDURES AND RESULTS

System I

The accuracy of bearing information was measured by setting the crab at known bearings TO the OBD station at a range of 15 miles and centering the deviation indicator by adjusting the omnibearing selector Table I lists the data taken in this test, and Fig 6 shows the error curve obtained

Maximum errors in the bearing information of System I at a range of 15 miles are ± 0 5°, however, it should be pointed out that bearings are unreliable at distances of less than one mile from the OBD station because of the mechanical construction of the simulator

The accuracy of distance information is shown in Table II in the form of resistance measurements from wiper to ground on the distance potentiometer This test was conducted by setting the crab at positions on a map corresponding to known distances to the OBD station and measuring resistance with a Type S Leeds and Northrup bridge

The maximum errors in the distance information of System I are less than 2 0 per cent Since the linearity of the distance potentiometer is within 0 1 per cent, this test primarily measured the accuracy of travel of the wiper arm The repeatability of distance settings is within 1 0 per cent In the final analysis the accuracy of distance indication is largely determined by the precision of calibration of the distance meter

System II

The accuracy of bearing information supplied by this system was measured by placing the crab at known bearings TO the OBD station and recording the indicated bearings of the OBI on the instructor's desk and the modified OBI in the trainer These readings are shown in Table III For reference, the readings of the CAA Type III pictorial computer are also included

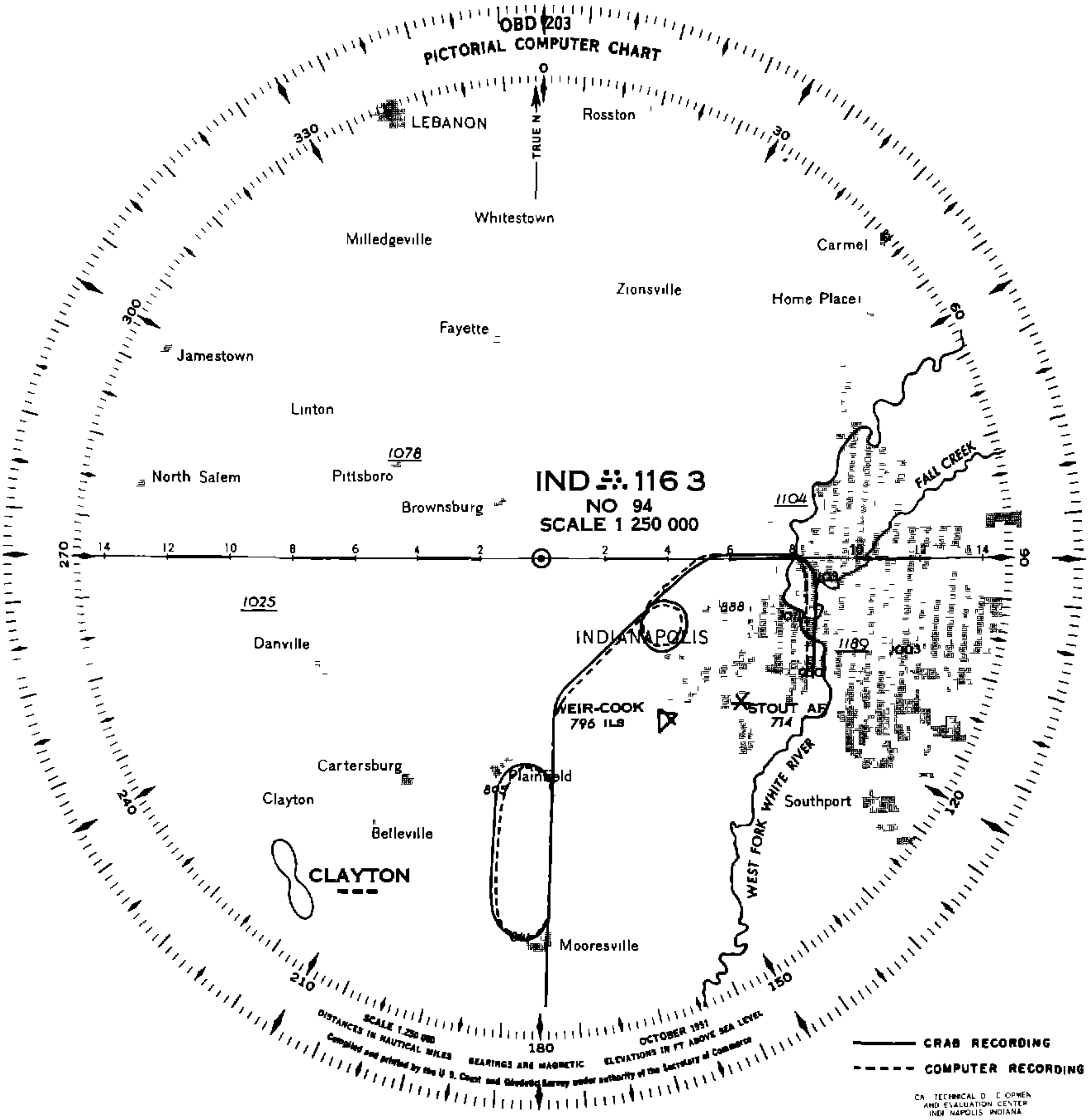

Fig 7 Simulated Flight Paths Recorded by Link Crab and CAA Type III Pictorial Computer

Maximum bearing errors, noted in System II, between the crab position and the modified OBI which drives the computers are ± 1 5° Errors in distance indications for this system are of the same magnitude as those discussed under System I Table IV is included to show the extent of error that may be encountered when using the distance potentiometer to drive a CAA Type III pictorial computer In this test the computer was calibrated at 5, 10, 15, 30, and 55 miles

To present an over-all picture of the accuracy with which System II operates, a problem was tried out in the trainer and recordings of both the crab and the pictorial computer tracks were made These are shown in Fig 7 Errors discernible in the turns are principally due to lag in the computer

INSTRUCTIONS FOR SETTING UP A PROBLEM

Place the map or chart to be used in the desired position on the instructor's desk Adjust the OBD positioning arm and extension to locate the cable guide over the station Energize the trainer and the teletorque motor in the crab Draw an initial bearing line at least ten inches long through the point of origin of the problem and the OBD station Determine the bearing from the point of origin to the station Place the crab on the initial bearing line ten inches from the station and adjust the trainer heading, as read on the crab, to agree with the trainer and with the map Rotate the stators of the Autosyn on the crab to make the desk OBI read the measured omnibearing

For additional problems on the same map it will only be necessary to determine the bearing TO the station from the new point of origin, to place the crab on the initial bearing line, and to rotate the crab frame until the correct desk OBI indication is obtained

TABLE I

BEARING ACCURACY

Crab Bearing (degrees)	OBS Reading to Center Deviation Indicator (degrees)	Error (degrees)
0	359 5	- 0 5
30	29 5	- 0 5
60	59 5	- 0 5
90	90 5	+ 0 5
120	120 0	0 0
150	150 5	+ 0 5
180	180 25	+ 0 25
210	210 25	+ 0 25
240	240 25	+ 0 25
270	270 0	0 0
300	300 0	0 0
330	329 5	- 0 5
360	359 5	- 0 5

TABLE II

DISTANCE ACCURACY

Distance to OBD Station (miles)	Resistance of Distance Potentiometer (ohms)	Error (ohms)
0	13 84	-
5	50 7	0 0
10	102 3	0 9
15	153 9	0 9
20	207 5	3 8
25	260 9	2 7
30	312 8	1 2
35	365 4	1 9
40	420 5	4 4
45	471 9	0 7
50	527 5	4 9
55	580 5	2 3
60	633 5	2 3

TABLE III

BEARING ACCURACY

Crab Bearing (degrees)	Desk OBI (degrees)	Modified OBI (degrees)	Error Crab Bearing to Modified OBI (degrees)	Type III Pictorial Computer (degrees)
0	0 0	358 9	- 1 1	358 4
30	29 0	28 5	- 1 5	28 1
60	59 0	58 4	- 1 6	57 9
90	89 0	88 8	- 1 2	88 5
120	119 5	119 5	- 0 5	118 9
150	149 0	149 0	- 1 0	148 8
180	179 0	179 3	- 0 7	179 0
210	209 0	209 7	- 0 3	209 8
240	240 0	241 4	+ 1 4	241 7
270	270 5	271 2	+ 1 2	270 0
300	301 0	300 5	+ 0 5	300 5
330	331 0	330 0	0 0	329 5
360	360 0	358 9	- 1 1	358 4

TABLE IV

DISTANCE ACCURACY

Distance to OBD Station (miles)	Distance Indicator on CAA Type III Pictorial Computer		
	60-Mile Scale (miles)	30-Mile Scale (miles)	15-Mile Scale (miles)
0	0 25	0 5	1 4
5	5 0	5 0	5 0
10	10 0	10 2	10 0
15	15 2	15 0	15 0
20	20 0	20 0	
25	25 2	25 0	
30	30 0	30 0	
35	34 9		
40	40 0		
45	45 0		
50	50 0		
55	55 0		

CPO 81-103980