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EVALUATION OF THE ANSCOPILOT

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EVALUATION OF THE ANSCOPILOT

SUMMARY

The Anscopilot is an autopilot for aircraft of the private-flyer class. It is an electromechanical system with the design emphasis on reliability, light weight, and low cost. This report explains the operation of the equipment and describes the performance obtained during a series of flight tests conducted at the CAA Technical Development and Evaluation Center in a Piper Pacer airplane.

INTRODUCTION

The complexity, high cost, and weight of commercially available autopilot systems prompted Mr. Monroe Sweet of Ansco Division of General Aniline and Film Corporation to attempt the development of a simplified autopilot suitable for aircraft of the private-flyer class. The design was intended to emphasize simplicity and reliability and, if necessary, to compromise some performance characteristics not considered essential to the private flyer.

The impressive results secured from an experimental model in a Navion caused Ansco to encourage its further development toward a marketable equipment. In 1952, the Civil Aeronautics Administration entered into a contractual agreement with Ansco Division of General Aniline and Film Corporation for the installation of an experimental model of the Anscopilot in a Piper Pacer airplane which was rented for the purpose. The contract specified that the autopilot installation must provide for control of the aircraft about the roll and pitch axes and must include provision for automatic flight on any selected magnetic heading and for homing on omnirange stations. The equipment as installed in the Piper Pacer satisfied these requirements. This report explains the operation of the equipment and describes the performance obtained in a series of flight tests conducted at TDEC.

DESCRIPTION

Roll-Axis Control

The most important and unique design feature of the Anscopilot is embodied in the roll-axis control. Roll-axis control uses a modified gyro horizon indicator. The modification involves mounting a pair of movable contacts on an assembly attached to the rear of the indicator. These contacts are so located and spaced that they engage a center contact secured to the roll-axis gimbal of the gyro. When the gyro axis is erect and the aircraft is in level flight, the center contact does not touch either one of the movable contacts. When the aircraft is displaced in roll, contact is established between the center contact and one of the movable contacts, and this closes a relay, energizing the roll-actuator motor to move the ailerons in a direction to return the aircraft to level flight.

Fig. 1 illustrates a complete cycle of operation from the time the aircraft is disturbed by a sudden gust until it is returned to level flight. The illustration is not an accurate representation of the mechanical layout, but accuracy is sacrificed here in the interest of clarifying the principle of operation.

Roll-axis control also utilizes information from the turn-bank indicator. The modification of this instrument also involves the use of a pair of contacts, so located and spaced that they engage a movable center contact. The center contact is attached to an arm pivoted about the same axis as the pointer of the turn indicator and moves in accordance with the position of the pointer. When the aircraft enters a turn, contact is established between the center contact and one of the contact pair, closing a relay which energizes the gyro-horizon trim motor to change the position of the contact pair on the gyro horizon. The contact pair on the turn-bank indicator is movable in an arc about the center contact, and this movement is controlled by the turn-bank trim motor. The purpose of this arrangement is discussed later.

The contact pair on the gyro-horizon indicator is assembled in a manner which permits it to be moved in an arc about the center contact. The contact pair can be displaced along the arc in several ways, each of which accomplishes a specific purpose. These ways are by: (1) the manual turn control; (2) the gyro-horizon trim motor, which is energized in accordance with information from the turn-bank indicator; and (3) mechanical coupling between the contact pair and the aileron cables.

When the position of the contact pair is changed from the normal or level flight position by the manual turn-control knob, the airplane will stabilize in a banked attitude corresponding to the changed position of the contact pair and will result in a co-ordinated turn. Rudder-aileron co-ordination is not provided by the autopilot but must be provided on the airplane as a separate modification. On the Piper Pacer which was used for the flight tests to be described, this modification was accomplished prior to the autopilot installation.

When the gyro-horizon contact pair is in the level-flight position and the aircraft deviates from straight flight, the turn-bank indicator senses the turn and contact is made between the center contact and one of the contact pair on the turn-bank indicator, energizing the gyro-horizon trim motor and causing the contact pair of the gyro horizon to initiate a co-ordinated turn to return the aircraft to straight flight.

The movement of the horizon-gyro contact pair by mechanical feedback is analogous to negative feedback as employed in electrical circuits. A mechanical linkage between the aileron-control cable and the shaft about which the contact pair rotates provides this feedback. It is negative feedback because the sensing is such that when the aileron cable moves the contact pair is moved in a direction to oppose this motion. This feedback action is responsible for the smooth recovery which the autopilot accomplishes when returning to level flight.

Pitch-Axis Control

Pitch-axis control is accomplished in essentially the same manner as roll-axis control. The gyro-horizon indicator is modified by attaching a contact pair which engages a center contact mounted on the pitch-axis gimbal. When the aircraft is displaced about the pitch axis from the level-flight position, the center contact establishes contact with one of the contact pair, energizing the pitch-actuator motor to move the elevator in the direction to return the aircraft to level flight. The position of the contact pair can be controlled manually, and the control provided for this purpose constitutes the autopilot pitch trim control. A trim motor is not used to position the contact pair since the autopilot does not include altitude control. In the experimental model installed in the Piper Pacer, a separate gyro-horizon indicator was used for pitch control. The same gyro which was modified for roll-axis control can be used, but delivery was expedited by the use of the two gyros.

Magnetic-Compass Coupler

With autopilot roll- and pitch-axis control, the aircraft is maintained in essentially level flight and will fly a constant heading. However, if the aircraft is disturbed from its level-flight attitude by gusts which predominate in a direction different from the initial heading, the autopilot will control attitude to maintain average level flight but the heading will change. If pitch- and roll-axis control only are employed, the aircraft will not continue on a constant heading indefinitely. The magnetic-compass coupler provides a means for automatically maintaining the aircraft on any selected magnetic heading.

A standard Model B-16 magnetic compass is modified to provide a source of heading information. The top of the compass card is divided into two 180-degree segments by painting one half white and the other half black. A light source is directed onto the top of the card, and the reflected light is collected on a photosensitive tube. The light source and the photo tube are mounted on a rotatable assembly which is geared to the heading-selector control. This control determines the position of the spot of light on the compass card. See Fig. 2. The system operates to cause the airplane to enter and to continue a turn until the spot of light rests on the same black-white dividing line on the top of the compass card. The ambiguity of 180 degrees is inherently eliminated. The aircraft heading will stabilize at a value corresponding to the position of the spot of light; and this position, and hence the desired heading, is selected by the heading-selector control. The system employed is a feedback-control system. The controlled system is the aircraft; the reference input is the position of the spot of light; and the controlled variable is the heading of the aircraft.

The operation of the magnetic-compass coupler system is as follows: The output of the photo tube is applied to the compass-coupler amplifier, where it is compared to the voltage at the arm of the turn-bank potentiometer which is mechanically coupled to the turn-bank trim motor.

The turn-bank trim motor will run and rotate the turn-bank contact pair until the voltage at the arm of the potentiometer balances the voltage supplied by the photo tube. The voltage supplied by the photo tube is a variable depending on the position of the spot of light on the painted disc. At some particular voltage value, the turn-bank trim motor will come to rest with the contact pair in such a position that the center contact is centered and the turn-bank pointer is indicating zero turn rate.

When the center contact associated with the turn-bank contact pair makes electrical contact to either one of the pair, the gyro-horizon trim motor is energized, causing a displacement of the gyro-horizon contact pair and initiating a co-ordinated turn. The turn continues until the spot of light, directed on the painted top of the compass card, reaches a position which develops a voltage in the photo tube which satisfies the turn-bank trim motor. The system will stabilize when the voltage developed by the photo tube corresponds to the voltage required to center the turn-bank contact pair in the zero-turn-rate position. A simplified schematic diagram of the magnetic-compass amplifier is shown in Fig. 3.

Omnirange Coupler

The omnirange coupler is an accessory to the autopilot and extends its usefulness to include automatic flight control in accordance with the VHF omnirange information. The additional components required for this function are contained in the omnirange-coupler control box, Fig. 4. The unit is shown with the housing removed in Fig. 5. The omnirange receiver, which in this installation was the Narco omnigator, was modified to adapt it for autopilot control. The operation of the receiver for navigation or communication purposes was not affected by the modification.

The course-selector control, including the potentiometer associated with it, was removed from the Narco omnigator and a Helipot with 360-degree rotation was substituted and mounted in the omnirange-coupler control box. A Sensitrol relay (5-0-5 microamperes) was inserted in series with the course deviation indicator and was also mounted in the omnirange-coupler control box. In addition to these components, the control box houses a d-c motor, relays, a gear train, and a shaft which provides remote control of the rotation of the photo tube and of the light source associated with the magnetic-compass coupler.

The omnirange coupler accomplishes its function by controlling aircraft heading through the magnetic-compass coupler. A description of the method employed is as follows: In referring to Fig. 4, it will be observed that the omnirange control box has two control knobs. These control knobs position the pointers on the face of the instrument. The single-bar pointer, which is mechanically coupled to the 360-degree Helipot, is the omnirange course selector. The knob on the lower left controls the double-bar pointer, and by means of a flexible shaft it also controls the photo tube and the light source of the magnetic-compass coupler, affording heading selection. Inside the omnicoupler control box, a gear train couples a d-c motor to the course-selector shaft and to the shaft which positions the magnetic-compass-coupler light source. When the d-c motor is energized, it simultaneously drives the course selector (single-bar pointer) and the magnetic-compass selector (double-bar pointer), thereby rotating the photo-tube and light-source assembly.

The d-c motor is connected, through relays, in series with the course deviation indicator. When the pointer of the course deviation indicator deflects to the right or left, the contacts of the double-throw Sensitrol relay make electrical contact to cause the d-c motor to initiate a sequence of actions terminating in a change of aircraft heading in the proper direction to fly toward the omnirange. The method employed for omnirange control can be visualized as equivalent to substituting VOR information for manual selection of the magnetic-compass selector setting.

In order to use the omnirange coupler, the single- and double-bar pointers are aligned so that they coincide. The omnirange is tuned in on the VOR receiver and the TO-FROM switch is thrown to the TO position. The autopilot will then cause the airplane to fly toward the station. If no crosswind component is encountered, the track of the aircraft will be along an omniradial to the station. In the presence of a crosswind component, the track will be a spiral heading directly into the wind as the station is approached. The effect is analogous to that observed when flying an ADF. Flight along a straight track to the station can be accomplished by compensating for wind direction and velocity and by using techniques similar to those employed when flying an ADF track.

A small amber lamp, visible to the pilot, is actuated by the TO-FROM circuit in the omnigator. This lamp lights when the aircraft arrives over the omnirange, indicating that it has reached the station.

All of the Anscopilot components, including the airborne radio equipment necessary for the operation of the omnirange coupler, are shown in Figs. 6 and 7.

Autopilot Controls

A brief description of the various controls employed in the operation of the autopilot is presented here. The location of the controls on the instrument panel is illustrated in Fig. 8.

1. ON-OFF Switch. This switch engages the autopilot. In order to eliminate any tendency of these contacts to influence the gyro, a cam on the shaft of this switch spreads the contact pair on the gyro-horizon indicator when the switch is in the OFF position.

2. Manual Turn Control. This knob controls the position of the contact pair which is on the modified gyro-horizon indicator and which engages the center contact of the roll-axis gimbal. The knob is calibrated for left and right turns, each division representing 5 degrees of bank. Bank-angle control is limited to 30 degrees in each direction.

3. Pitch-Trim Control. This control, labeled "Nose Up" and "Nose Down," provides manual positioning of that contact pair on the gyro horizon which engages the center contact attached to the pitch-axis gimbal. The limits are 5 degrees above and below level flight.

4. Magnetic-Compass Course Selector. This knob is connected by a flexible shaft to the magnetic compass. It is used to rotate the phototube and light-source assembly and thus to select the heading on which the airplane will stabilize.

5. Magnetic-Compass Switch. This switch, labeled "ON-OFF," controls the power to the compass amplifier.

6. Omnicoupler Switch. Three positions are provided on this switch: TO-OFF-FROM. When this switch is in the OFF position, the omnigator can be operated as a conventional VOR receiver. In the TO position, the omnicoupler is engaged and the aircraft will fly a rhumb line to the station to which the receiver is tuned. In the FROM position, the aircraft will fly away from the omnirange station.

7. Omnicoupler-Reset Push Button. When activated, this button turns off the FROM amber light after the aircraft has again resumed a TO course on the VOR.

8. Omnicourse Selector. This controls the single-bar pointer on the omnicoupler-control box and is analogous to the course selector on the navigation receiver.

9. Course-Trim Control. This is a potentiometer which controls the ratio of the voltages applied to the roll actuator motor. It provides a means for trimming the aircraft to maintain a constant heading.

Weight and Power Requirements

Weight. In assessing the weight attributable to the autopilot system installation, the weights of several components which were modified are listed in Table I, both in the modified and unmodified form. This is appropriate since the flight instruments involved serve as useful or necessary instruments, their use being only negligibly affected by the modification. This applies to the magnetic compass, the turn-bank indicator, and the gyro-horizon indicator.

TABLE I

WEIGHTS OF AUTOPILOT COMPONENTS

Component	Unmodified Weight (Pounds)	Modified Weight (Pounds)	Weight Assignable To Autopilot (Pounds)
Gyro-Horizon Indicator (Roll)	4.5	6.2	1.7
Turn-Bank Indicator (with Electrical cabling)	1.5	2.4	0.9
Gyro-Horizon Indicator (Pitch)	4.5	5.7	1.2
Magnetic Compass, Light Source, and Photo-Tube Assembly (with electrical cabling)	1.6	3.4	1.8
Compass Amplifier	-	2.7	2.7
Omnicoupler	-	2.6	2.6
Roll Actuator (with associated cables)	-	4.2	4.2
Pitch Actuator (with associated cables)	-	4.4	4.4
Relay Box and Control Panel	-	2.9	2.9
Pitch-Control Switch)			
Course Trim Control)			
Circuit Breaker)			
Mechanical Feedback Coupling (aileron)	-	0.3	0.3
Mechanical Feedback Coupling (elevator)	-	0.3	0.3
Magnetic-Compass Coupler Balance Indicator (with electrical cabling)	-	0.8	0.8
Rudder-Aileron Co-ordination Kit	-	3.3	3.3
Miscellaneous Hardware	-	1.3	1.3
Total	12.1	40.5	28.4

The weight can be classified according to the function provided as shown in Tables II, III, IV, and V.

TABLE II

ROLL-CONTROL WEIGHTS

Component	Unmodified Weight (Pounds)	Modified Weight (Pounds)	Weight Assignable To Autopilot (Pounds)
Gyro-Horizon Indicator (Roll)	4.5	6.2	1.7
Turn-Bank Indicator (with electrical cabling but without trim motor)	1.5	1.8	0.3
Roll Actuator (with associated cables)	-	4.2	4.2
Relay Box	-	1.5*	1.5*
Mechanical Feedback Coupling (aileron)	-	0.3	0.3
Miscellaneous Hardware	-	0.4*	0.4*
Rudder-Aileron Co-ordination Kit	-	3.3	3.3
Total	6.0	17.7	11.7

* Estimated.

TABLE III

PITCH-CONTROL WEIGHTS

Component	Unmodified Weight (Pounds)	Modified Weight (Pounds)	Weight Assignable To Autopilot (Pounds)
Gyro-Horizon Indicator (Pitch)	4.5	5.7	1.2
Pitch Actuator (with associated cables)	-	4.4	4.4
Relay Box	-	1.4*	1.4*
Mechanical Feedback Coupling	-	0.3	0.3
Miscellaneous Hardware	-	0.3*	0.3*
Total	4.5	12.1	7.6

* Estimated.

TABLE IV

MAGNETIC-COMPASS-COUPLER WEIGHTS

Component	Unmodified Weight (Pounds)	Modified Weight (Pounds)	Weight Assignable To Autopilot (Pounds)
Magnetic Compass, Light Source, and Photo-Tube Assembly (with electrical cabling)	1.6	3.4	1.8
Turn-Bank-Indicator Trim Motor	-	0.6	0.6
Compass Amplifier	-	2.7	2.7
Magnetic-Compass Coupler-Balance Indicator (and associated electrical wiring)	-	0.8	0.8
Miscellaneous Hardware	-	0.3*	0.3*
Total	1.6	7.8	6.2

* Estimated.

TABLE V

OMNIRANGE-COUPLER WEIGHTS

Component	Unmodified Weight (Pounds)	Modified Weight (Pounds)	Weight Assignable To Autopilot (Pounds)
Omnicoupler	-	2.6	2.6
Miscellaneous Hardware	-	0.3*	0.3*
Total		2.9	2.9

* Estimated

Power. All electrical power required to operate the autopilot is supplied by the aircraft 12-volt, d-c supply. The roll- and pitch-actuator motors consume approximately 24 watts each when delivering full power. The omnirange coupler consumes 14 watts maximum (this is an intermittent demand). The magnetic-compass-coupler amplifier uses 28 watts. The power consumption of the trim motor and relays is negligible.

RESULTS

A series of flight tests was conducted during which recordings of performance were made. TDEC pilots also made observations while in routine flight and during recovery from unusual attitudes. The equipment assembled in the airplane for making recordings consisted of an Esterline-Angus recorder and a vacuum-driven directional gyro, an Aneroid altimeter, and a vertical gyro, all with provisions for electrical pick-off. The test equipment is shown in Fig. 9.

Roll-Axis Control

A recording of roll-axis performance is shown in Fig. 10. As will be noted from the graph, the stability in the roll axis was very good, displacement about the roll axis being confined to approximately plus or minus 3 degrees. In flight, these relatively rapid oscillations are not detected and are not associated with any roughness.

When the airplane was manually controlled into a 30-degree or greater bank and released, the autopilot accomplished a smooth recovery and no oscillation could be detected as the aircraft returned to level flight.

Since the heading of the aircraft must be recognized as a function of its roll attitude, recordings were made of aircraft heading with roll control engaged. The results are shown in Figs. 11, 12, and 13. These recordings were in each instance started after the autopilot roll control was trimmed for level flight. It will be noted that heading was held approximately constant for the intervals of time recorded.

In obtaining the recordings of heading, the aircraft was first trimmed for level flight and its heading was noted from observation of section lines. The recording gyro was then caged and released. At the completion of the recording, the aircraft was manually flown on the original heading and the gyro was again caged. Since the difference between the two settings of the gyro in the caged position would be a measure of gyro precession, this method provides a means for compensating for gyro precession.

The results of measurements of yaw-axis stability over longer periods will be discussed further in a later part of this report. It will be noted that the graphs showing heading stability were recorded with both pitch and roll controls engaged. Essentially the same results would be obtained if pitch control were not used. This was confirmed on later tests.

Pitch Control

The results of tests to determine pitch-axis stability are illustrated in Figs. 14 and 15. The recordings show that pitch control was effective in confining the excursions about the pitch axis to approximately 2 degrees. While altitude control is not incorporated in the autopilot, it is of interest to observe the effect of pitch control on altitude. A typical recording is shown in Fig. 16. This is not typical in the sense that the performance would be duplicated in atmospheric conditions where severe thermals are encountered; but neither does it represent unusually favorable atmospheric conditions, since during most of the flight testing this degree of performance was obtained. In Fig. 17 the effectiveness of pitch control in maintaining a uniform rate of climb is shown.

Roll and Pitch Control

The effectiveness of roll and pitch control during turns was measured by recording altitude throughout the turn. Fig. 18 shows a recording of altitude during a 360-degree turn with 15-degree bank, and Fig. 19 is a recording of a 360-degree turn with 30-degree bank.

Magnetic-Compass Coupler

The graphs previously discussed showed that the autopilot, when properly trimmed and when the roll- and pitch-axis controls were engaged, maintained essentially constant heading for the time interval recorded. However, under these conditions the heading of the aircraft will not remain constant indefinitely. The period for which heading will remain constant depends on the degree of turbulence and on other conditions of the atmosphere. If these are such that they show a preponderence in one direction, a corresponding change in heading will result when no heading reference is employed.

The magnetic-compass coupler provides a method for using the magnetic compass as a heading reference, and its effectiveness was evaluated in two ways. In Figs. 20, 21, 22, and 23, the results shown were obtained in the following manner. A magnetic-compass heading was selected, the aircraft was manually controlled to assume this heading; the gyro was caged, then uncaged; and the aircraft was manually displaced by approximately 20 degrees and released. With the compass-coupler heading selector set for east, west, or south, the recordings show that the autopilot quickly returned the aircraft to the selected heading. When north heading was selected, however, the response was considerably slower. This performance is inherent with this type of control, since the magnetic compass has a decided indication lag on northerly headings.

In another test of the magnetic-compass-coupler performance, a cross-country flight was recorded. The flight originated at Indianapolis, Indiana, with Vandalia, Ohio, as the destination, a distance of 112 miles.

After take-off, the magnetic-compass-coupler heading selector was set to agree with the bearing of the course to the destination and was compensated for magnetic variation, compass deviation, and wind. The autopilot successfully guided the aircraft to the destination. A plot of the track of the aircraft is shown in Fig. 24, and a continuous recording of the en route heading is shown in Fig. 25. It will be observed that the heading is not as stable as when roll and pitch control only is engaged but that the magnetic-compass coupler is effective in maintaining an average heading necessary for flying a straight track.

On the return flight from Vandalia, Ohio, to Indianapolis, the airplane was started on a track directed to Indianapolis and the autopilot roll- and pitch-axis control only was engaged. The plot of the track is shown in Fig. 26 and the heading is recorded in Fig. 27. Short-period excursions of heading are confined to approximately plus or minus 3 degrees; but over long periods the heading drifts considerably, and this is reflected on the plot of the track of the aircraft.

<u>Omnirange Coupler</u>

Flight tests to determine the performance of the omnirange coupler were conducted on a calm day and also during a period when a 30-knot wind prevailed. The tests consisted of a succession of trials to observe the track of the aircraft from the time the omnirange coupler was engaged when the aircraft was approximately 20 miles from the VOR.

When the 30-knot wind was encountered, the starting points for the trials were chosen in such a manner that they required the aircraft to fly directions with and against the wind, and perpendicular to it for a straight track to the VOR. Figs. 28, 29, 30, and 31 show the track of the aircraft when controlled by the omnirange coupler from starting points approximately 20 miles south, east, north, and west, respectively. The wind was 6 knots northeast. The tracks starting from points south or east led directly over the station; but from starting points north or west the aircraft did not arrive directly over the station, the errors being 1/4 mile and 3/4 mile, respectively.

It will be noted that each track exhibits the same tendency to approach the station along a path curved counterclockwise. This cannot be accounted for by the direction of the wind. A likely explanation, which was supported by further flight tests, is that the photo-tube and light-source assembly associated with the magnetic-compass coupler was not properly oriented with respect to the magnetic-compass card.

The tracks plotted in Figs. 32, 33, 34, and 35 were flown when the wind was 30 knots at 335 degrees. It is significant that the tracks flown with and against the wind are characterized by the same curvature as those flown previously in a calm-wind condition. This would seem to establish that the curvature is not affected by the wind conditions.

The tracks flown from starting points causing the aircraft to fly crosswind are revealing. When the starting point was northeast of the station, the track was affected by the wind in a manner to compensate for the inherent error in the equipment. When the starting point was southwest of the station, the direction of the wind was such that it exaggerated the equipment error. The tracks plotted in Figs. 33 and 35 reflect these conditions.

Finally, the track shown in Fig. 36 shows that the equipment is potentially capable of flying a straight track to the station when a relatively high crosswind prevails. This track resulted when the initial setting of the omnicoupler pointer was displaced from the magnetic-heading selector to agree with the crosswind component.

FLIGHT CHARACTERISTICS

The foregoing text describes each of the more or less standard maneuvers with which the autopilot was designed to cope. However, it was believed that for a complete functional evaluation, other maneuvers of a more drastic nature should be imposed. During a series of tests, the autopilot pitch and roll were engaged continuously (except as noted) and were overpowered by the human pilot in order to place the aircraft in "unusual positions." The following descriptions relate to the autopilot performance after the controls were released.

Stall, Power On

A cruising power, straight and level, nose-high stall was entered. After the first sign of a complete stall was encountered, the aircraft was released. The autopilot caused the aircraft to assume a nose-below-the-horizon attitude and to gain air speed. As cruising speed was approached, the aircraft gradually and smoothly returned to level flight and remained there. A slight change of direction was noted before straight flight was resumed. This resulted from the abruptness of air-speed change wherein the turn-and-bank trim motor was unable to operate rapidly enough to compensate for aircraft rigging. No overshooting or oscillating was noted about the pitch axis.

Stall, Power Off

The power-off stall was entered from a straight and level flight in a three-point attitude. As before, the aircraft was released after a complete stall was encountered. The recovery was similar to the power-on recovery with one exception: Instead of returning to level flight, the aircraft was brought to equilibrium in a glide (power still off) which allowed a safe air speed to be maintained. When cruising power was applied, the aircraft returned to level flight as before. Again, slight directional changes were observed for reasons previously noted.

Climbing Turns, Power On

The aircraft was manually forced into 45-degree, banked, steep, climbing turns, then released. Roll and pitch recoveries were simultaneous, and after the wings became level the recoveries progressed as described previously under power-on stalls.

Spirals

The aircraft was allowed to enter a diving, power-on spiral with the autopilot disengaged. Recovery was made by the autopilot as soon as it was engaged. A slight over-correction was noted, causing a gradual turn in the opposite direction before straight and level flight was resumed.

Simulated Power Failures

Autopilot pitch and roll controls were continuously engaged during these tests. In each test all changes in throttle, pitch trim, and roll control were accomplished manually. All changes in aircraft attitude as a result of these manual adjustments are attributed directly to the autopilot performance.

A full-power steep climb was entered with the pitch trim in the maximum nose-high position. An air speed of 93 mph was maintained. The throttle was then closed causing the nose to lower, and the aircraft entered a glide at a speed oscillating between 85 and 90 mph. A slight right turn was noted.

The maximum (30-degree) bank and nose-up trim were applied. The power was reduced from cruising to idling. The air speed dropped to approximately 95 mph. A safe glide and the same angle of bank were maintained. Results were the same for turns in either direction.

Slow flight was maintained by using maximum nose-up trim on the pitch control. Power failure was simulated. The air speed changed from 85 mph before power failure to a 90 mph glide after failure. Full throttle was then added to determine the autopilot reaction. A climb was established at an air speed of 95 mph straight ahead. At no time was a dangerous air speed or attitude evident.

Power failure at straight and level flight resulted in an air-speed change from 118 mph to 95 mph with a 1,000-fpm descent. A slight heading change was noted.

The compass coupler was not used during any of the foregoing tests because its stability is questionable under conditions where any turbulence or unusual attitudes may be encountered. It was found in previous tests that a heading could be maintained more accurately in turbulence for short periods of time without the magnetic-compass coupler.

The forces necessary to override the autopilot were noted in flight when the controls were operated manually with the autopilot engaged. When the aircraft was flown in this manner it was evident from the stiffness of the control column that the autopilot was engaged, but this did not seriously affect manual control.

CONCLUSIONS

It is concluded that the equipment meets the design objective by a comfortable margin. The autopilot performs in a thoroughly satisfactory and reliable manner and, from an inspection of the components, it is evident that considerable ingenuity was exercised in the mechanical design.

The weight, size, and power requirements of the system are compatible with the capacity of light aircraft. During the flight tests which were devoted to observing how safely the autopilot performed, the results were very favorable. This is significant, since a familiar cause of accidents to the private flyer is traceable to the pilot's inability to control the aircraft's attitude when reference to the horizon is lost.

Finally, it is concluded that the autopilot contributes to the enjoyment of private flying, since in a routine flight it can relieve the pilot of constant attention to maintaining attitude and heading.

RECOMMENDATIONS

It is recognized that these recommendations include some items which are the normal consequence of a hand-made experimental model, and their correction in production is obvious. However, since this report reflects the performance of the equipment as received, those easily or obviously correctible items are listed along with others which were observed as the tests progressed.

1. The turn control is calibrated in 5-degree increments of bank on each side of a center position. These increments are small and the level flight or center position is not easily distinguishable. When the turn control is in any position other than center, the electrical connection to the turn-bank contact is broken and the autopilot does not perform as designed for level-flight operation. It is possible to mistake the 5-degree detent for the center position. It is recommended that the detents be spread over a longer arc.

2. The card of the magnetic compass is poorly illuminated.

3. It is possible to turn on the autopilot while taxiing, with the result that the contact pair on the gyro-horizon indicator may be displaced from level-flight position. If, subsequently, the autopilot is

engaged in flight, the aircraft will assume an angle of bank before stabilizing in level flight. It is recommended that some provision be incorporated to prevent this condition.

4. The installation in the Piper Pacer was provided with a meter to indicate proper balance in the magnetic-coupler amplifier. For proper autopilot operation it is necessary to set this meter at a voltage previously determined as the setting for level flight. This is a detail which gave considerable trouble to pilots unfamiliar with the operation of the equipment.

5. The rudder-aileron co-ordination is advantageous and necessary for flight on autopilot control, but, for manual flight, taxiing, and especially for take-off and landing, it would be very desirable if a means were provided for disengaging this co-ordination linkage.

6. The photo tube and the light source which are assembled on the magnetic compass can be oriented in relation to the azimuth ring, but no detent is provided to determine when it is correctly oriented. This was the probable cause of the inconsistent results which were observed when the omnirange coupler was evaluated. It is recommended that some form of detent or index mark be provided.

7. The omnirange coupler provides for autopilot control of flight using VOR information. However, the track to the station departs considerably from a straight line when severe crosswinds are encountered. The usefulness of the omnirange coupler would be extended a great deal if it should function to provide automatic flight along a radial track to the omnirange.

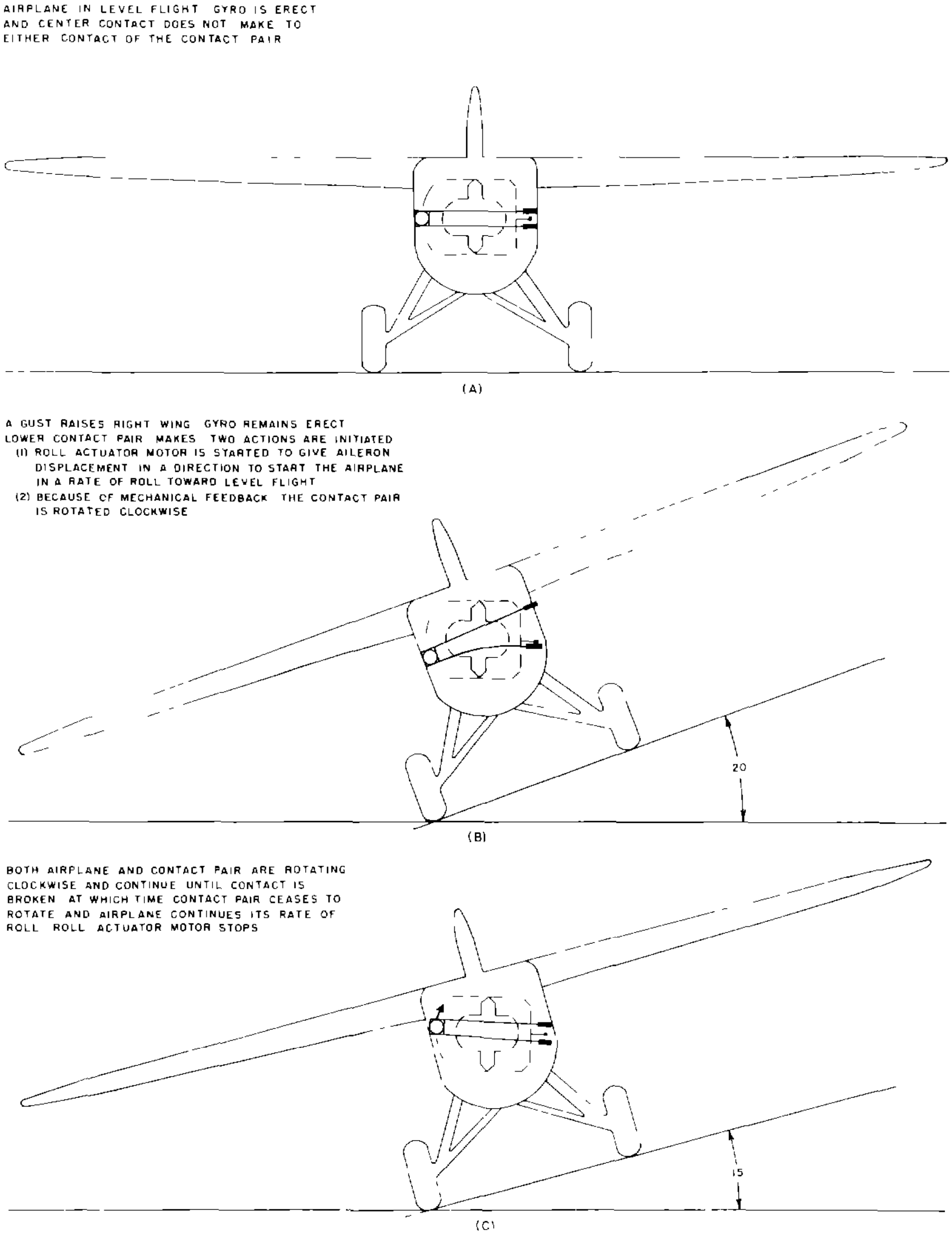
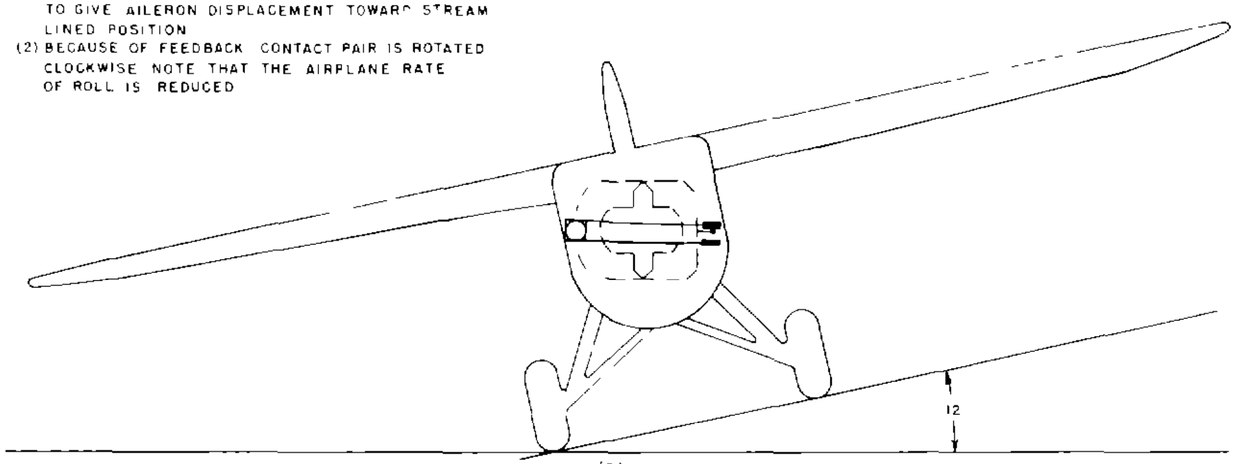


FIG I ROLL AXIS CONTROL

THE AIRPLANE CONTINUES ITS RATE OF ROLL TOWARD LEVEL FLIGHT AND WITH CONTACT PAIR MOMENTARILY STATIONARY CONTACT MAKES WITH UPPER CONTACT. THIS AGAIN INITIATES TWO ACTIONS

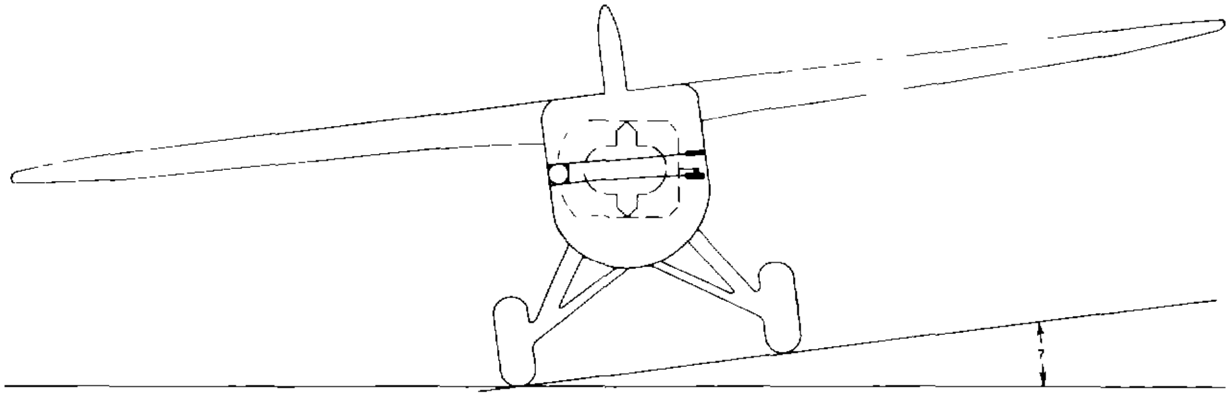
(1) ROLL ACTUATOR MOTOR IS STARTED IN A DIRECTION TO GIVE AILERON DISPLACEMENT TOWARD STREAM LINED POSITION

(2) BECAUSE OF FEEDBACK CONTACT PAIR IS ROTATED CLOCKWISE. NOTE THAT THE AIRPLANE RATE OF ROLL IS REDUCED



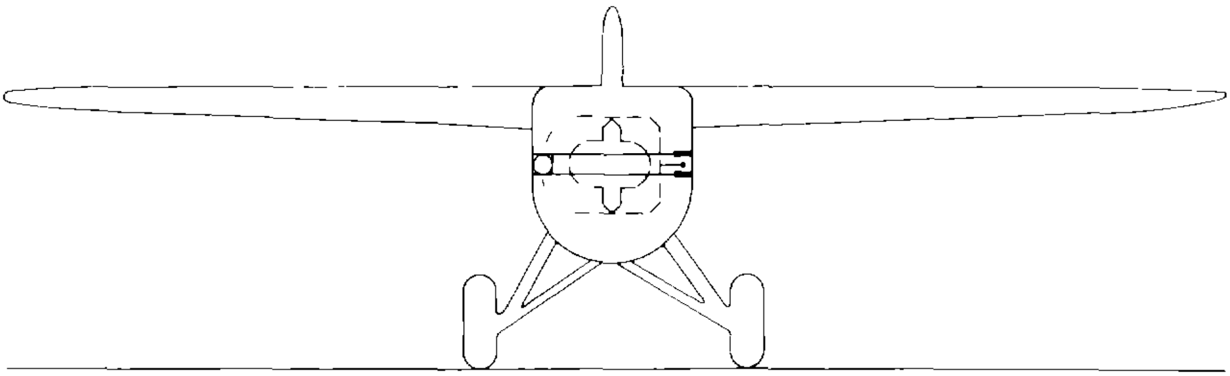
(D)

ONE CYCLE OF OPERATION IS COMPLETE. CONTACT IS AGAIN MADE TO LOWER CONTACT OF PAIR



(E)

AIRPLANE HAS REACHED STABLE POSITION. CONTACTS ARE CENTERED AND AIRPLANE IS IN LEVEL FLIGHT



(F)

FIG 1 CONT'D

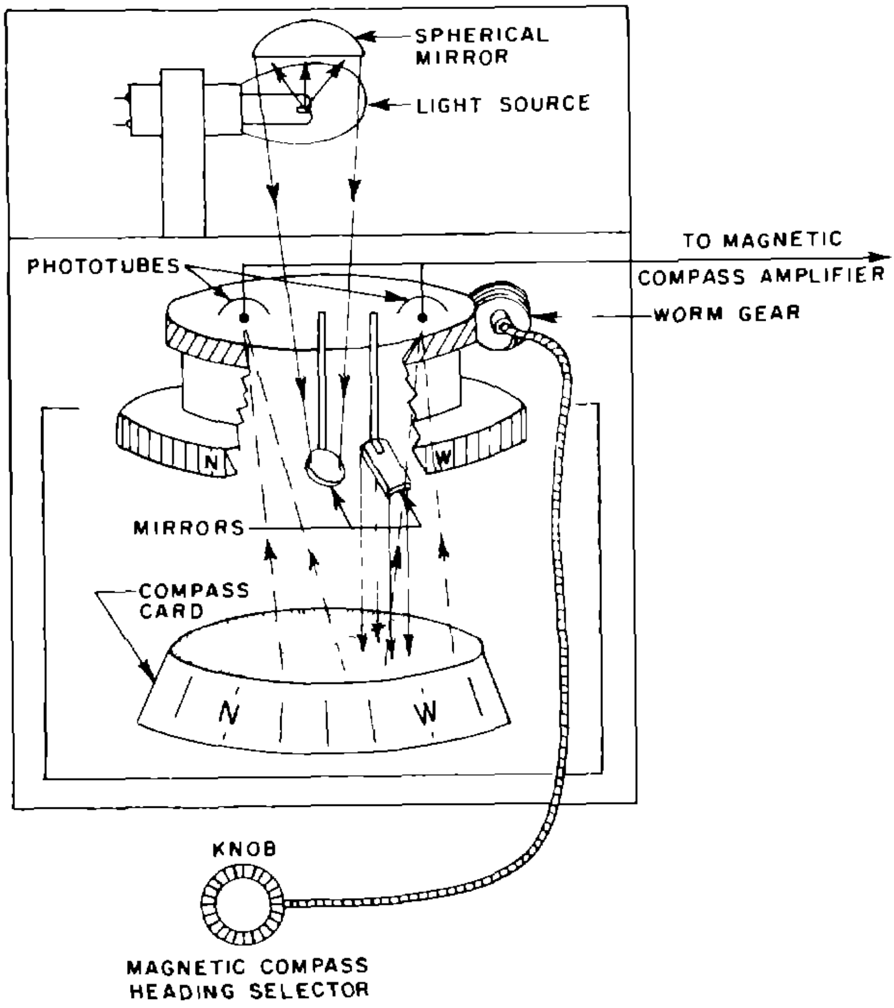


FIG 2 MAGNETIC COMPASS COUPLER PHOTOTUBE AND LIGHT SOURCE ASSEMBLY

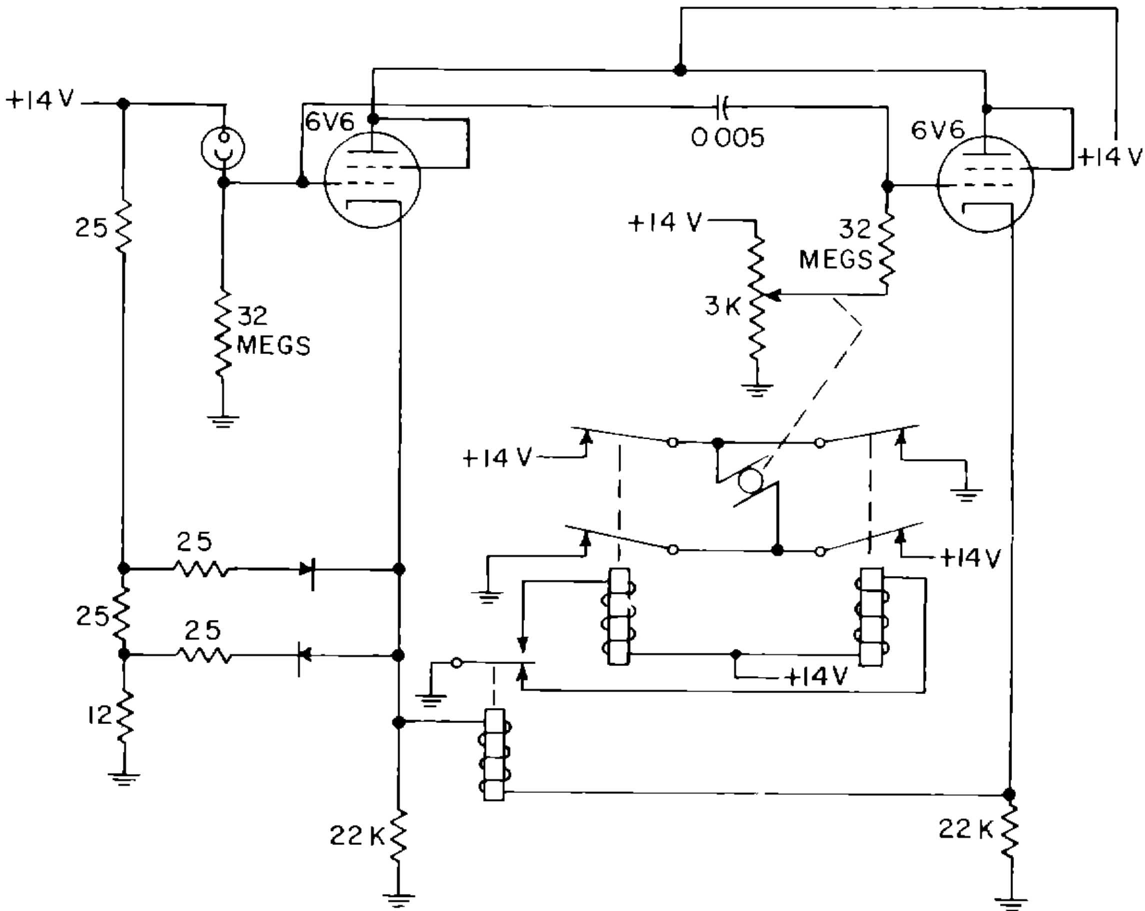


FIG 3 SIMPLIFIED SCHEMATIC OF MAGNETIC
COMPASS COUPLER AMPLIFIER

FIG. 4 OMNIRANGE COUPLER CONTROL BOX

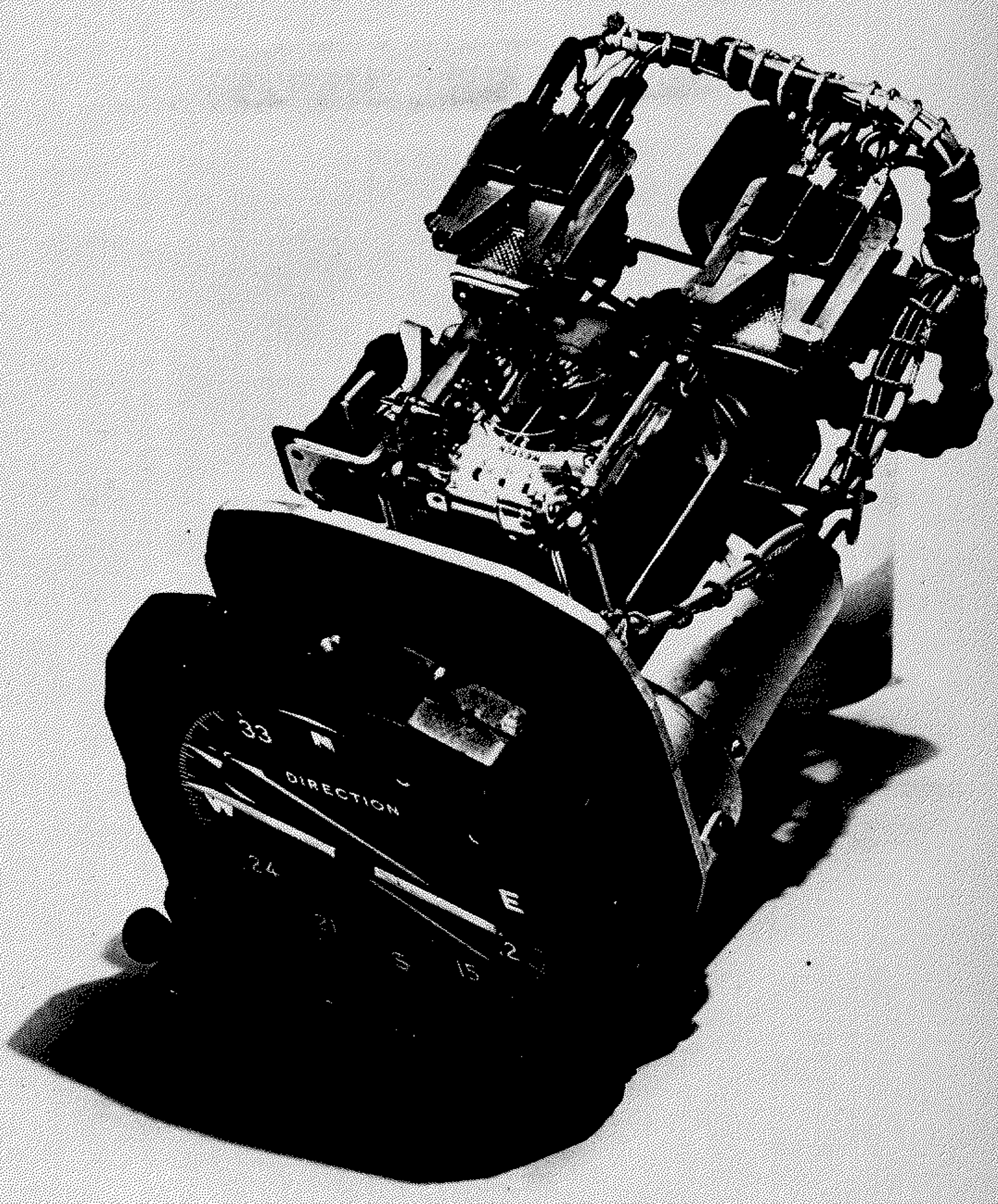
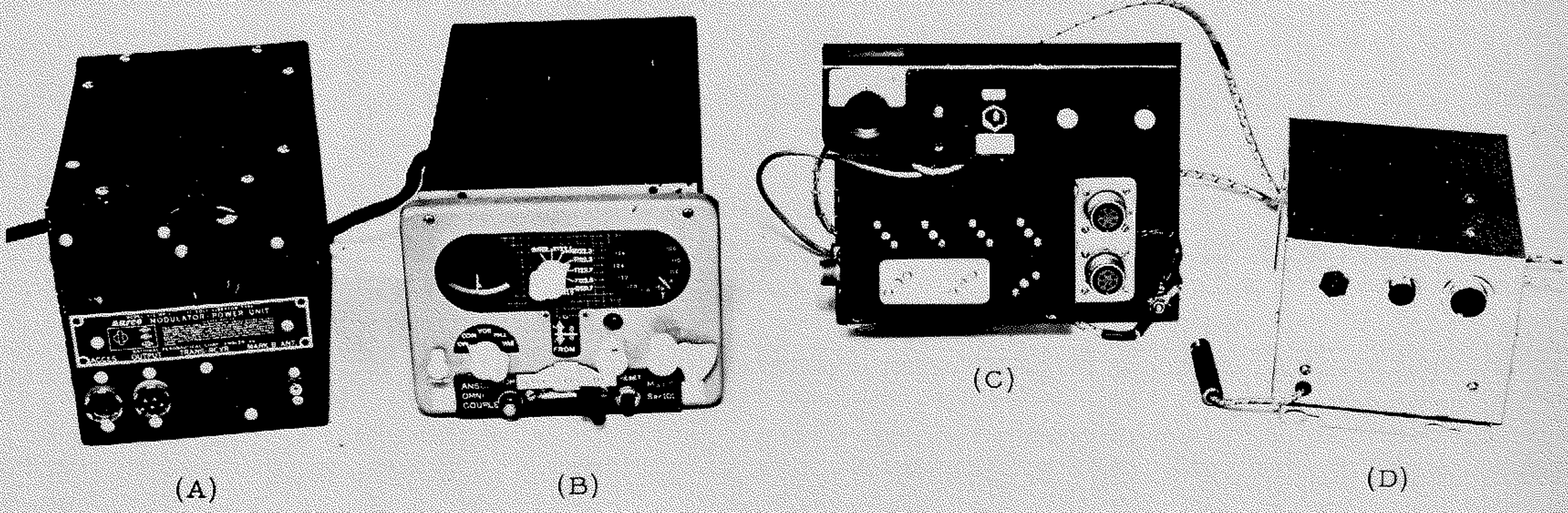


FIG. 5 OMNIRANGE COUPLER WITH THE HOUSING REMOVED



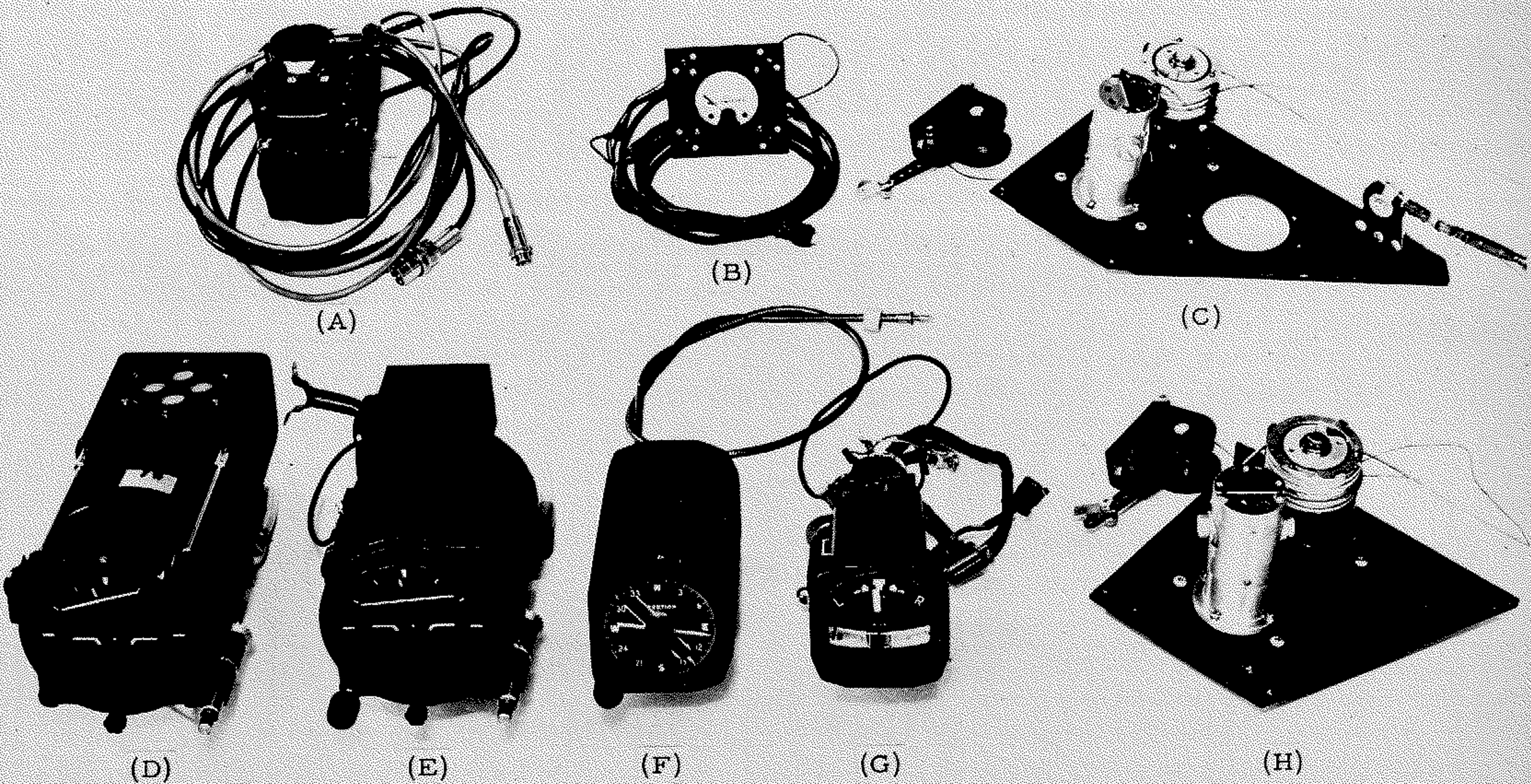
A. Modulator and Power Unit for Narco Omnigator

B. Modified Narco Omnigator

C. Junction and Relay Box

D. Magnetic-Compass Amplifier

FIG. 6 ANSCOPILOT COMPONENTS



CAA TECHNICAL DEVELOPMENT AND EVALUATION CENTER INDIANAPOLIS, INDIANA

A. Magnetic-Compass With Phototube and Light-Source Assembly

B. Magnetic-Compass Balance Indicator

C. Pitch-Axis Actuator and Mechanical-Feedback Linkage

D. Modified Gyro-Horizon Indicator (Roll-Axis Control)

E. Modified Gyro-Horizon Indicator (Pitch-Axis Control)

F. Omnirange-Coupler Control Box

G. Modified Turn-bank Indicator

H. Roll-Axis Actuator and Mechanical-Feedback Linkage

FIG. 7 ANSCOPILOT COMPONENTS

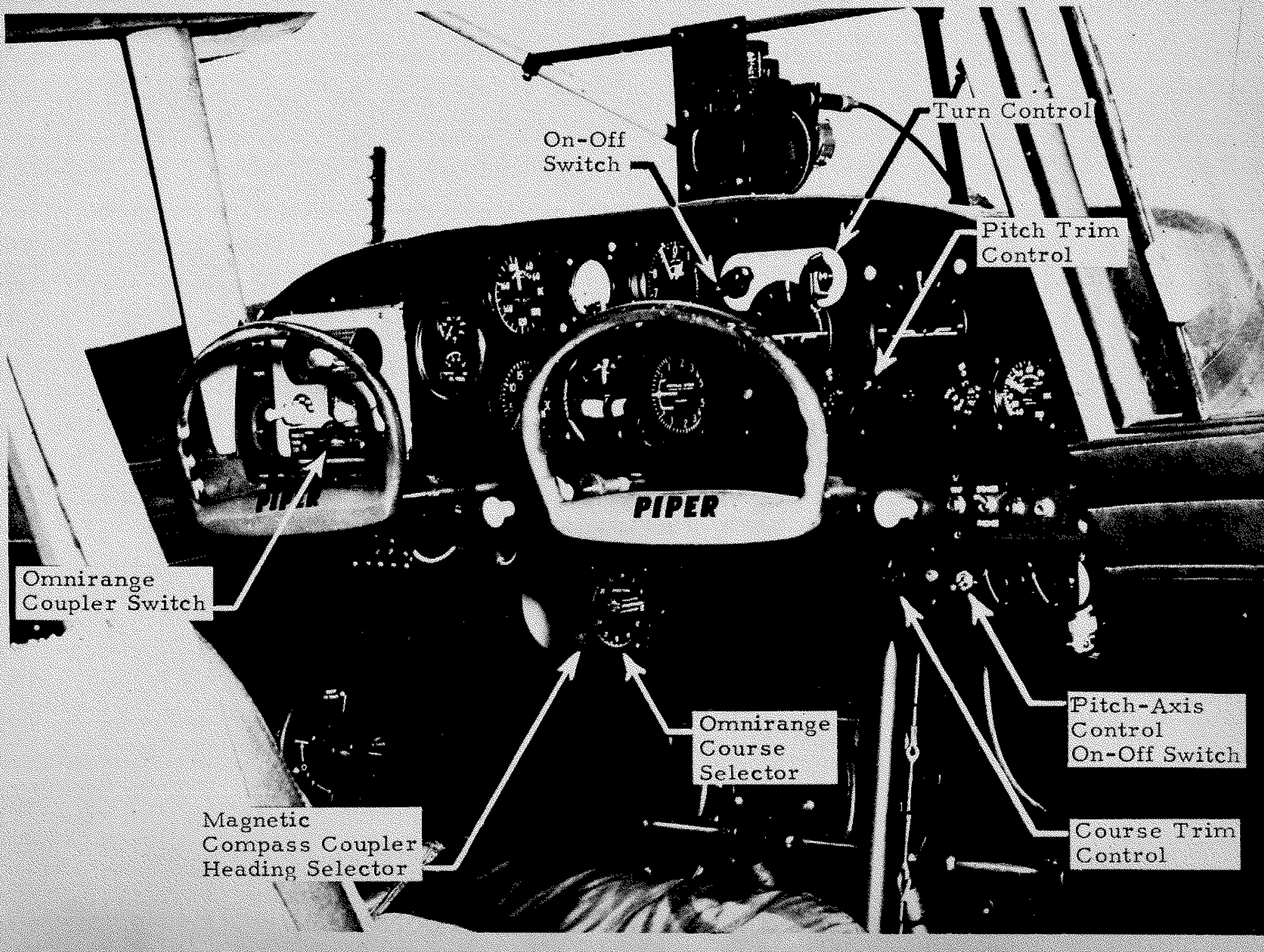
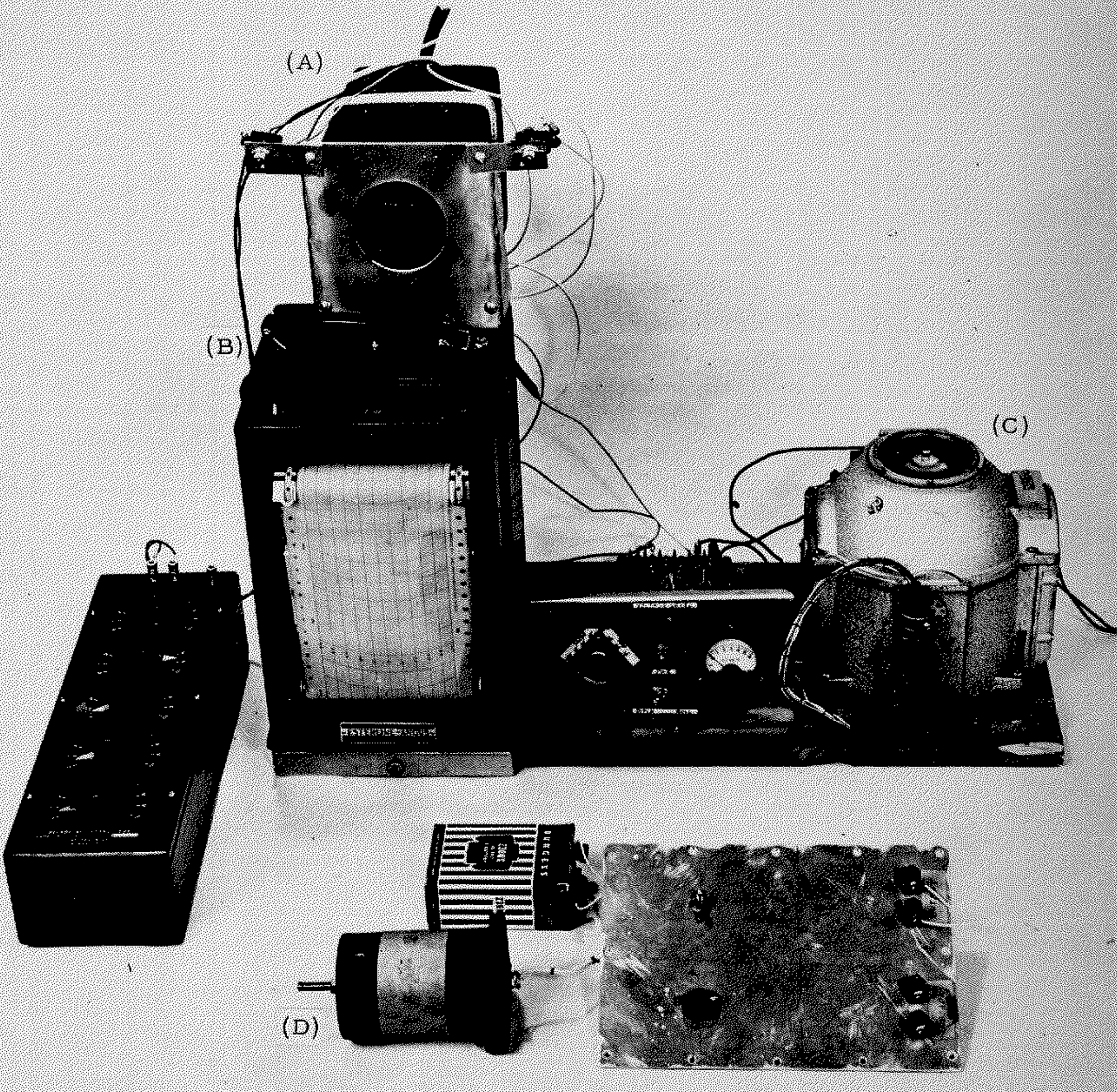


FIG. 8 INSTRUMENT PANEL SHOWING LOCATION OF AUTOPILOT CONTROLS



A. Vacuum Driven Directional Gyro
B. Recorder
C. Vertical Gyro
D. Barometric Pressure Indicator

FIG. 9 ASSEMBLY OF TEST EQUIPMENT

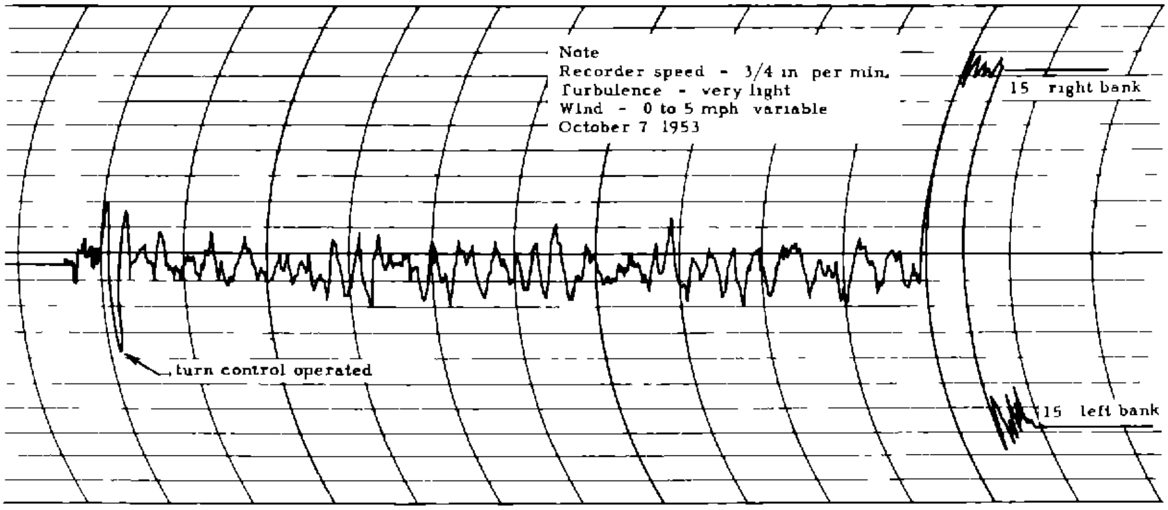


FIG 10 ROLL AXIS STABILITY

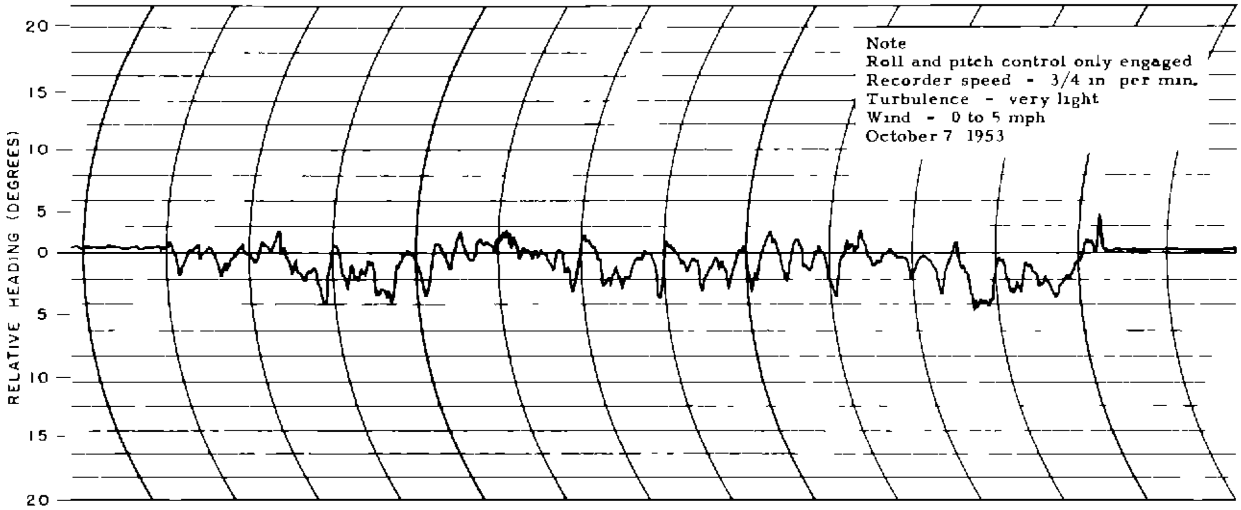


FIG 11 HEADING STABILITY

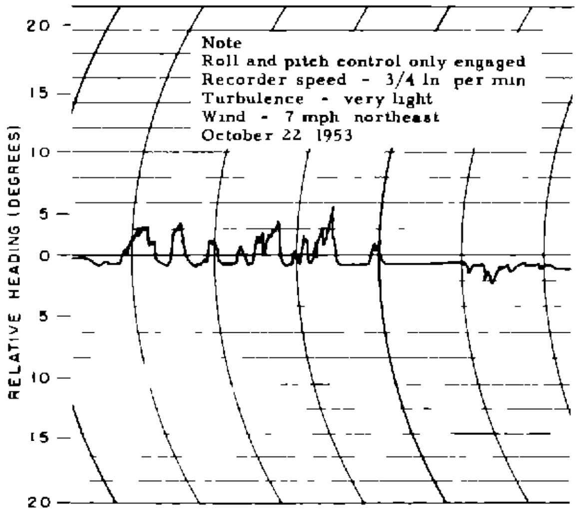


FIG 12 HEADING STABILITY

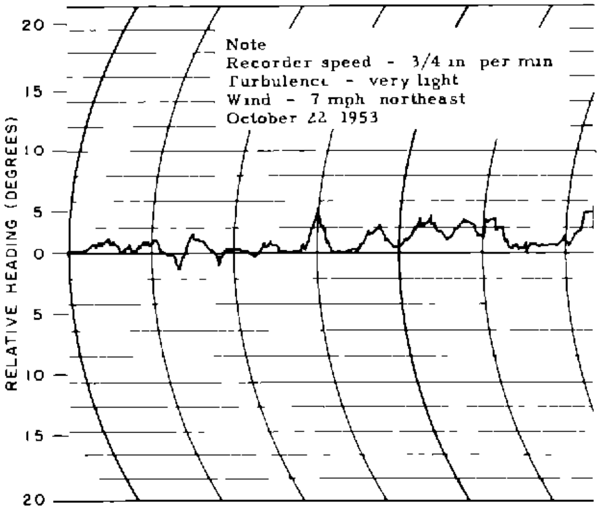


FIG 13 HEADING STABILITY

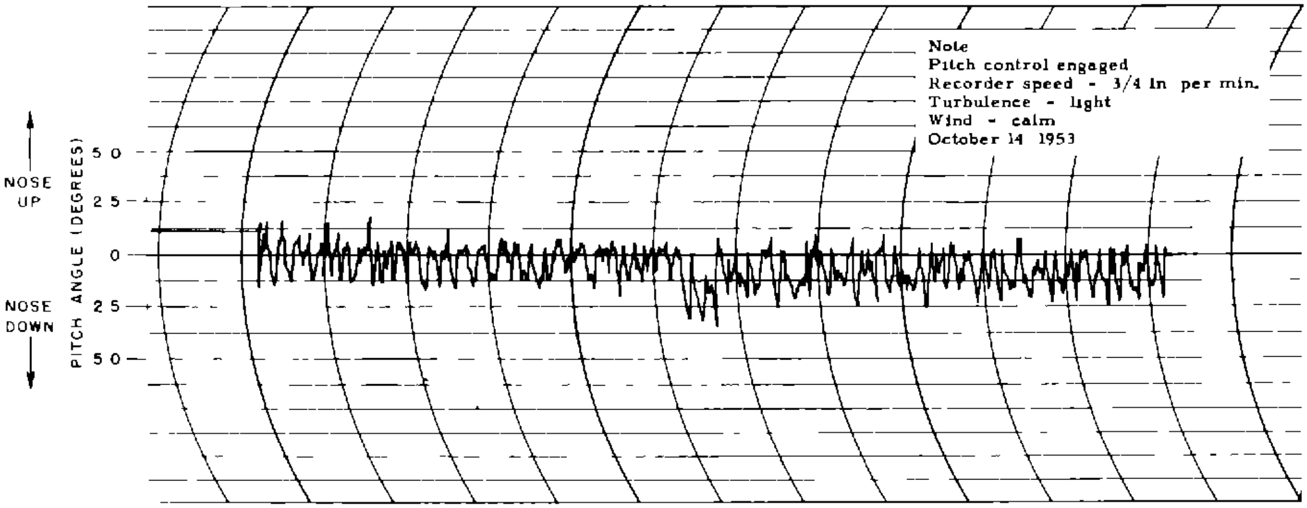


FIG 14 PITCH STABILITY

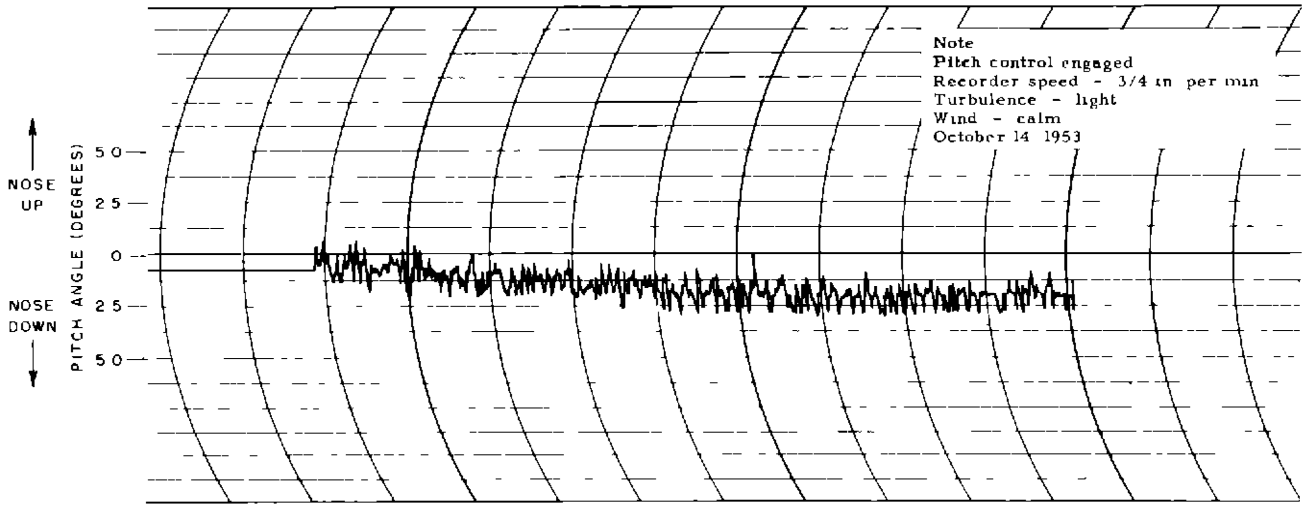


FIG 15 PITCH STABILITY

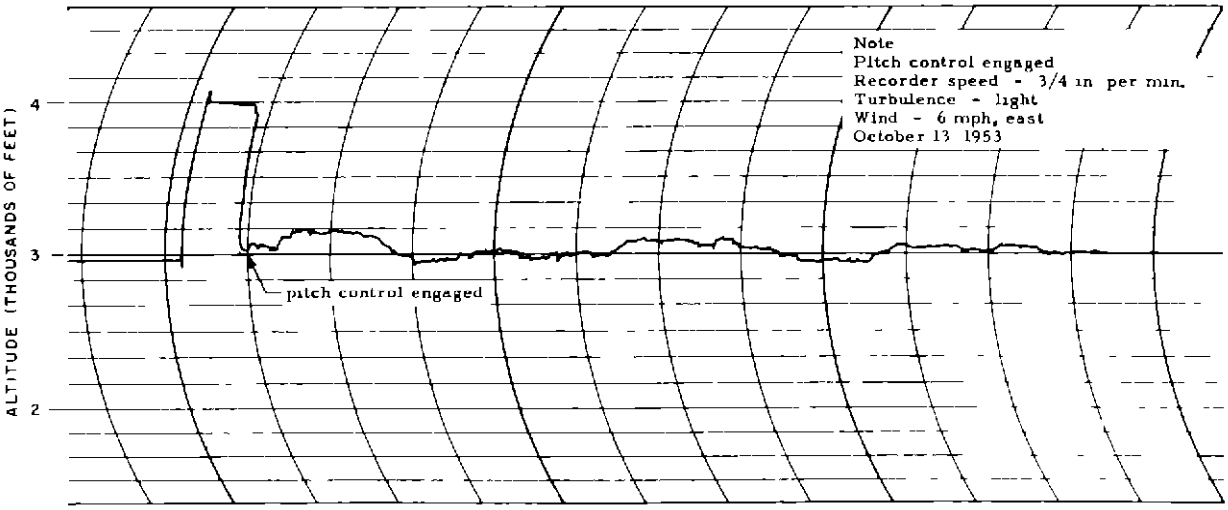


FIG 16 ALTITUDE STABILITY

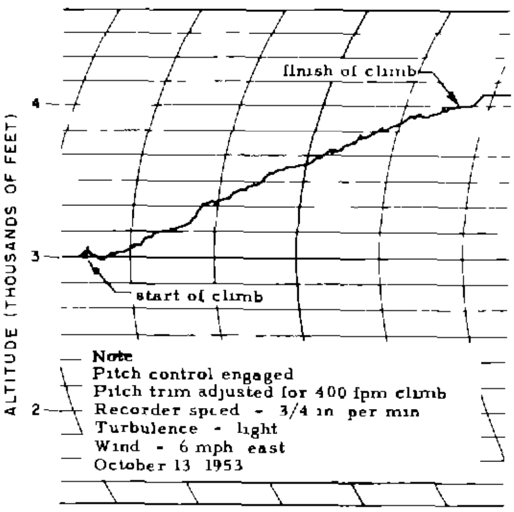
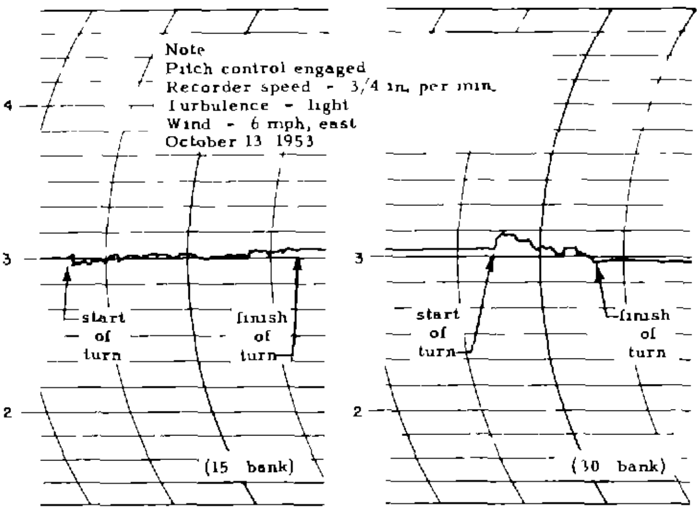


FIG 17 ALTITUDE RECORDING DURING CLIMB



FIGS 18-19 ALTITUDE STABILITY DURING 360° TURN

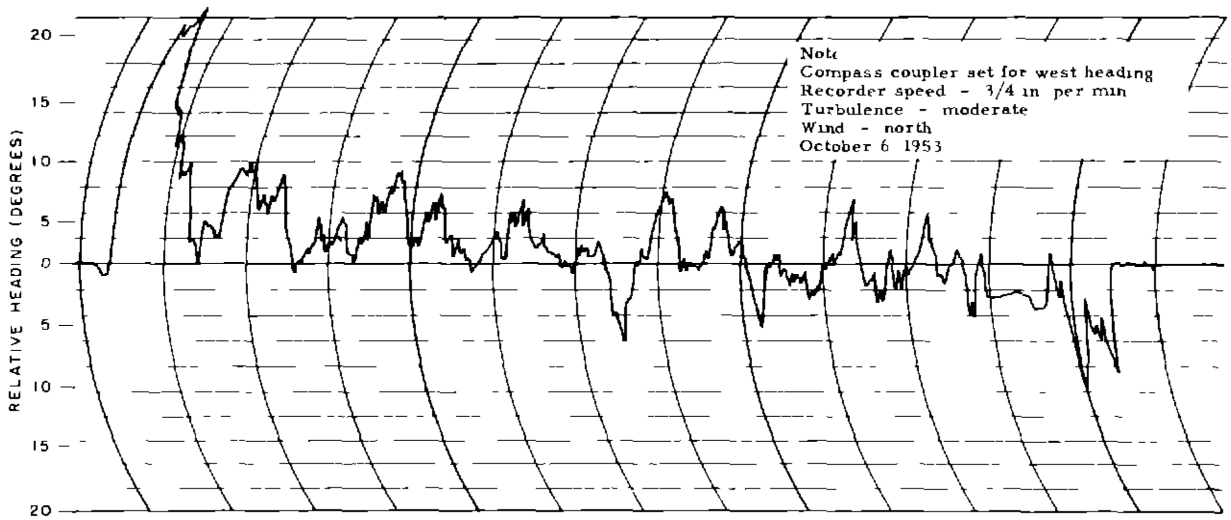


FIG 20 HEADING STABILITY

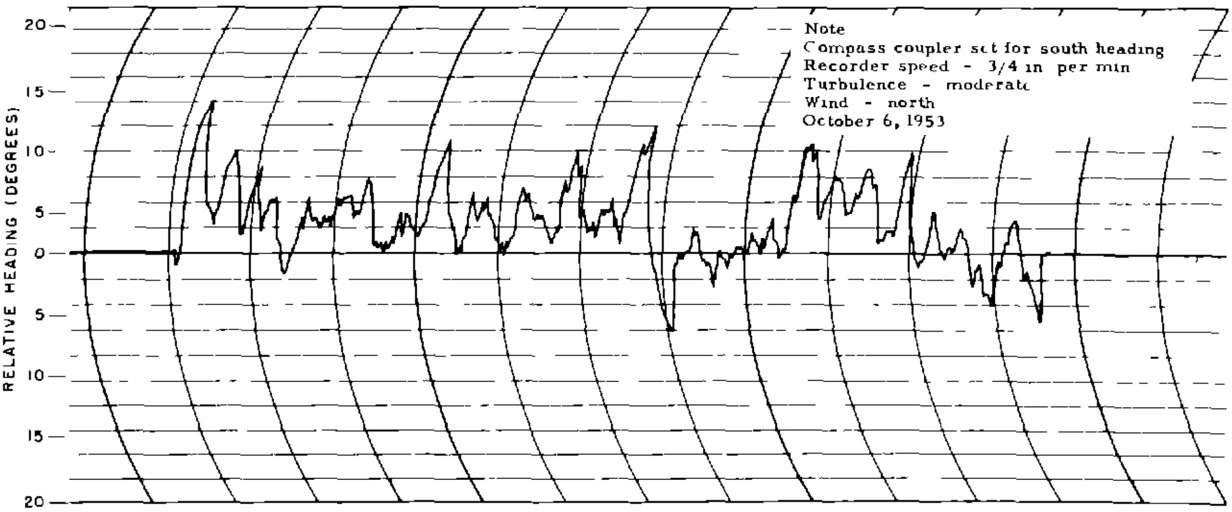


FIG 21 HEADING STABILITY

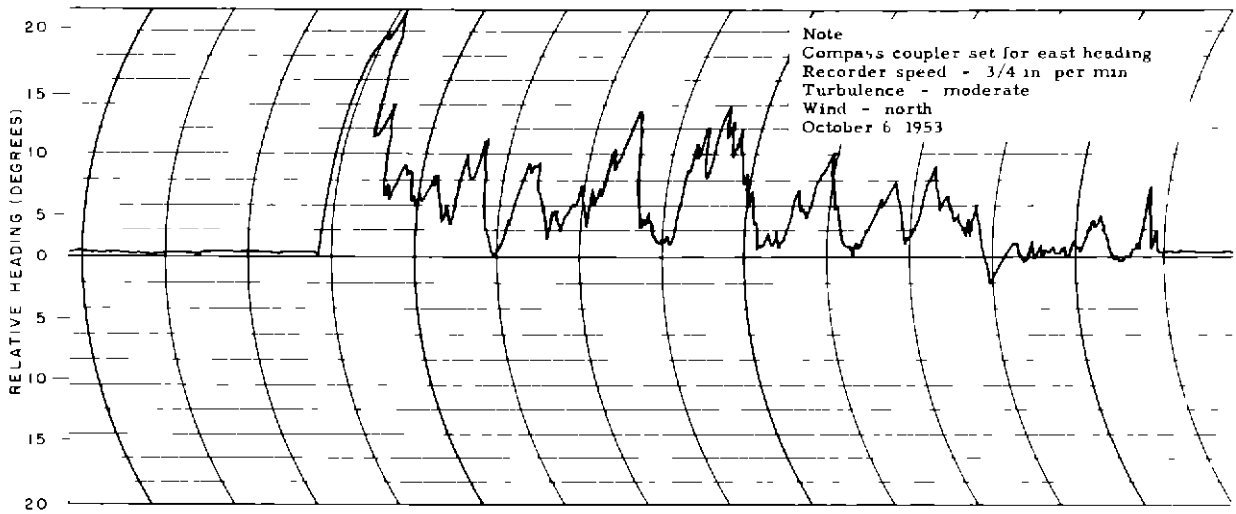


FIG 22 HEADING STABILITY

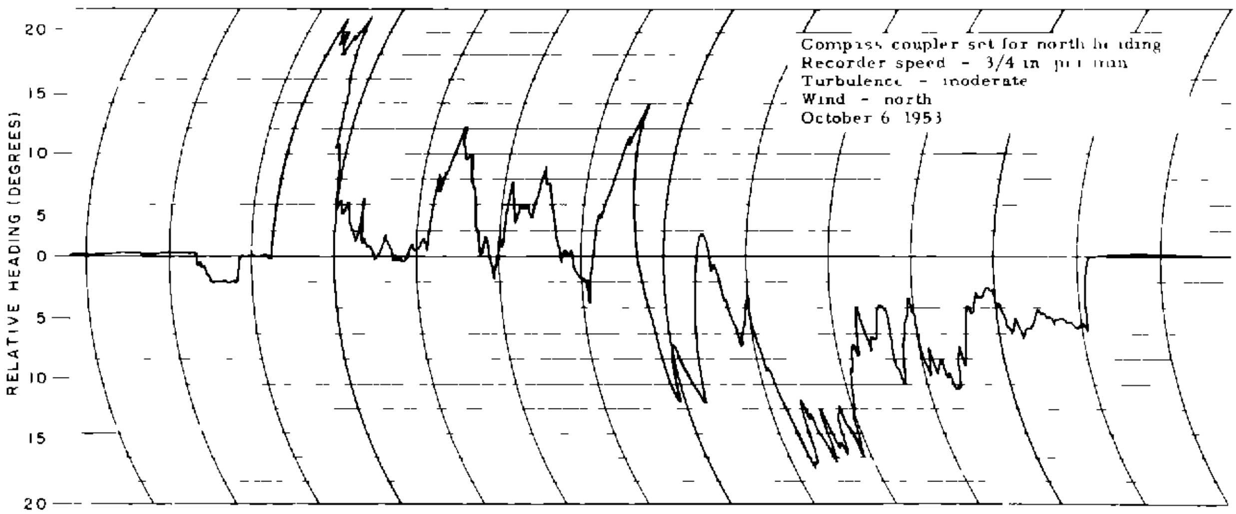


FIG 23 HEADING STABILITY

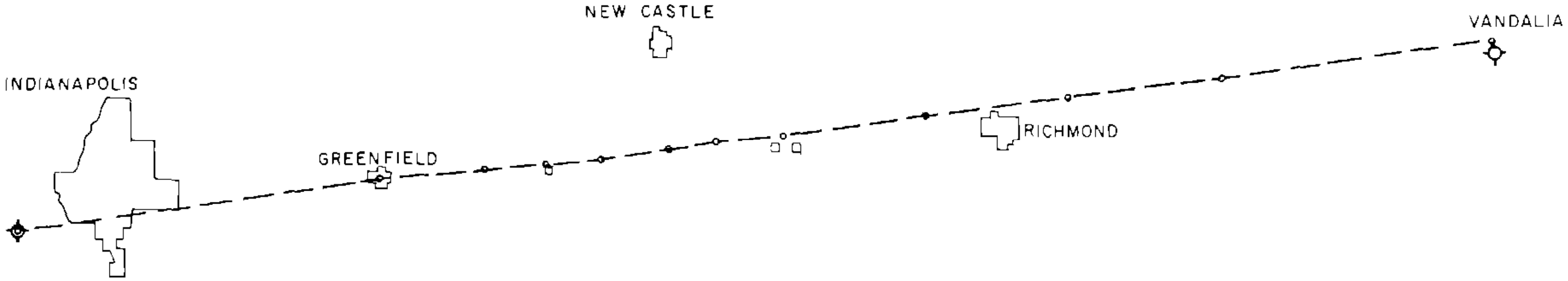


FIG 24 PLOT OF AIRPLANE TRACK FROM INDIANAPOLIS, IND TO VANDALIA, OHIO

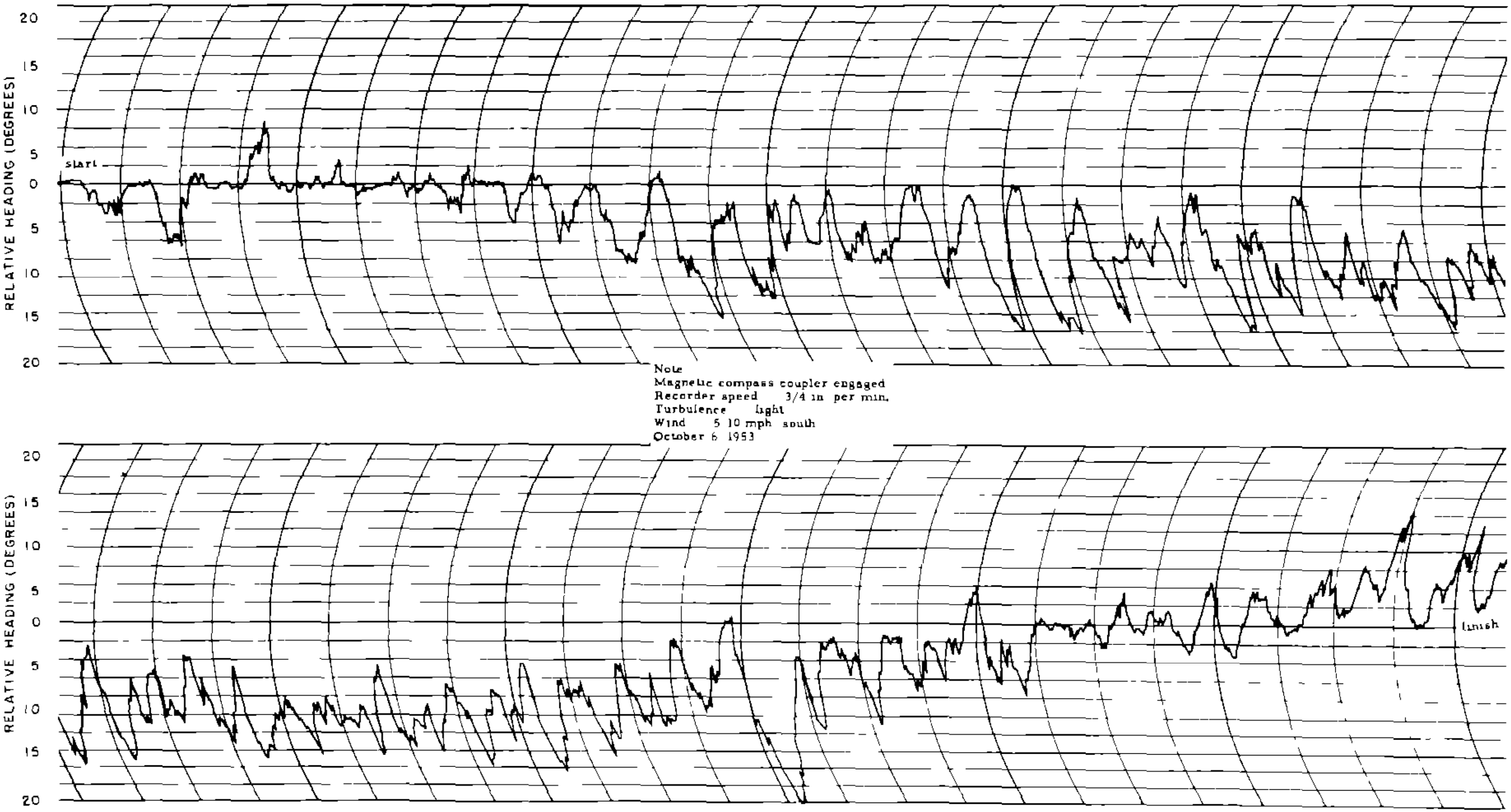


FIG 25 CONTINUOUS RECORDING OF ENROUTE HEADING INDIANAPOLIS, IND TO VANDALIA, OHIO

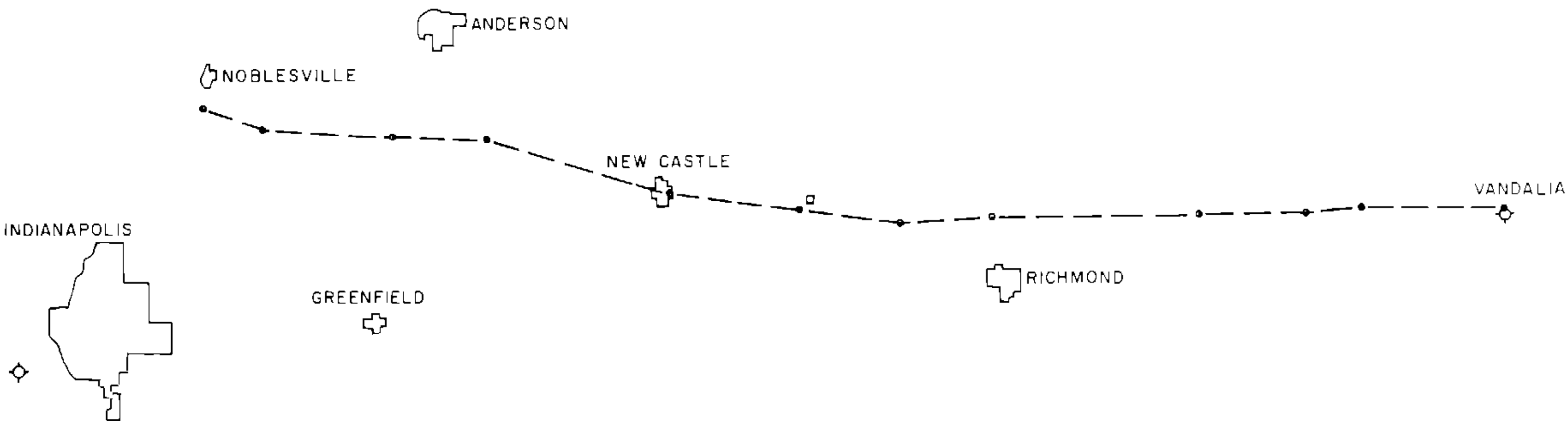


FIG 26 PLOT OF AIRPLANE TRACK DEPARTURE FROM VANDALIA, OHIO, DESTINATION INDIANAPOLIS, IND

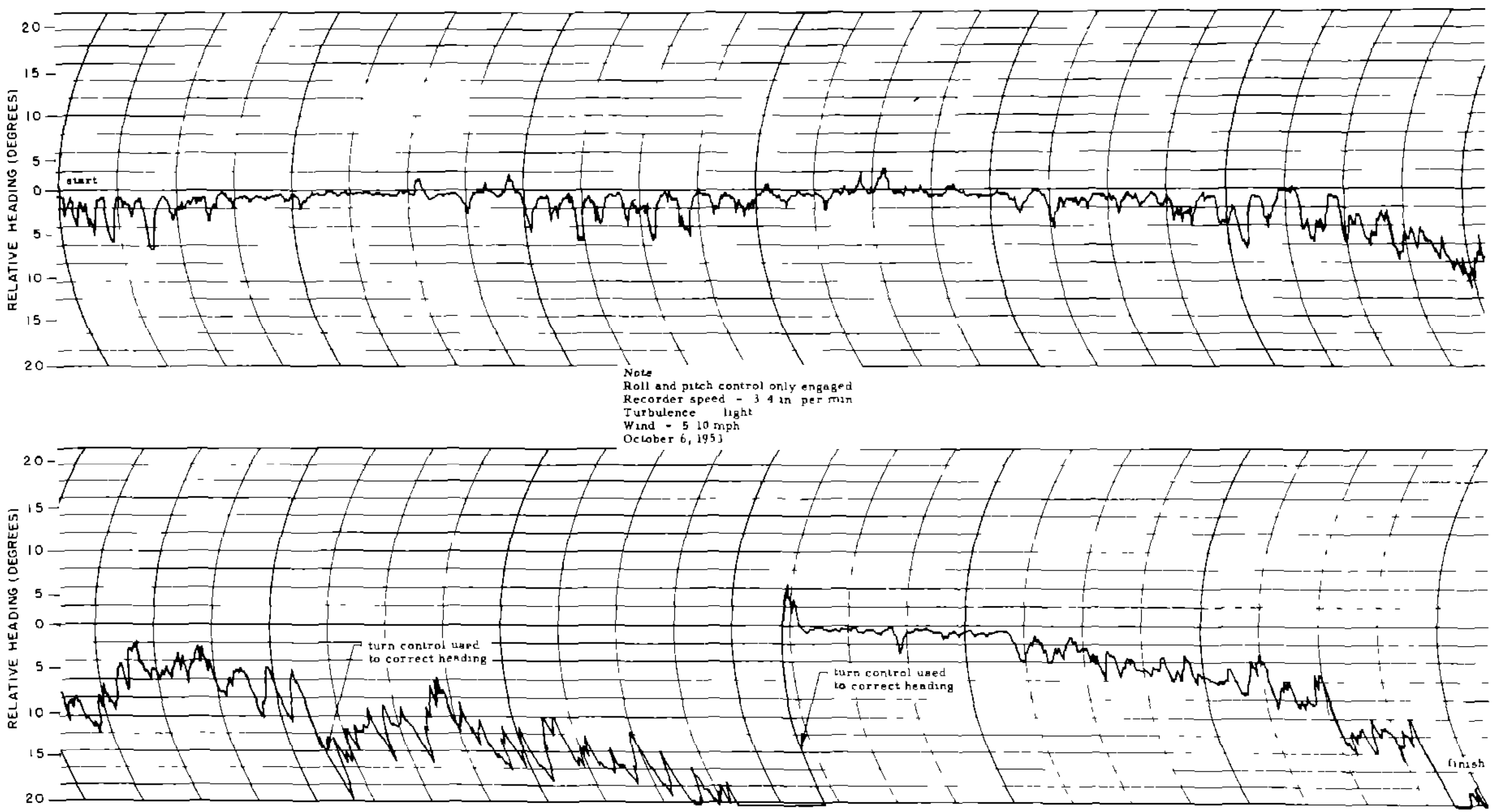


FIG 27 RECORDING OF ENROUTE HEADING DEPARTURE FROM VANDALIA, OHIO, DESTINATION INDIANAPOLIS, IND

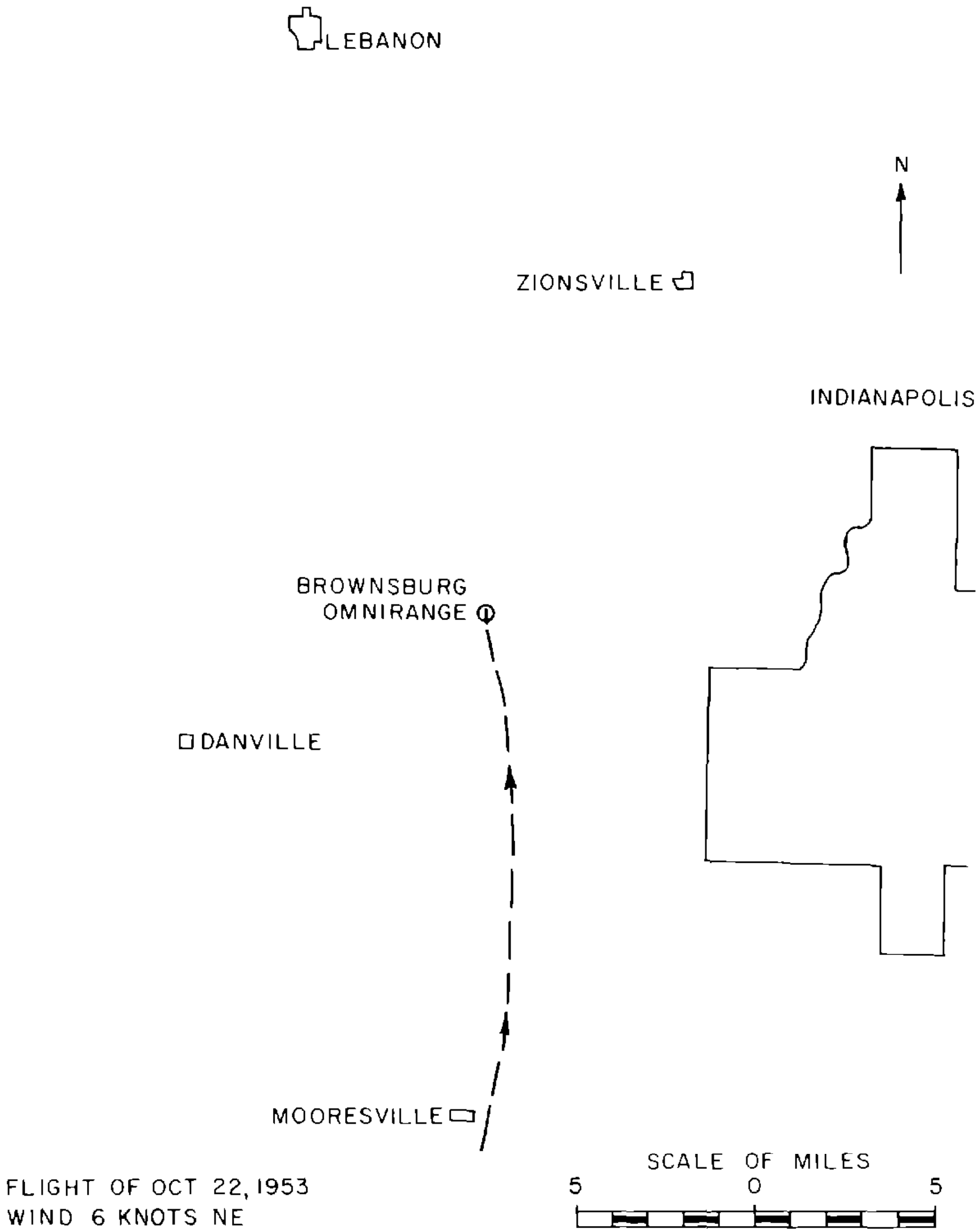


FIG 28 TRACK OF AIRCRAFT WITH OMNIRANGE COUPLER ENGAGED

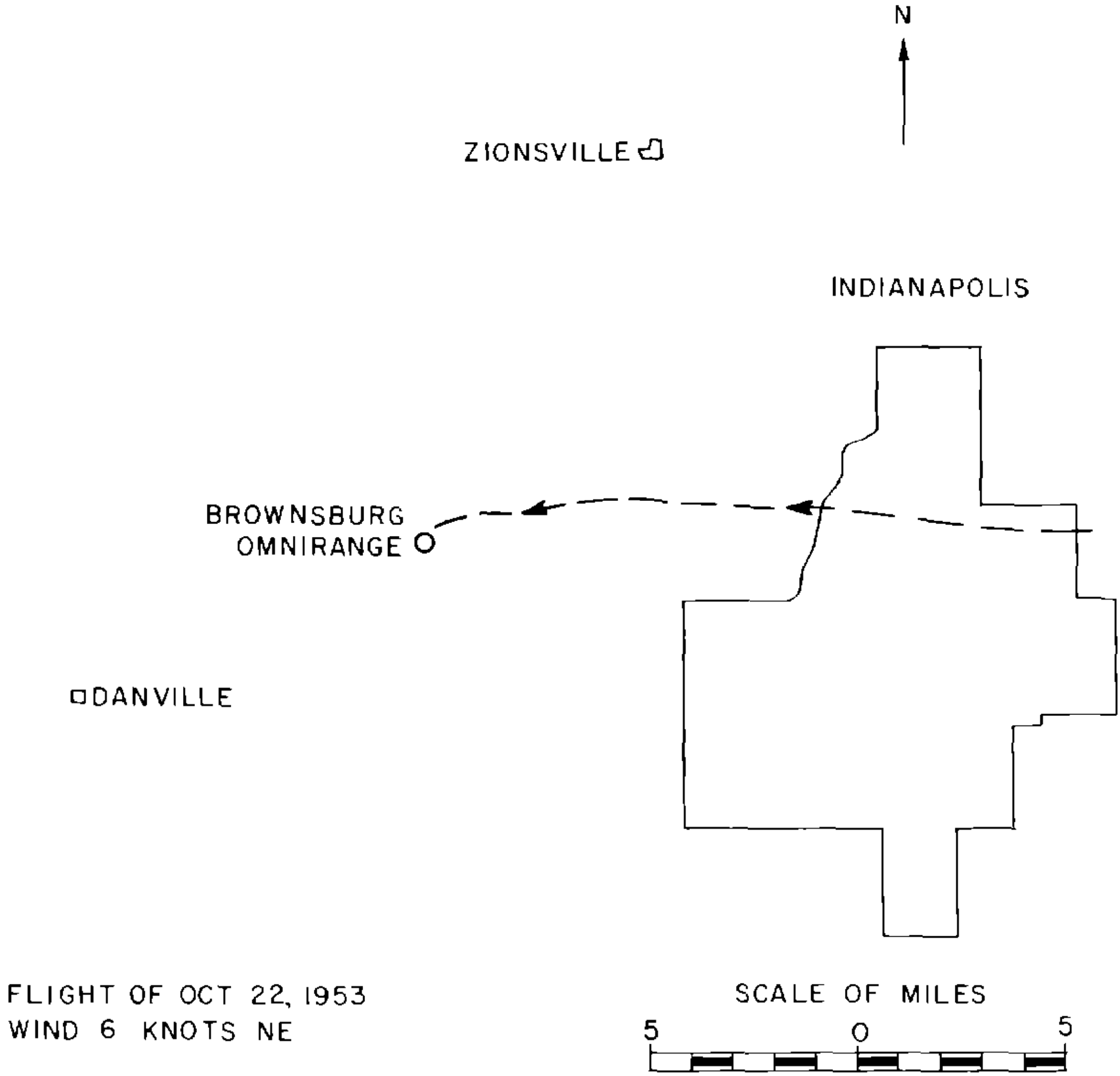


FIG 29 TRACK OF AIRCRAFT WITH OMNIRANGE COUPLER ENGAGED

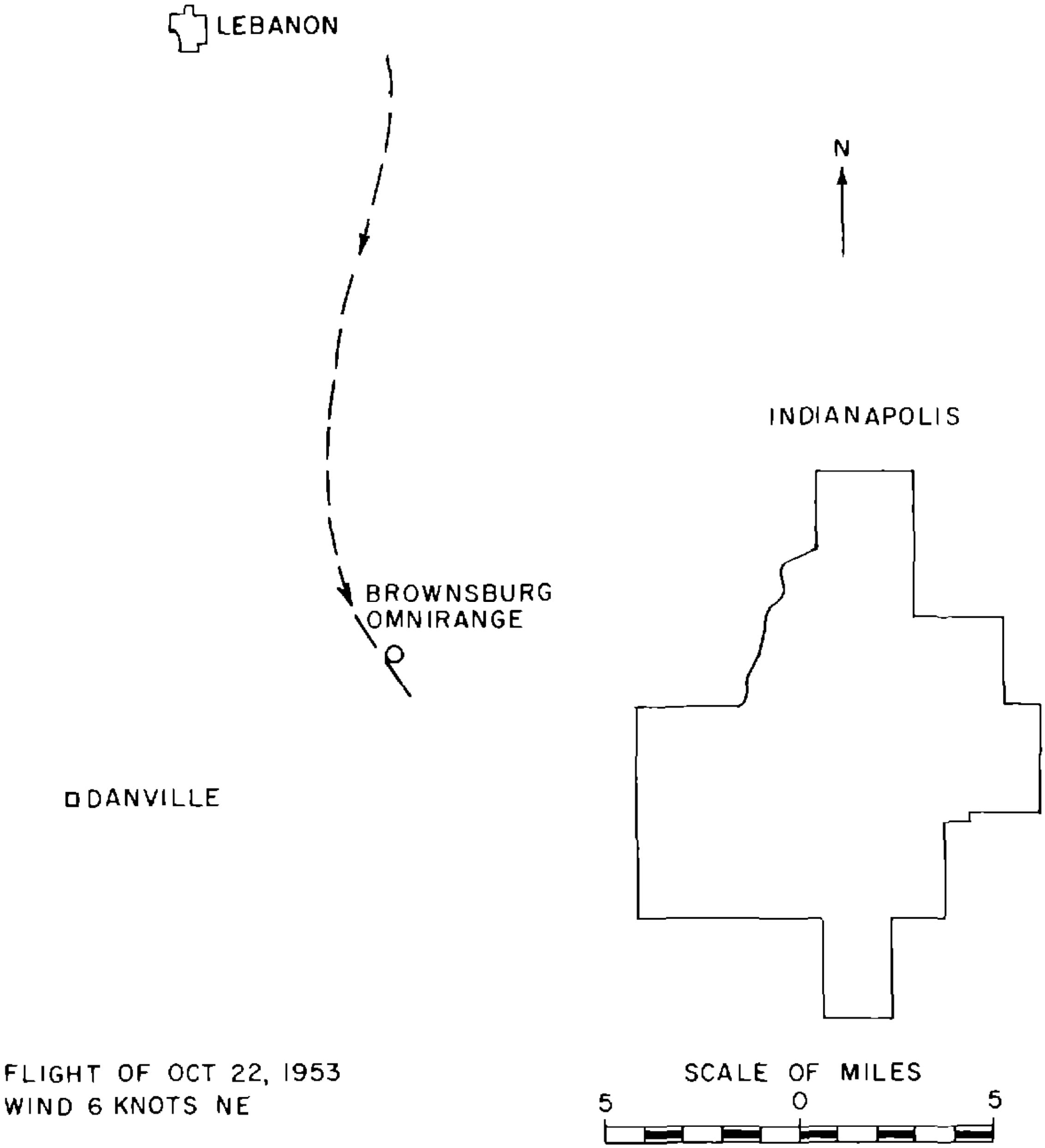


FIG 30 TRACK OF AIRCRAFT WITH OMNIRANGE COUPLER ENGAGED

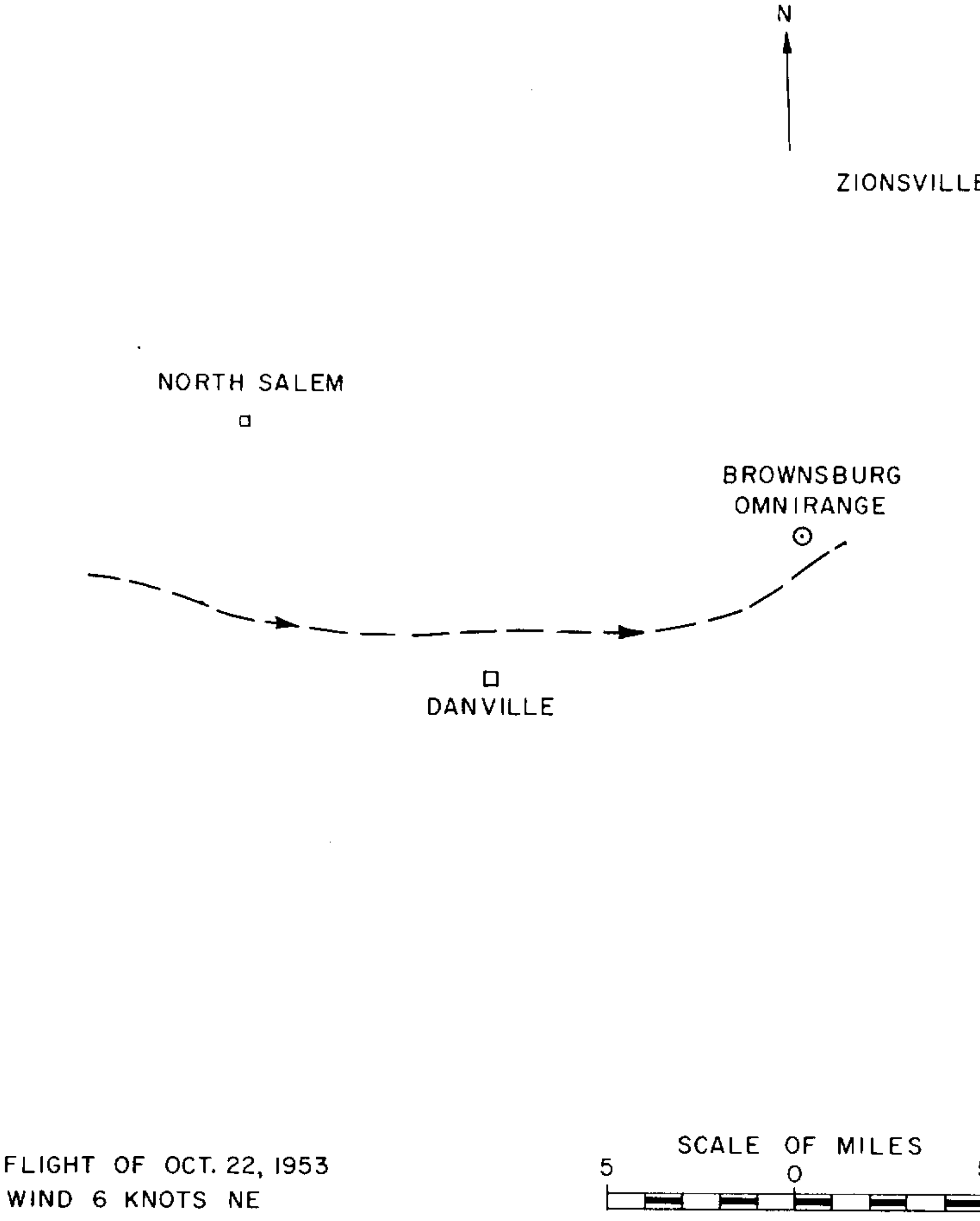


FIG. 31 TRACK OF AIRCRAFT WITH OMNIRANGE COUPLER ENGAG

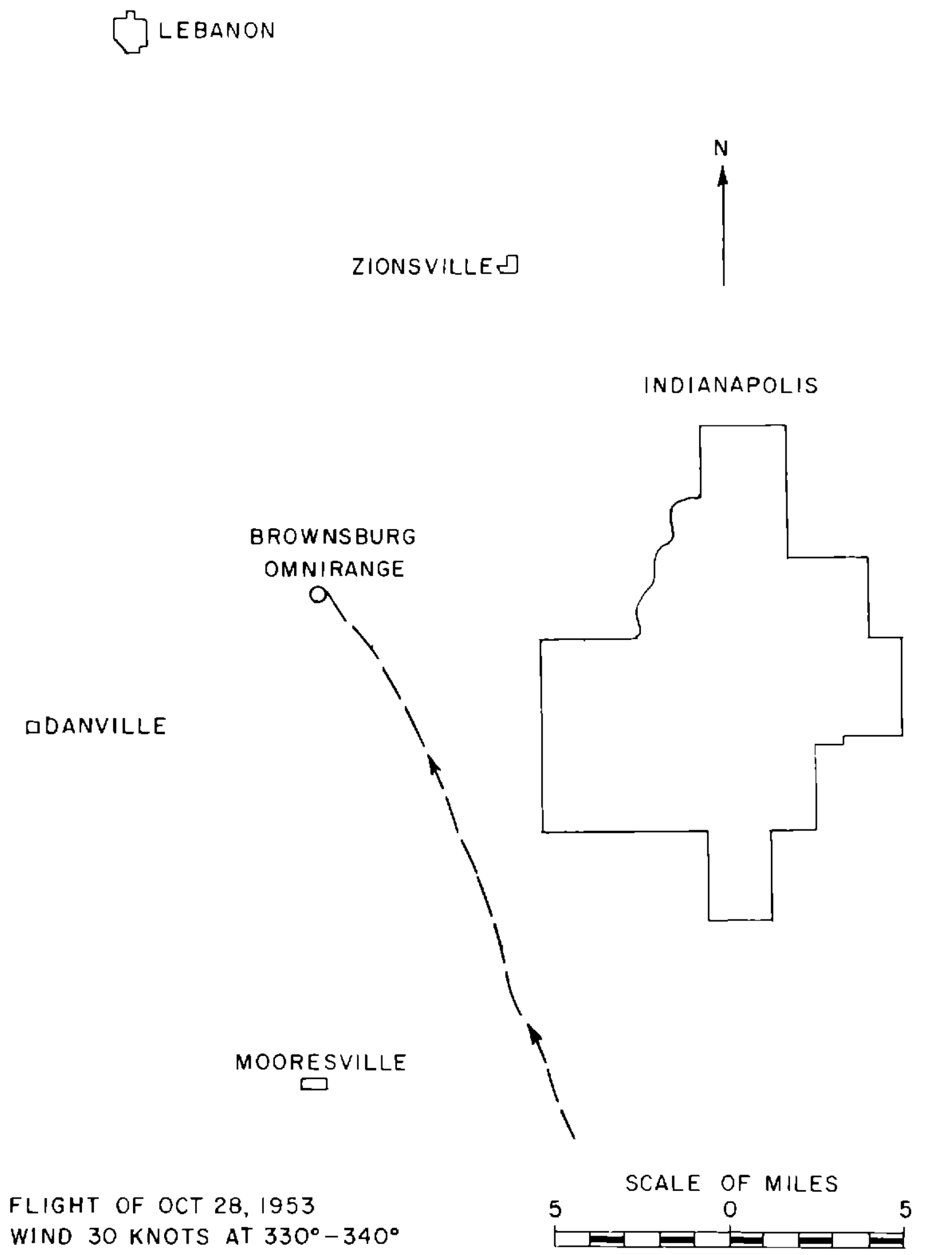


FIG 32 TRACK OF AIRCRAFT WITH OMNIRANGE COUPLER ENGAGED

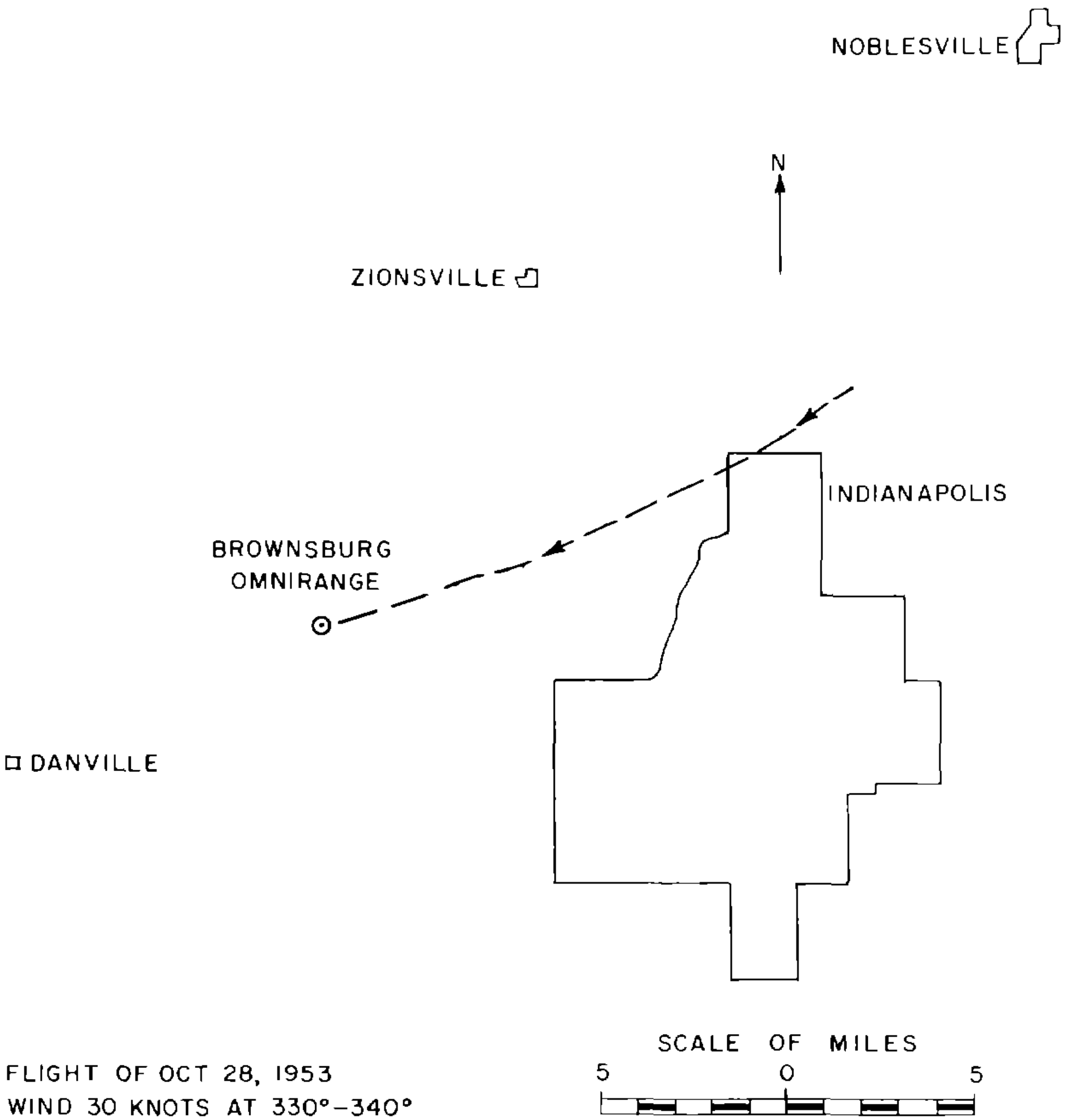


FIG 33 TRACK OF AIRCRAFT WITH OMNIRANGE COUPLER ENGAGED

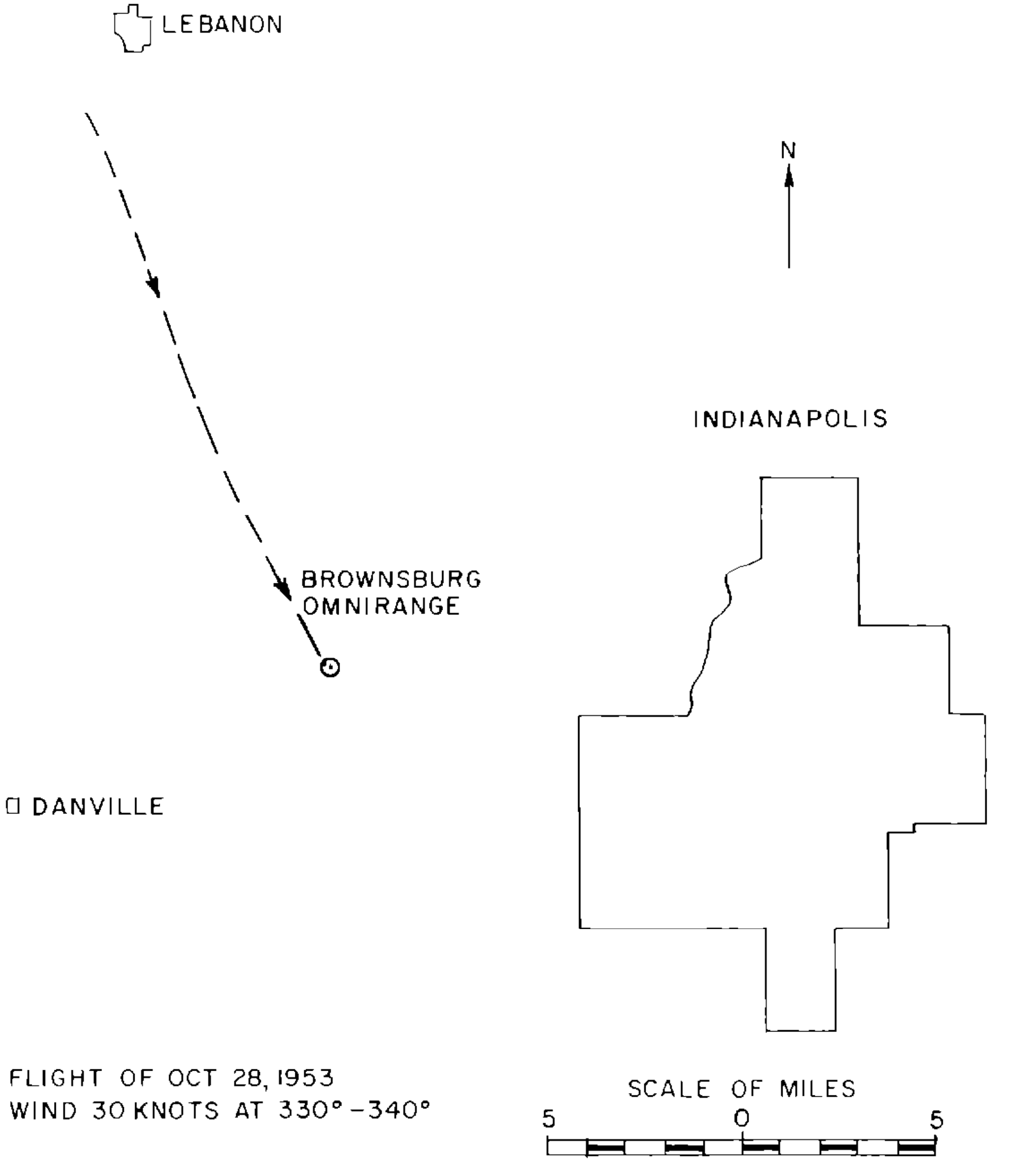


FIG 34 TRACK OF AIRCRAFT WITH OMNIRANGE COUPLER ENGAGED

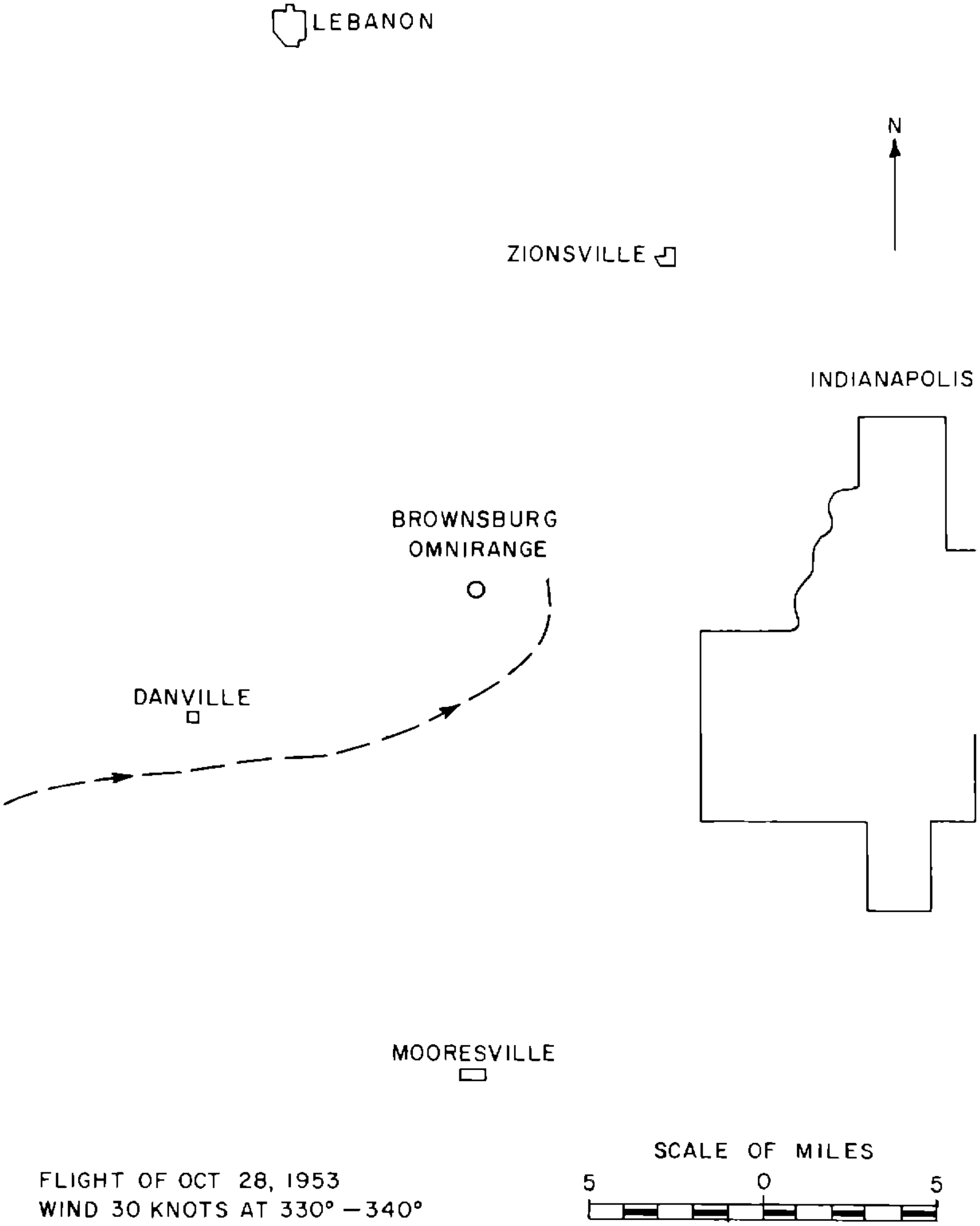
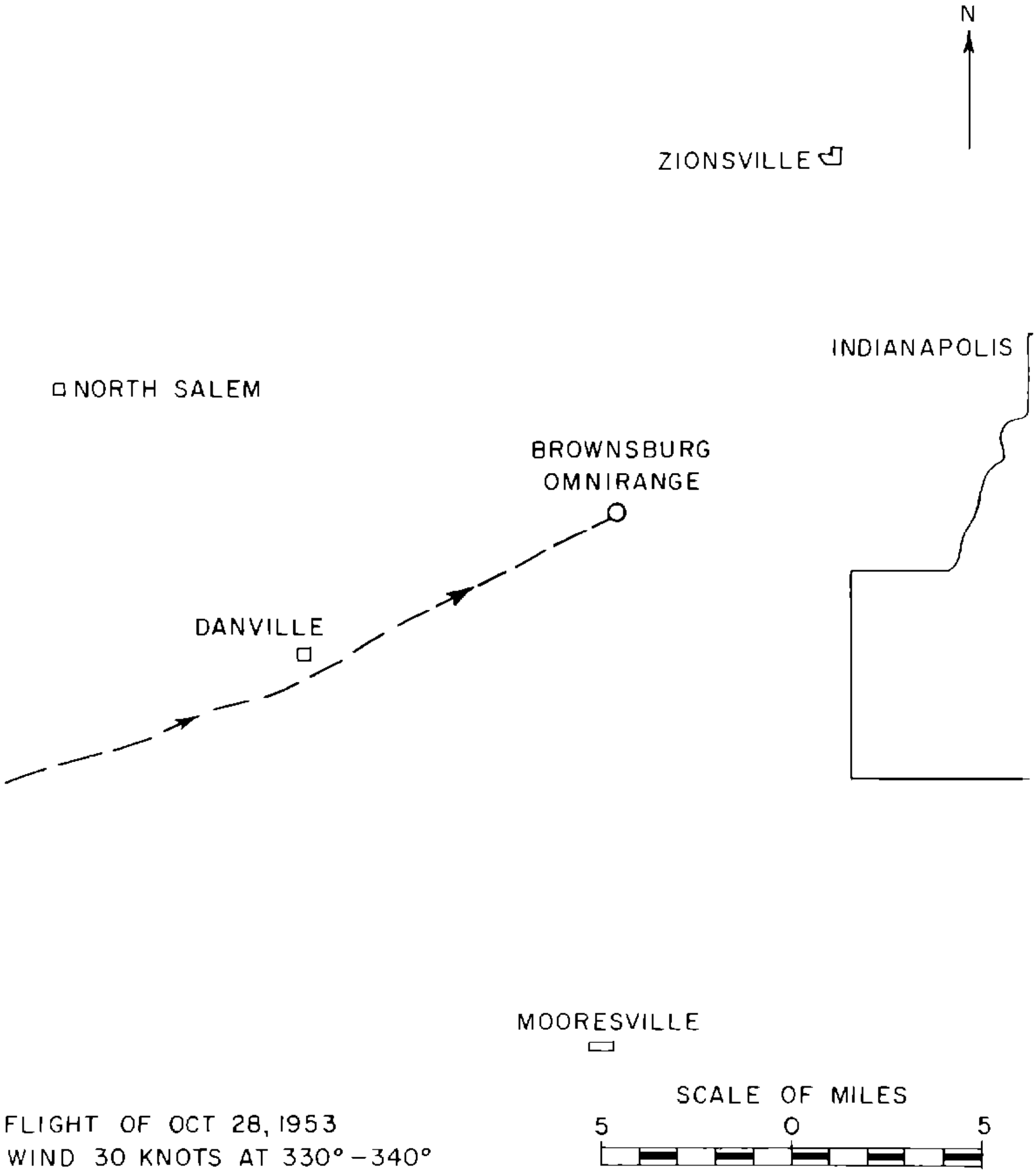


FIG 35 TRACK OF AIRCRAFT WITH OMNIRANGE COUPLER ENGAGED



FLIGHT OF OCT 28, 1953
WIND 30 KNOTS AT 330° – 340°

FIG 36 TRACK OF AIRCRAFT WITH OMNIRANGE COUPLER ENGAGED