PRELIMINARY EVALUATION OF THE COLLINS TVOR

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by

Thomas S. Wonnell
Robert B. Flint
Arthur E. Frederick

Electronics Division

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CIVIL AERONAUTICS ADMINISTRATION
TECHNICAL DEVELOPMENT
AND EVALUATION CENTER
INDIANAPOLIS, INDIANA

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SUMMARY

This report describes the tests conducted and the results obtained from a preliminary evaluation of the Collins Radio Company TVOR. These tests were conducted at the Collins Radio Company TVOR site at Cedar Rapids, Iowa. Special emphasis is placed on bearing accuracy, polarization effects, and cone characteristics.

The bearing accuracy compares favorably with the TDEC TVOR using the four-loop antenna system. The five-mile calibration circle, which takes the site into account, showed an over-all error of ±1.2°. A 20-mile calibration circle showed an error of ±1.75°. Ground and flight test measurements revealed low polarization errors at low angles which changed in both phase and amplitude with azimuth. The cone was sharp and well defined; however, a deep null existed at approximately 22° elevation angle which caused the course deviation indicator to show errors averaging ±3° in the null.

INTRODUCTION

The experience gained in the operation of the Federal Airways omnirange system pointed out the fact that there were many advantages to be gained by placing an omnirange facility on an airport. Accordingly, in 1950 the Technical Development and Evaluation Center developed the Terminal VHF Omnirange (TVOR)[1].

Several manufacturers are now producing TVOR equipments. This is a preliminary evaluation report of a TVOR facility manufactured by the Collins Radio Company, Cedar Rapids, Iowa.

DESCRIPTION

The Collins TVOR consists of an antenna, counterpoise, equipment shelter, transmitter and associated equipment, and monitor with external antenna The antenna is a cylinder built of plastic and sheet metal with an internal rotating dipole. The cylinder has 12 vertical slot radiators fed in-phase to radiate the carrier signal. The spinning dipole supplies the rotating figure-of-eight sidebands. The antenna is placed at the center of a 12-foot diameter counterpoise. Extending from the counterpoise periphery are 32 equally spaced ground plane extension rods. These rods are adjusted in length to minimize the polarization error.

[1] S. R. Anderson, T S. Wonnell, "The Development and Testing of the Terminal VHF Omnirange" CAA Technical Development Report No. 225, April 1954.

The equipment shelter consists of a corrugated steel cylinder ten feet in diameter and eight feet high which supports the counterpoise. The transmitter and associated equipment are mounted on a rack consisting of two vertical channels which extend from the concrete floor to the counterpoise. The transmitter, using a 4X150A radial-beam tetrode, delivers 50 watts of rf power. Included on the rack is an automatic voice identification system employing a magnetic drum. The remainder of the TVOR equipment, with the exception of the monitor, is of conventional design.

The monitor is an adaptation of the Collins navigation receiver circuits. The resolver (azimuth selector) is replaced by a step-type RC phase shifter which provides eight courses with 45° separation. An azimuth increment dial provides a vernier adjustment of ±2.0°. The monitor alarm circuits use Sensitrol relays with fixed resistors in shunt for factory adjusted sensitivities in accordance with ICAO standards. The monitor employs a remote Collins aircraft antenna connected by coaxial cable to the detector circuit contained within the monitor proper.

GROUND TESTS

Bearing errors were measured by means of the monitor, and by rotating the antenna. The monitor design limited azimuth error checks to eight bearings. A bearing error spread of 1.77° is shown in Fig. 1. An error in repeatability of ±0.1° was experienced during rotating of the antenna due to mechanical difficulties in the rotating mechanism.

Previous experience with other spinning dipole antennas has shown them to be susceptible to bearing errors caused by cross-coupling between the carrier and sideband antennas. This cross coupling causes the bearing error curve to be quadrantal in shape because of the introduction of second harmonic distortion of the 30-cps variable phase modulation. The cross coupling effect can be varied by changes in rf phasing. An intentional rf phase shift of ±27° was introduced to determine the cross coupling effect of this antenna. A maximum course shift of 0.35° was observed, a relatively small error considering the large change in phasing See Fig. 1. This test is indicative of the improvement which may be possible by additional adjustments or modifications to reduce the cross coupling.

The polarization error, shown in Table I, was measured with a portable polariscope[2].

[2] Sterling R. Anderson, Wendell A. Law, "The Measurement of VOR Polarization Errors," CAA Technical Development Report No. 202, May 1953.

TABLE I
Ground Measurements of Polarization Errors

Azimuth (Degs.)	Error (Degs.)	Relative Phase (Total of Both Phasers) (Degs.)	Distance (Feet)
83	±0.75	73	1000 +
130	±0.50	0	1000 +
271	±0.55	-56	1000 +
93	±0.9	14	2640

The variation with azimuth of the relative phase between the vertically and horizontally polarized signals indicates that the effect of polarization error as observed in an aircraft, will vary with azimuth[3]. However, these measurements indicate that this antenna possesses small polarization errors at low angles.

For comparison purposes, polariscope measurements of several VOR antennas are listed in Table II.

TABLE II
Polariscope Measurements of Polarization Error

Antenna Type	Polarization Error in Direction of Maximum Error (Degs.)
TDEC four-loop on 12-foot diameter counterpoise	±0.8
Collins TVOR on 12-foot diameter counterpoise	±0.9
TDEC four-loop on 35-foot diameter counterpoise	±0.9
TDEC five-loop with Uskon cloth on 35-foot counterpoise	±3.0

The Collins TVOR monitor uses an aircraft antenna (Collins 37J-3) mounted eight feet high and 76 feet distant at 180° azimuth. RG-8/U cable connects the antenna to the tuned circuit and diode detector mounted in the monitor unit in the TVOR shelter. No tests were made to determine possible rf leakage into the detector circuit.

[3] Ibid. See Fig. 16

Tests were made to determine possible course scalloping due to reradiation from the monitor antenna. A truck with an aircraft receiver was located at 135° azimuth and 500 feet distant. The monitor antenna was mounted on a 4 × 4 inch post 8 feet high and moved radially on the 180° azimuth while the course variation at the receiver was being observed. This test was repeated with the monitor antenna ten feet high, at 90° azimuth. The results are listed in Table III.

TABLE III
Ground Measurements of Monitor Antenna Scalloping
Receiver Located 500 Feet at 135°

Antenna Location (Degs)	Antenna Height (Feet)	Distance (Feet)	Scalloping (Degs.)
180	8	70	±0.29
180	8	85	±0.41
90	10	40	±0.94
90	10	127	±0.18

The scalloping increase at 85 feet was apparently due to normal variations in the rf field pattern which caused an increase in signal at the greater distance.

The CAA Type CA1278 VOR field detector causes less than ±0.2° scalloping at 200 feet, when 10 feet high; so an attempt was made to reduce scalloping by the Collins 37J-3 antenna to that level. The antenna was connected to a 52-ohm Termaline wattmeter to simulate the monitor load and moved outward on the 90° radial at a height of 10 feet. It was necessary to increase the distance to 127 feet as may be seen in Table III. Lack of time prevented further tests to determine if sufficient signal was available at that point for satisfactory monitor operation.

FLIGHT TESTS

Flight tests were conducted on the Collins TVOR for the purpose of measuring the vertical plane field pattern, distance range, polarization checks, cone measurements and azimuth accuracy. The results obtained during these tests are compared with the results previously obtained when the same test was conducted on the TVOR developed at the Technical Development and Evaluation Center, Indianapolis, Indiana.

Vertical Plane Field Pattern

The polar plot of the vertical plane field pattern on the Collins TVOR is shown in Fig. 2. A similar plot for the TDEC TVOR is shown in Fig. 3.

Distance Range

The distance range of a TVOR is defined as the distance in statute miles from the station at which the course width in degrees becomes double the course width measured at ten miles. This test is conducted at an altitude of 1000 feet above ground. The distance range of the Collins TVOR was 70 miles and that of the TDEC TVOR was 56 miles.

The Collins TVOR distance range measurement of 70 miles is considerably greater than the theoretical or operational distance range obtained on the Federal Airways VOR stations throughout the U.S. This indicates that unusual VHF propagation conditions existed at the time the distance range tests were conducted; however, an examination of the vertical plane field pattern indicates that the distance range of the Collins TVOR should be very satisfactory.

Polarization Checks

The following polarization flight tests were conducted at an altitude of 1000 feet above ground and at a distance of 20 miles west of the station.

(a) Heading Effects.

While recording the course deviation indicator current, the aircraft was flown on eight different headings, crossing a ground check point at every 45° heading. The course recording was marked each time the airplane crossed the check point and the indicated bearing was then compared with the magnetic bearing. The zero reference point in each case was taken on the heading to the station.

	Total Heading Effect
Collins TVOR	±0.45°
TDEC TVOR	±0.6°

(b) Wing Rock

Headed to the station, the aircraft was banked ±30°. The nose of the airplane was held "on the point" during this maneuver. The course deviation indicator current was recorded, and then converted to degrees of course displacement.

	Polarization Error
Collins TVOR	±0.18°
TDEC TVOR	±0.5°

(c) 360-Degree Circle

Headed toward the TVOR and starting from a ground check point, a 360° circle was flown at a constant 30° bank. The course deviation indicator current was recorded during this circle and converted into degrees of error from the azimuth course being flown at the beginning of the circle. Since the aircraft in the 360° circle was changing azimuth with respect to the station, this deviation was computed in degrees and subtracted from the course deviation indicated error, resulting in the numerical value of polarization error, following the removal of the receiver error.

	Total Polarization Error
Collins TVOR	±0.6°
TDEC TVOR	±0.7°

Cone Measurements

A series of flights across the TVOR 1000 feet above ground was conducted to record the action of the course deviation indicator in the so-called cone area above the antenna array. In measuring the cone of a VOR from a recording of the course deviation indicator a definition of the cone is stated so that the beginning and end of the cone may be positioned on the recording. The course deviation indicator sensitivity full-scale left to full-scale right is 20°. When the indicator deviates beyond 2° and this deviation is due to the normal course disturbances encountered above a TVOR, the cone is considered to begin. In a similar manner, the cone ends at the 2° deflection point as the straight line course indication is resumed on the other side of the cone.

	Cone Angle of Elevation
Collins TVOR	60° (Approximately)
TDEC TVOR	75°

The absolute value of the angle of elevation of the Collins TVOR cone could not be calculated from the recordings. At the time the flight tests were conducted, the existing weather conditions were five miles visibility and a cloud ceiling of 1600 feet above ground. The radial flights over the TVOR for the purpose of measuring the cone characteristics were made at an altitude of 1000 feet above ground. On the radial flights over the cone severe course disturbances averaging ±3° were encountered in the nulls at 22° and 55° which are shown in the vertical plane pattern, Fig. 2. A sample course recording is shown in Fig. 4. At 1000 feet above the TVOR, the angular velocity of the aircraft, as viewed from the ground, was so great (at high angles) that the course deviation indicator with its associated wiggle filters could not recover from the null-induced course disturbances in sufficient time to permit an accurate cone measurement. Normally such a test would be conducted with the aircraft at an altitude of 10,000 feet above the TVOR, at which altitude the recovery time would be adequate.

The recordings of the TO-FROM indicator obtained on the cone check flight revealed one smooth movement of the indicator from the TO position to the FROM position, providing a precise check as to when the aircraft is directly over the TVOR. See Fig. 5. This precise check type of indication was obtained each time the aircraft passed over the TVOR under theodolite guidance. On several other flights over the TVOR without theodolite aid, the pilot passed slightly to one side of the station and the single cross-over of the TO-FROM indicator was not obtained as shown in Fig. 6 On radial passes not directly over the TVOR, the TO-FROM indicator moves from the TO position toward the FROM position, passing the center position slightly, returns to the TO position and then crosses over completely to the FROM position.

Theodolite Flight Calibration

The TVOR azimuth accuracy was flight checked by the theodolite calibration method. The actual calibration consisted of recording the current of the course deviation indicator in the airplane as it circled the TVOR at a radius of five miles. The omnibearing selector was advanced in 10° steps to keep the course deviation indicator on scale, and to present (at center scale) the indicated magnetic bearing from the station. This indicated bearing was compared with the magnetic bearing from the TVOR as measured by a theodolite on the ground at the TVOR. The error curves of the Collins and TDEC TVOR facilities are shown in Fig. 7.

Orbit Calibration - 20-Mile Radius

A second calibration to measure the azimuth accuracy of the Collins TVOR was conducted employing the orbit calibration method. This calibration procedure consisted of recording the TVOR course indication on a 20-mile radius circle around the TVOR and marking specific points on the recording as the aircraft crosses identifiable ground check points. At the completion of the flight, a data sheet containing the precise magnetic bearing of each of the ground check points with respect to the TVOR, the course recording, and the aeronautical chart used during the orbit calibration were forwarded to the CAA Aeronautical Center, Oklahoma City, Oklahoma, where this material was processed on an azimuth calculator. The measured error curve resulting from the 20-mile orbit flight test is shown in Fig. 8.

Flight Test Observations and Comments

Approximately five hours flight time was required to obtain data on the operational characteristics of the Collins TVOR. The operation of ground and airborne equipments, plus the coordination between ground and airborne crews were excellent, resulting in a high order of accuracy in the data obtained on the specific tests conducted. However, the flight testing of the Collins TVOR cannot be considered a complete operational evaluation of the system. As previously stated, adverse weather conditions prevented the conduct of more tests for further investigation of cone characteristics, and additional azimuth accuracy calibrations which require 12 to 15 miles visibility for proper theodolite operation. All of the polarization flight checks were conducted on the 270° radial of the TVOR. In view of the ground polarization check results, it is obvious that these tests should be repeated on several more radials around the TVOR.

CONCLUSIONS

The preliminary evaluation of the Collins TVOR was conducted during two working days; therefore, a complete analysis is not possible. On the basis of flight and ground observations it is concluded that:

1) A null of sufficient depth occurs at 22° and 55° elevation to cause course disturbances of ±3°.

2) A cross coupling existed between the carrier and sidebands. Although this condition is not serious, it was evidenced in the bearing error of the station as the phasing between the carrier and sidebands was changed

3) The antenna of the Collins TVOR performed satisfactorily on a counterpoise 12 feet in diameter, however, evaluation of its operational characteristics was not performed on counterpoises of larger diameters at this time.

4) The accuracy of the bearing information is well within the minimum requirements.

5) The polarization error measured at low angles is acceptable.

6) The cone causes multiple crossovers of the TO-FROM indicator unless the aircraft passes directly over the station.

7) Scalloping was produced by the monitor antenna due to its present design and location.

8) The present design of the antenna array rotating mechanism is not adequate for rapid, accurate ground calibration of the TVOR.

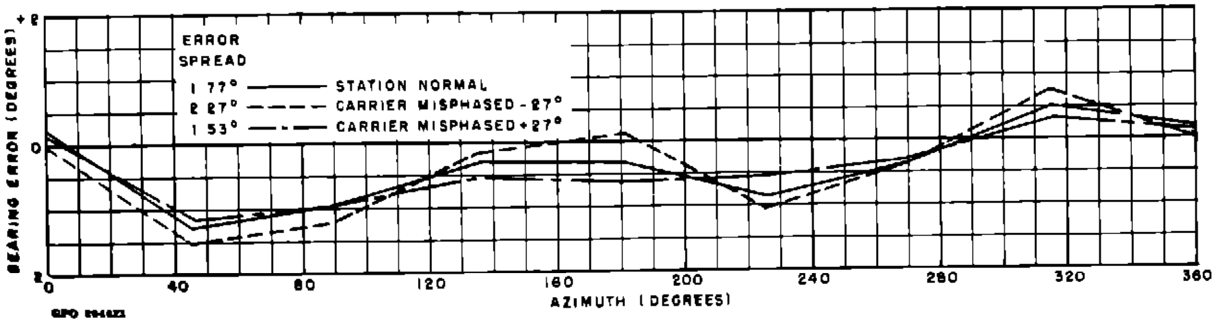

FIG 1 GROUND CALIBRATION USING COLLINS MONITOR AND ROTATING ANTENNA

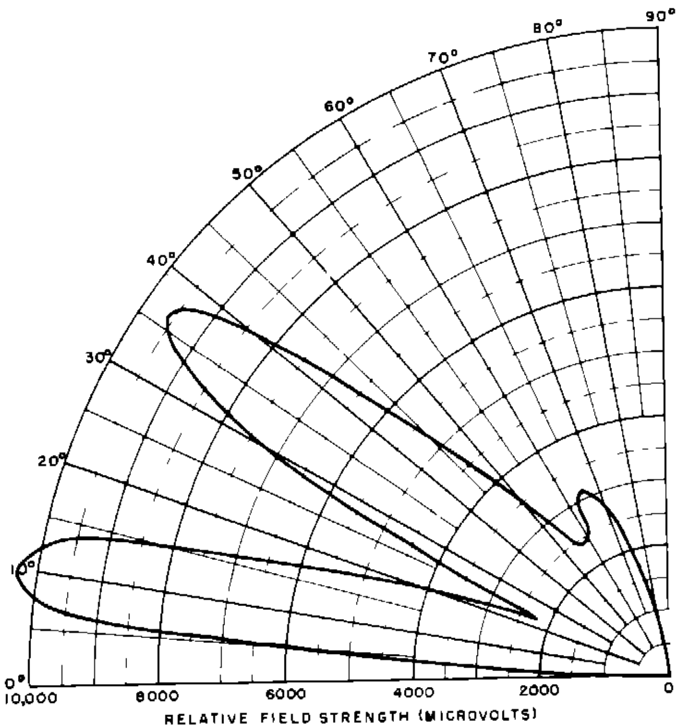

FIG 2 COLLINS TVOR VERTICAL-PLANE FIELD PATTERN

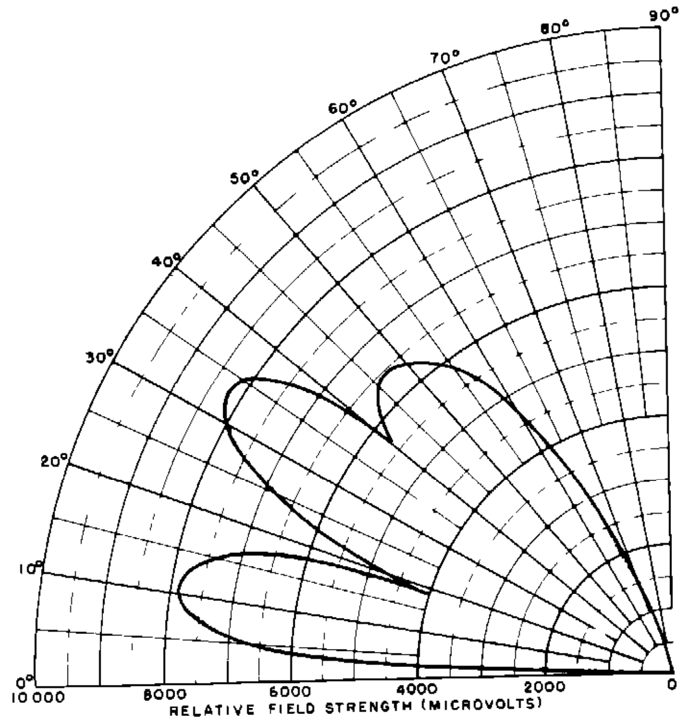

FIG 3 TDEC FOUR-LOOP TVOR VERTICAL-PLANE FIELD PATTERN

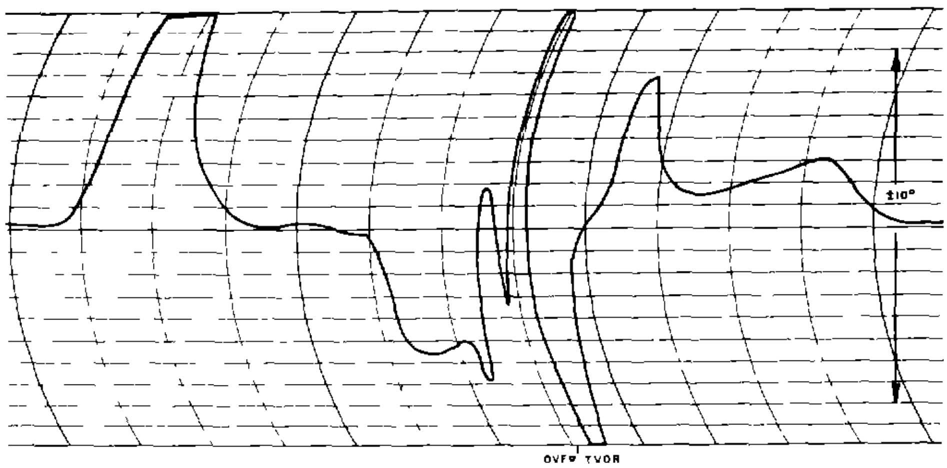

FIG 4 COURSE DEVIATION INDICATOR RECORDING FLIGHT DIRECTLY OVER TVOR

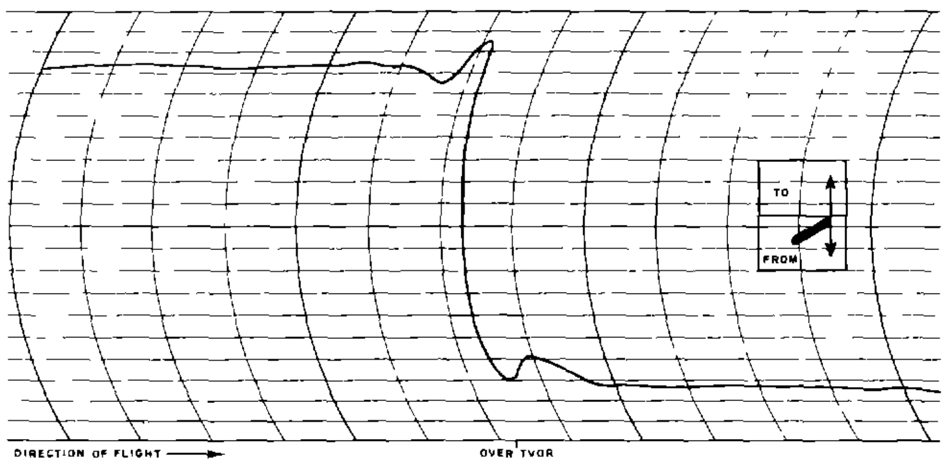

FIG 5 TO FROM INDICATOR RECORDING FLIGHT DIRECTLY OVER TVOR

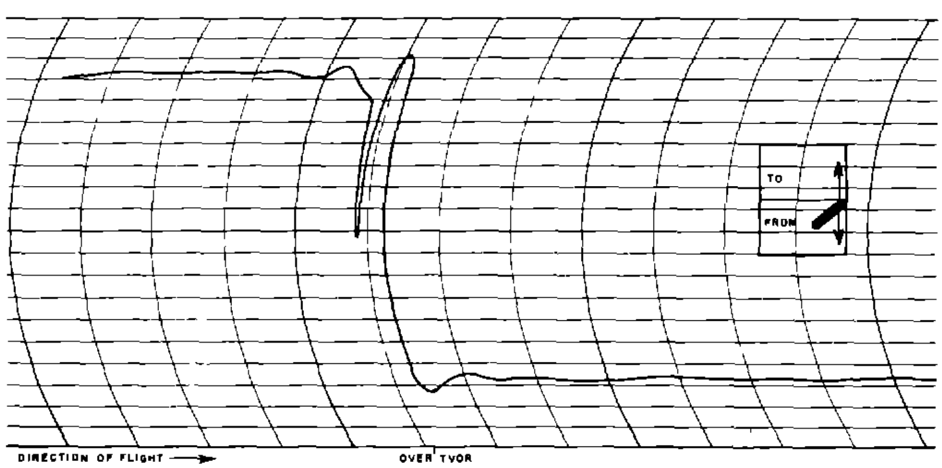

FIG 6 TO FROM INDICATOR RECORDING FLIGHT NOT DIRECTLY OVER TVOR

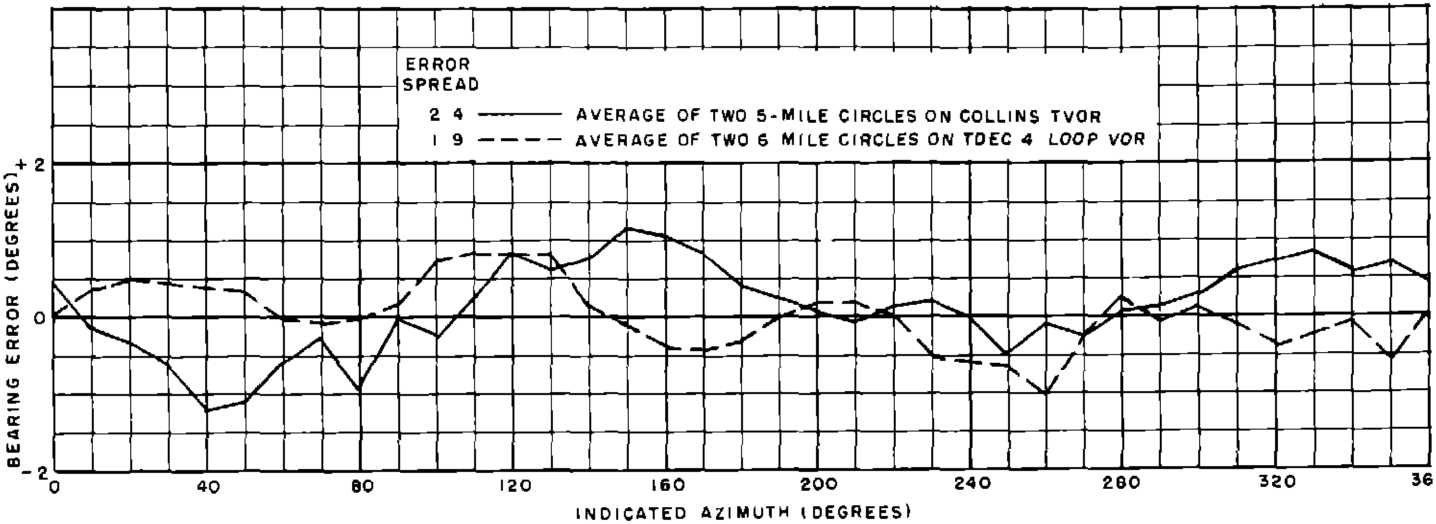

FIG 7 THEODOLITE FLIGHT CALIBRATION OF COLLINS TVOR COMPARED WITH TDEC FOUR-LOOP VOR

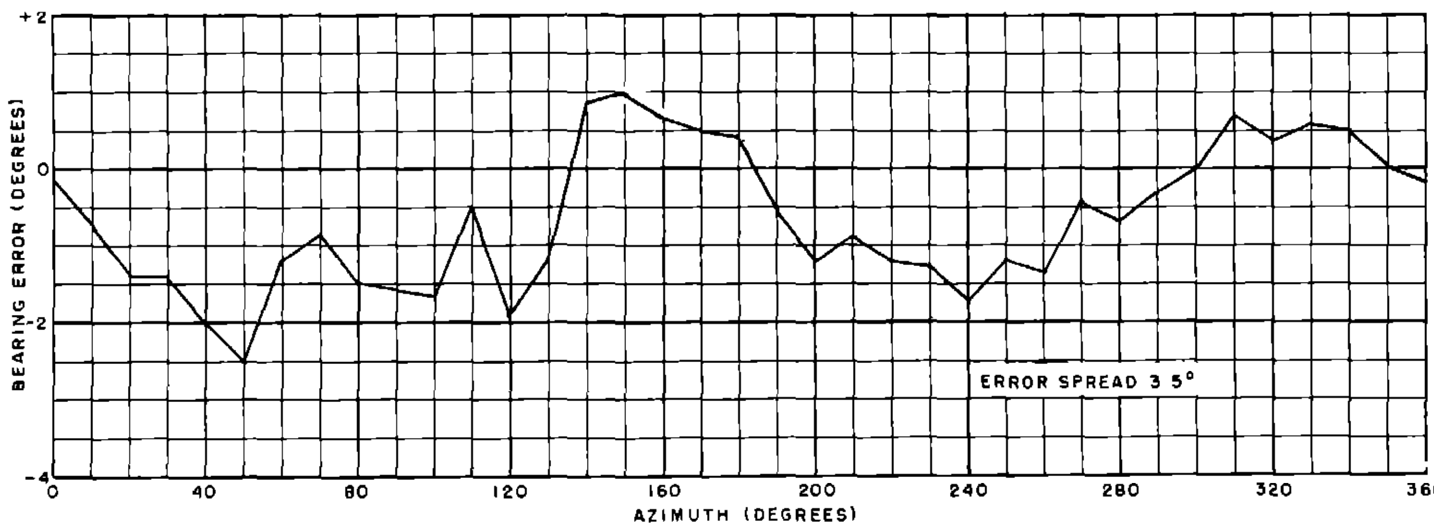

FIG 8 20-MILE-RADIUS CALIBRATION CIRCLE

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