TECHNICAL DEVELOPMENT REPORT NO. 214

CHARACTERISTICS OF THE MOHAWK AIRLINES TVOR
ITHACA, NEW YORK

<u>FOR LIMITED DISTRIBUTION</u>

by

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INTRODUCTION

In September 1950, the Technical Development and Evaluation Center installed the first Terminal VHF Omnirange (TVOR) at the Weir Cook Municipal Airport, Indianapolis, Indiana. The express purpose of this project was to develop a low-cost, low-power VOR which could be located within the boundary of an airport, which could be used as a low-approach navigational aid; and which might be procured, installed, and operated by airlines or municipalities at certain desired terminals as the need arose. The TVOR was primarily intended for use at airports where the traffic density is too small to justify the installation and maintenance of a complete instrument landing system (ILS).

The successful results obtained in the Indianapolis tests led to the further performance testing of the TVOR at several other airports, and it was concluded that the TVOR can be an extremely useful aid in the guidance of aircraft to or from an airport, in low approaches to the field for landing, and as an accurate fix or holding aid.[1]

The limited funds granted to the Office of Federal Airways for installation and maintenance of TVOR facilities precluded their installation at numerous airports where they were needed. Realizing the necessity for more TVOR stations, the Air Transport Association proceeded to assemble a low-cost TVOR that the individual airlines could purchase and install at desired terminals. Mohawk Airlines of Ithaca, New York, was the first airline to install a TVOR under the ATA program for private operation and maintenance.

Operation of the Ithaca TVOR has been very unsatisfactory, and the facility was approved by the Office of Federal Airways for use only on approaches in line with the airport runway. At the request of the Air Transport Association and Mohawk Airlines, TDEC investigated the Ithaca TVOR to determine the cause of its excessive bearing errors and generally unsatisfactory operation. Accordingly, two TDEC engineers were dispatched to Ithaca, New York. This report covers the brief investigation from June 16 to 20, 1953.

EQUIPMENT

The Mohawk Airlines TVOR antenna system consists of a Type 2602 Alford Slot antenna mounted at the center of a counterpoise approximately eight feet in diameter and four feet above the ground. The enclosed

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[1] T. S. Wonnell and S. R. Anderson, "The Development and Testing of the Terminal VHF Omnirange," CAA Technical Development Report not yet published.

space beneath the counterpoise houses a 50-watt Wilcox Electric Company transmitter, a Maryland Electronic Manufacturing Company modulation eliminator, a CAA Type CA-1337-A goniometer, and a CAA Type CA-1277 VOR monitor.

In comparison to the Ithaca TVOR, the CAA standard TVOR consists of a counterpoise 12 feet in diameter and 10 feet above the ground. A four-loop antenna array, developed at TDEC, is mounted at the center of the counterpoise with a plastic dome shelter protecting the antennas and cables from the weather. The enclosed space beneath the counterpoise houses component equipment similar to that of the Mohawk Airlines TVOR.

In addition to the CAA monitor equipment installed at the Mohawk Airlines TVOR, the TDEC supplied a CAA Type CA-1430 phase standard and a CAA Type 2559 oscilloscope for use in the tests described in this report.

TESTS

The 30-cycles per second frequency modulation of the 9.96-kilocycle subcarrier is known as the reference-phase signal. The reference-phase signal has a circular radiation pattern of constant phase at all azimuths. The 30-cps modulation produced by the rotating figure-of-eight pattern is known as the variable-phase signal. The phase angle of the variable-phase signal varies directly with azimuth. The tone wheel producing the reference-phase modulation and the goniometer producing the variable phase modulation are driven by the same synchronous motor.

The initial test was conducted without any adjustments at the station to establish the operating bearing-error curve of the station. Stakes were driven into the ground at a radius of approximately 100 feet from the center of the antenna and spaced at 15° intervals. A portable field pick-up unit, designed to be used with a CAA monitor, was used to obtain calibration data at each stake. The bearing-error curve derived from these data is shown in Fig. 1.

A comparative bearing-error curve was made by measuring the phase of the variable-phase signal with the phase standard. The variable-phase signal was taken from the variable-phase channel of the monitor (this may be obtained directly from the output of the portable field pick-up unit) and fed to the vertical amplifier of an oscilloscope. The phase-standard output was connected to the horizontal amplifier of the same oscilloscope. The phase was read on the phase standard when a linear trace was observed on the oscilloscope. An error curve was derived from the difference between the phase-standard reading and the known azimuth marked by the stakes. The 10-kc reference-phase modulation does not affect the bearing error with this method. Fig. 2 shows the results of this method of determining the bearing-error curve.

A comparison of Figs. 1 and 2 indicates a maximum bearing-error spread of about 11° with a definitely defined duantal shape. This duantal shape of the bearing-error curve may be the result of an undesired modulation of the carrier, which would combine vectorially with the variable-phase signal. Another possible source which might produce a duantal-shaped bearing-error curve is an undesired hum entering the phase-measuring circuit of the monitor. The monitor was suspected as the logical source; however, a further test showed that the monitor was operating satisfactorily. A signal was taken directly from the portable field pick-up unit before entering the monitor, and a bearing-error curve was obtained by comparing the variable phase with the phase standard. The bearing-error curve obtained with the monitor compared favorably with the bearing-error curve obtained directly from the field pick-up, therefore, it was concluded that the monitor was not the cause of the duantal-shaped error curve.

A ground check of the station was made to determine whether proper modulation levels and radio-frequency phasing were being maintained. The variable-phase modulation was very close to the correct value, 30 per cent; however, the 10-kc tone-wheel modulation was measured at 45 per cent. This 10-kc modulation was reduced to 31 per cent. An examination of the modulation-eliminator output revealed 7 per cent modulation remaining on the carrier fed to the goniometer. Five per cent is considered the upper limit for satisfactory operation of a TVOR. The tubes were replaced in the modulation eliminator and the unit was retuned. With the 10-kc tone-wheel modulation set at 30 per cent, the residual modulation was reduced to 2 per cent, which is normal.

Fig. 3 shows the calibration-error curve of the station after completing the ground check and adjustment. A comparison of Figs. 1 and 3 will show the effect of having the 10-kc tone-wheel modulation at a value greater than 30 per cent. The modulation eliminator becomes less effective, and it is not able to perform the function intended. The small amount of duantal error remaining in the bearing-error curve indicates that the high tone-wheel modulation level and poor operation of the modulation eliminator were not the entire cause but did contribute the greater amount of error.

Upon analyzing the output of the transmitter with an oscilloscope, approximately 1 1/4 per cent of 60-cps modulation was noted. A capacity of 11 microfarads was placed between the high voltage output and the ground. This lowered the 60-cps modulation to approximately 1/4 of 1 per cent. The 60-cps modulation may combine with the 30-cps variable-phase signal to produce part of the duantal error of the bearing-error curve. To substantiate this, the transmitter was replaced with a CAA Type TUQ transmitter supplied by TDEC. The station was completely retuned and a bearing-error curve was taken. Fig. 4 shows the results of this test.

The bearing-error curve of Fig. 4 shows a spread of 3.4°, and the curve has an octantal shape. Previous tests conducted at similar stations using Alford antennas indicate that this octantal shape is normal. The octantal shape is caused by the deviation of the figure-of-eight sideband patterns from that of a sine wave. A bearing-error spread of 2° has been obtained, however, with the figure-of-eight deviations associated with this type antenna.

During the first tests conducted at the station, it was noted that the stub tuner of the modulation eliminator had to be reset several times between tests. The replacement of the tubes and, eventually, the replacement of the modulation eliminator with a spare unit failed to correct the trouble. The unstable condition necessitated rephasing of the sidebands-to-carrier for proper operation. Prior to rephasing, a measurement of the variable modulation showed a change from the normal 30 per cent to a value between 15 and 25 per cent. The change could be attributed to either a change in antenna characteristics or to a frequency shift in the transmitter. Retuning the stub tuner and rephasing the sidebands-to-carrier usually returned the variable modulation to normal.

A final bearing-error calibration of the monitor was in progress when another kind of instability was observed. A further check revealed that the variable modulation had increased to 50 per cent and that the sidebands-to-carrier phasing had changed approximately 45°. The stub tuner of the modulation eliminator was not out of tune. A bearing-error curve was taken. This is shown in Fig. 5. It is believed that an internal change of large magnitude had taken place in the antenna. A study of Fig. 5 shows that the bearing-error curve is quadrantal in shape, indicating an inequality in the size of the figure-of-eight patterns. This was not observed during the preceding tests. The inequality of the figures of eight would produce maximum error at each cardinal direction. Since the Alford antenna has been observed from previous tests at this Center to change in this manner because of rain, no further tests were conducted at Ithaca.

CONCLUSIONS

1. Observations indicated that the tubes of the modulation eliminator were in need of replacement.

2. The 45-per cent, 10-kc, tone-wheel modulation overloaded the modulation eliminator, so that it did not operate properly.

3. The antenna is not adequately sealed against moisture and is easily affected by moisture and humidity conditions.

4. The audio-response curve of the transmitter is not flat between 9,000 and 11,000 cps. A certain amount of slope detection of the 10-kc modulation places a 30-cps amplitude modulation on the carrier. This condition increases the magnitude of the quadrantal bearing-error curve.

5. The amplitude modulation of the tone-wheel signal was accentuated by the transmitter audio-input circuitry, causing a change from 4.2 to 9.2 per cent.

6. A change in operating constants took place intermittently for no apparent reason; that is, the variable-phase modulation changes from 30 to 50 per cent, the modulation-eliminator stub tuner required retuning, and the r-f phase between the sidebands and the carrier necessitated resetting. A substitution of the spare modulation eliminator for the one in service failed to alter the intermittent fault. The antenna was suspected, but a measurement of the VSWR for all three inputs indicated that this was unlikely.

7. A large change in operating constants with no change in modulation-eliminator stub tuner took place immediately following the recording of a very satisfactory bearing-error curve. A quadrantal bearing-error curve was noted after the station was retuned to normal conditions. It is believed that faulty operation of the antenna is responsible for this change.

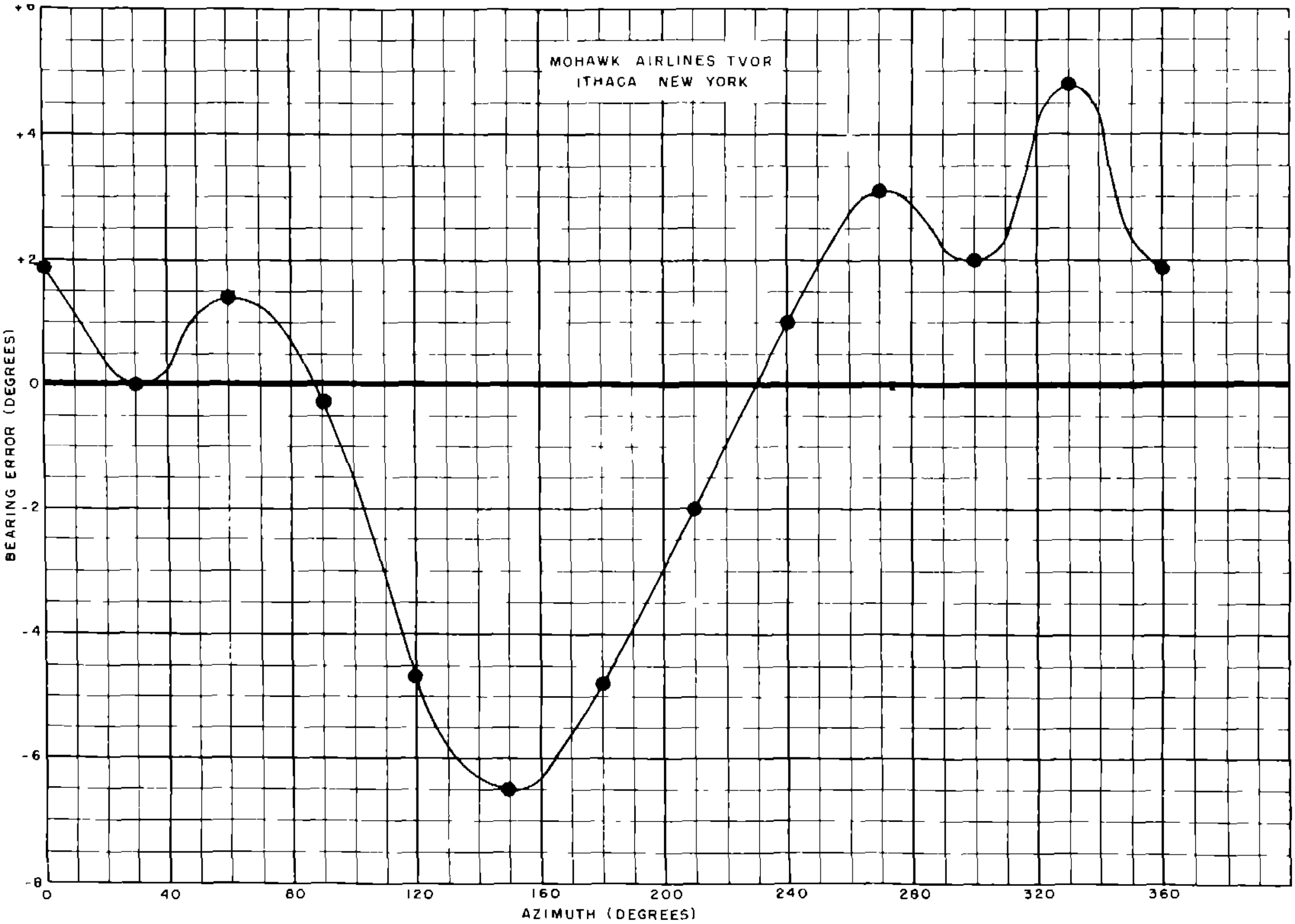

FIG I BEARING ERROR VERSUS AZIMUTH ANGLE OBTAINED WITH A CALIBRATED CAA MONITOR

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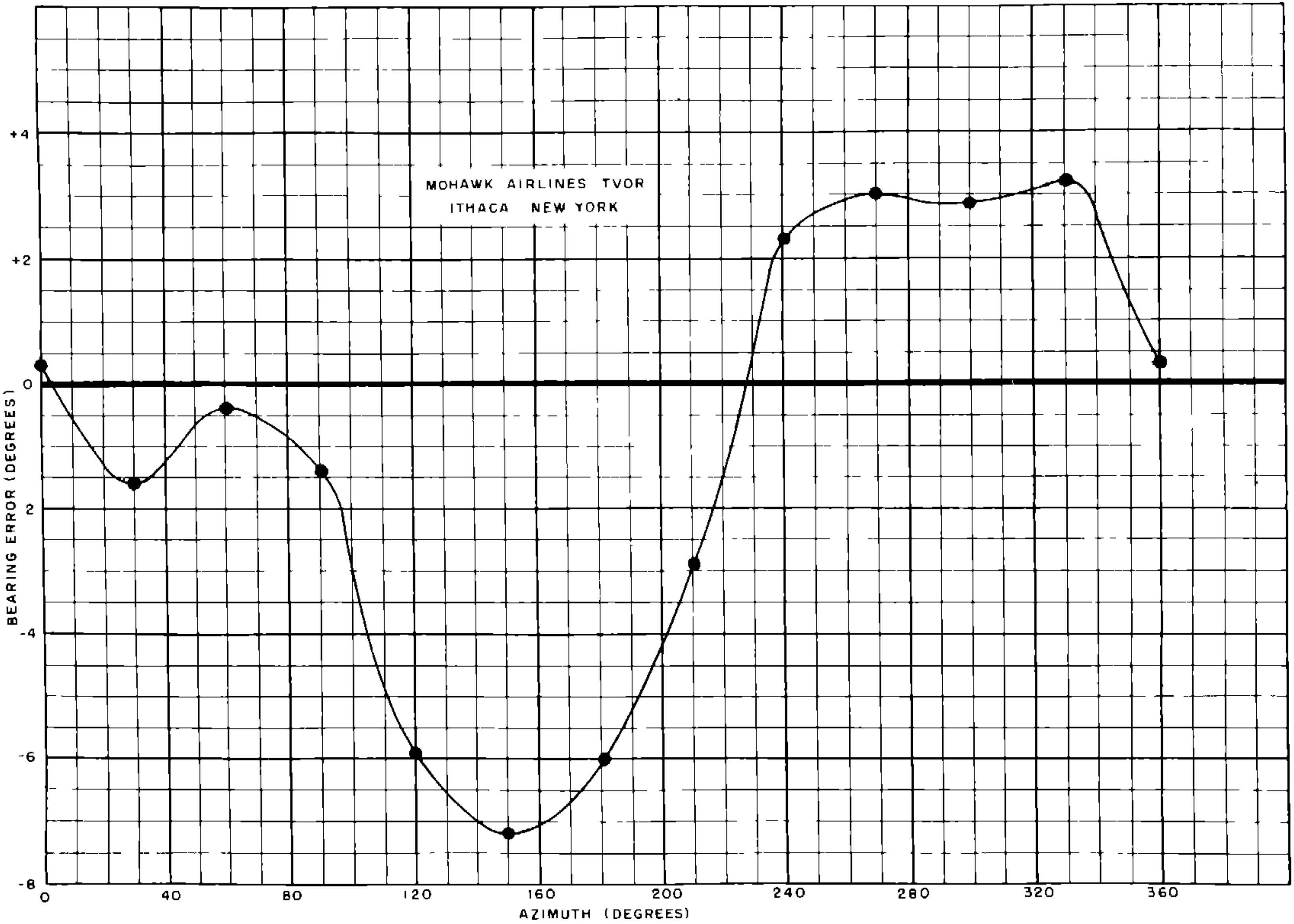

FIG 2 BEARING ERROR VERSUS AZIMUTH ANGLE OBTAINED BY MEASURING THE VARIABLE PHASE ANGLE WITH A CAA TYPE 1430 PHASE STANDARD

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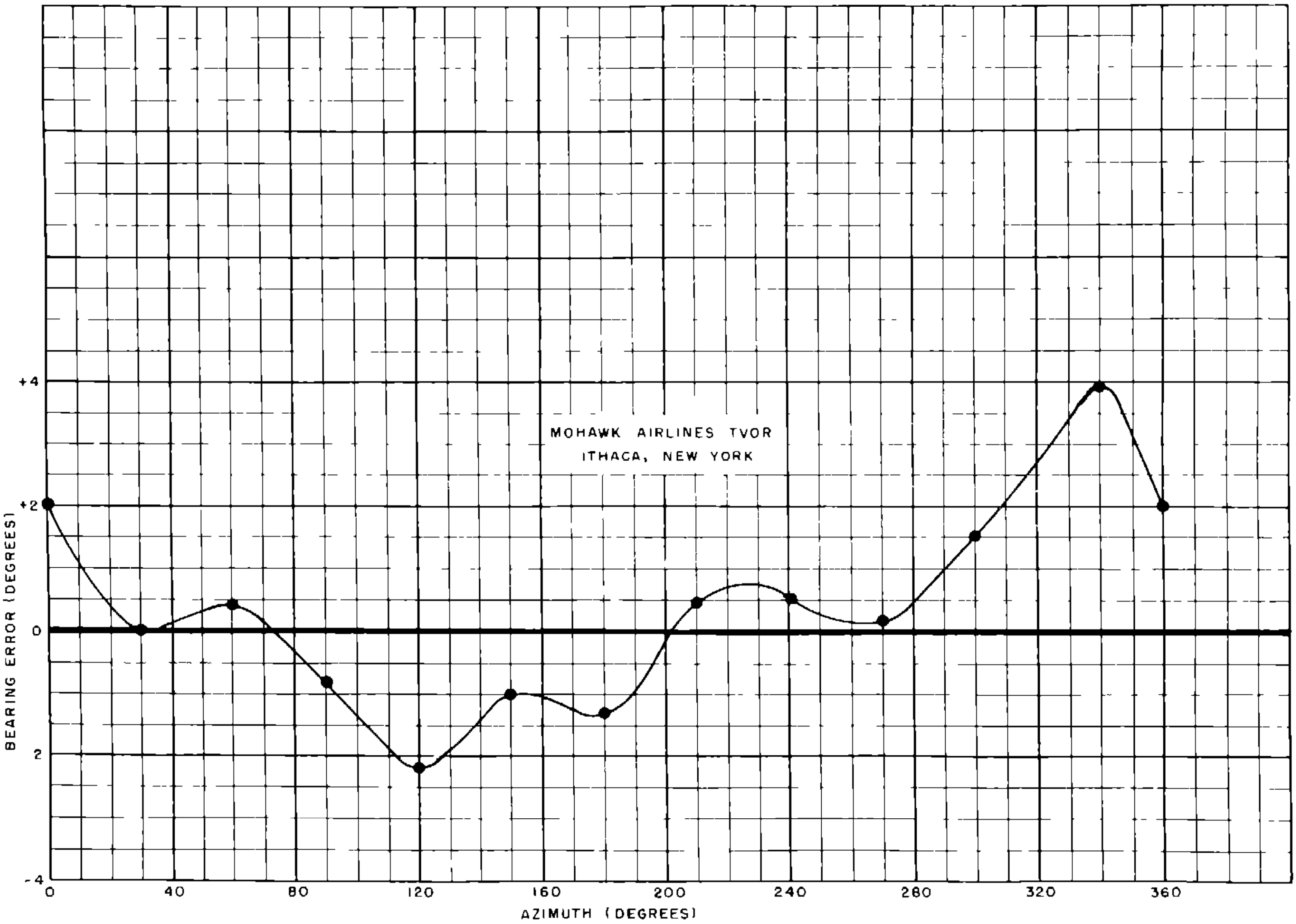

FIG 3 BEARING ERROR VERSUS AZIMUTH ANGLE OBTAINED
WITH A CALIBRATED CAA MONITOR

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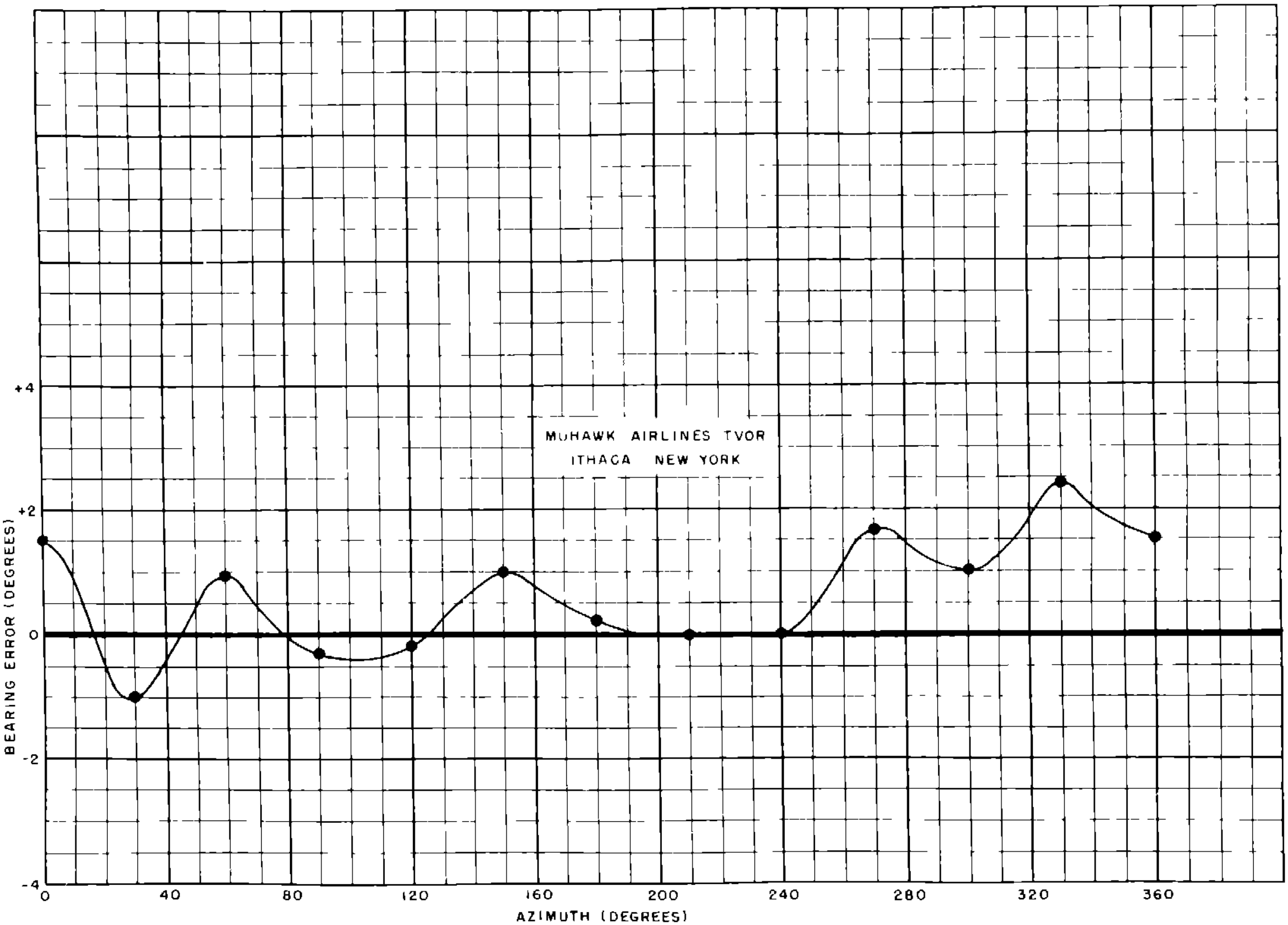

FIG 4 BEARING ERROR VERSUS AZIMUTH ANGLE OBTAINED WITH A CALIBRATED CAA MONITOR

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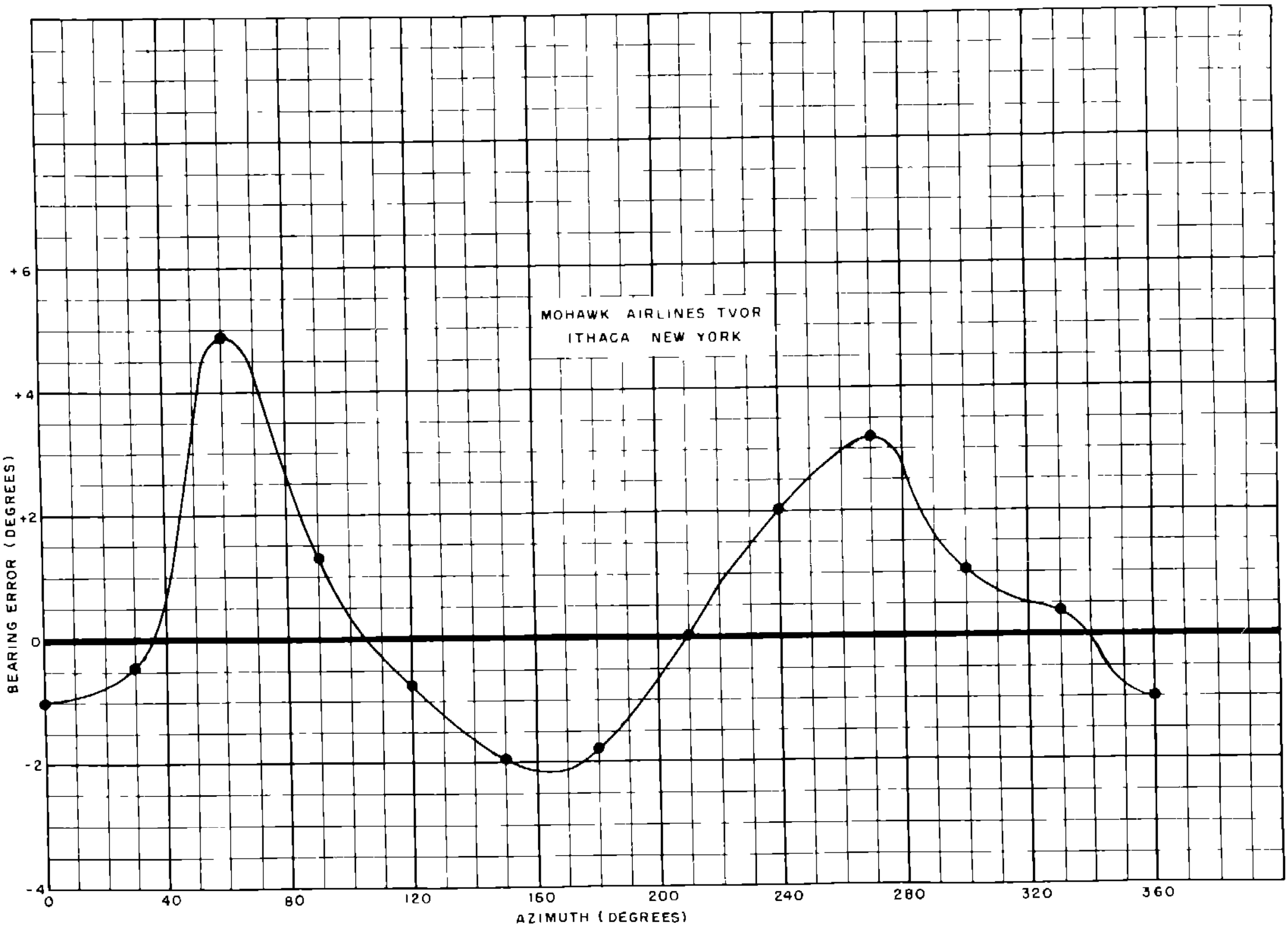

FIG 5 BEARING ERROR VERSUS AZIMUTH ANGLE OBTAINED
WITH A CALIBRATED CAA MONITOR