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Evaluation of the Tacan System

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EVALUATION OF THE TACAN SYSTEM*

SUMMARY

This report describes an evaluation of TACAN (the military short-range navigation system) conducted by the Technical Development Center of the Civil Aeronautics Administration, Indianapolis, Indiana The evaluation consisted primarily of approximately 120 hours of flight tests in DC-3 type aircraft and various laboratory tests Results of the evaluation revealed that

1 Insofar as information supplied to the aircraft is concerned, that is, bearing and distance from the ground station, TACAN is identical to the present CAA VOR/DME system
2 TACAN is subject to siting errors similar to those of the VOR
3 TACAN is not suitable for civil use because of its complexity and attendant unreliability
4 Complexity of the equipment renders TACAN impractical for use in small aircraft for reasons of weight, space, and economy
5 The propagation characteristics of the frequency band occupied by TACAN are not reliable for that service

INTRODUCTION

TACAN (Tactical Air Navigation) originally was developed for military tactical use as a short-range navigation system providing continuous position information in terms of polar co-ordinates relative to fixed or mobile bases The very-high-frequency omnirange, distance-measuring equipment (VOR/DME) system now in widespread use is a similar system, providing information in the same terms, although major equipment and frequency differences exist between the two systems It has been shown previously that there is no practical way of rendering the two systems compatible [1,2]

Pursuant to a solution to this dilemma, implementation of TACAN in the domestic United States as a replacement for VOR/DME has been proposed, to permit military aircraft to employ a single airborne equipment for either tactical or nontactical navigation Because such a move would have a tremendous impact on the thousands of users of VOR and/or DME, and because it would involve a major and expensive procurement, training, and reinstallation program by the Civil Aeronautics Administration, the military services afforded the Department of Commerce an opportunity to evaluate the TACAN system Accordingly, ground and airborne TACAN equipments were made available to the CAA for installation and testing at the Technical Development Center

A number of prior evaluations had been conducted covering various aspects of the TACAN system, notably, the evaluation performed by Melpar, Inc , under Air Force contract,[3]

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*Report submitted for publication November 1955

[1] Committee on Compatibility of DME, Final Report, September 22, 1953, prepared for Secretaries of Defense and Commerce

[2] The term "compatible" refers to the use of a single airborne equipment capable of deriving information from both TACAN and VOR/DME ground stations

[3] "Final Engineering Report on Short Range Tactical OBD Evaluation Program (TACAN)," Volumes I and II, Melpar, Inc , Alexandria, Virginia, January 16, 1954

earlier Navy evaluations at the Naval Air Test Center, Patuxent River, Maryland,[4] and a VOR/DME-TACAN co-location evaluation conducted at the Rome Air Development Center, Rome, New York, by the Air Force with TDC participation [5] Although the reports on these evaluations contained a great deal of factual data, it was not possible to draw from them any direct comparisons between the operating characteristics of TACAN and the civil VOR/DME system This was particularly true with respect to the azimuth portions of the two systems

Wide experience with VOR by the CAA has demonstrated that on a practical basis the azimuth accuracy of the system is generally limited by siting errors In the absence of siting errors, it has been shown that equipment, including transmitters, receivers, and antennas, may be readily designed which will produce over-all system accuracies of the order of ±1 0° Equipments providing system errors of ±1 5° not only are available commercially, but they are currently in use in civil and military aircraft and as a part of the Federal Airways ground system

A study of the TACAN system indicates that TACAN azimuth accuracy also should be susceptible to siting errors Siting error exists when the field at the airborne antenna is the resultant of components arriving over multiple paths Multiple-path transmission occurs because of the reflection of energy from objects such as trees, hangars, and wires in the vicinity of the ground station As the aircraft moves, the lengths of transmission paths change, causing corresponding changes in the phase relationships between the fields arriving at the receiving antenna Accordingly, the detected intelligence fed to the azimuth-determining circuits of the receiver denotes instantaneous azimuth information which varies with the relative amplitudes and phases of the component fields The resultant fluctuation of the azimuth indicator is known as scalloping In special cases the amplitude and frequency of scalloping may be predicted with a good degree of accuracy,[6] however, in practical cases where many wave reflections are present, it is almost impossible to determine the severity of the scalloping which will occur

Fundamentally, the severity of the scalloping depends upon (1) the relative amplitude of the direct and reflected energy, and (2) the scalloping frequency The ratio of direct energy to reflected energy, which is likely to be encountered at any given time, cannot be predicted with accuracy in a practical case Among the variables which preclude an accurate computation of this ratio are the electrical properties, geometrical size and shape, depolarization characteristics, and movement of the multitude of reflecting objects which invariably are present at all except perfect sites It is fundamentally true that the efficiency of an object as a reflector increases as its dimensions increase in wavelengths Thus, objects which are relatively poor reflectors at VOR frequencies (112 Mc to 118 Mc) may become very efficient reflectors at TACAN frequencies (960 Mc to 1215 Mc)

Scalloping at frequencies above a few cycles per second may be damped out easily, and it does not result in operational inaccuracy Scalloping at lower frequencies, particularly below one cycle per second (cps), cannot be damped out completely without rendering the instrumentation sluggish to the point that flying a straight course becomes almost impossible. Everything else being equal, the frequency of scalloping varies directly with the radio frequency employed by the system One of the primary goals of the TDC evaluation of TACAN was to determine the derogation of azimuth accuracy resulting from reflected energy received over indirect paths between the transmitter and the aircraft

EQUIPMENT

Installation

The following TACAN equipment was made available to TDC

1 ARN-21, Serial No 63 (airborne TACAN unit)
2 ARN-21, Serial No 52 (airborne TACAN unit)

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[4] "Final Report, Observation of TACAN," Evaluation at Naval Air Test Center, Patuxent River, Maryland, October 20, 1953

[5] "TACAN/VOR Co-Location, Phase I," and "TACAN/VOR Co-Location, Phase II," Rome Air Development Center, Rome, New York

[6] S R Anderson and H F. Keary, "VHF Omnirange Wave Reflections from Wires," CAA Technical Development Report No. 126, September 1950

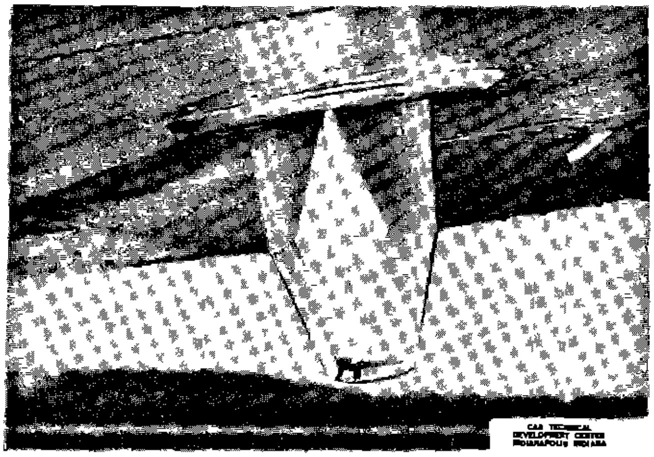

Fig 1 Typical Airborne Antenna Installation

3 URN-3, Serial No 12 (ground TACAN unit)
4 URN-3 Simulator (test equipment for ARN-21)

In addition to these basic equipments, TDC was supplied with adequate spare parts by the equipment manufacturer For the airborne equipments (ARN-21), these spares consisted largely of spare subunits The ARN-21 configuration consists of a main base chassis on which are mounted a number of subchassis All electrical connections are made through multipin plugs on the subchassis and through mating receptacles on the base chassis In general, each subchassis contains all of the components and circuitry required to perform one of the basic ARN-21 functions, such as decoding, range tracking, or azimuth gating

Both ARN-21 equipments were supplied complete with instrumentation and mounted on breadboards with all interunit cabling in place Thus, installation was simple and flexible All three of the TDC DC-3 aircraft are equipped with work benches at which both 115-volt, 400-cps ac and 28-volt dc are available through a combination receptacle In addition, all aircraft were already equipped with antennas suitable for TACAN operation These antennas were designed for DME service which operates in the same frequency band as TACAN Several antenna locations were available on each aircraft Early experimentation with various locations revealed that antennas underneath the aircraft fuselage are most suitable This confirmed earlier experience with locating DME antennas Both half-wave and quarter-wave antennas were employed with no observed differences in performance The particular aircraft employed for any specific flight test was determined by expediency and availability, and no recognizable differences in recorded data were observed as being related to the particular aircraft in which the installation was made Figure 1 is a photograph showing a typical antenna installation beneath the fuselage of a DC-3 aircraft

With the exception of site No 2, installation of the URN-3 was also a relatively simple matter. At sites Nos 1 and 3, housing for the equipment was available At site No 2, the equipment shelter formerly employed at site No 1 was relocated, and because no commercial three-phase power was available, an engine-driven alternator was placed in service This unit provided more than adequate power, however, due to the inconvenience of replenishing the gasoline supply, the URN-3 at site No 2 was operated during the working day only At the other two sites the URN-3 remained in continuous operation

Maintenance and Reliability

Substantially more equipment maintenance was required for TACAN than is acceptable when gauged by electronic-equipment standards for civil aviation Although TACAN is purportedly beyond the development phase and in production, the reliability of the equipment is substandard The unreliability exhibited is believed due primarily to the complexity of the system Considering the large numbers of tubes and components required and the space limitations involved, it is reasonable to expect a high rate of failure For example, it is recognized by CAA that DME interrogators probably never will attain the average operational life between breakdowns achievable with VOR receivers The fundamental reason is the same the DME interrogator is far more complex than the VOR receiver Similarly, an ARN-21 unit cannot be expected to possess reliability characteristics equal to those of a DME interrogator, because the airborne TACAN unit performs all of the basic functions of the interrogator in addition to the azimuth-determining function No criticism of the manufacturer's design is intended Considering the complexity of the system and the space and weight restrictions, it is believed that the final design represents an outstanding engineering achievement

Following is a tabulation of failures encountered with the ARN-21 equipments

1 Preselector cavity arcing, 2 occasions.
2. Relay failure (K-901), 2 occasions
3 Tube failure (V-207), AGC circuit.
4. Condenser failure (C-204), video decoder
5. Delay line failure (L-202), video decoder
6. Resistor failure (R-347), electronic azimuth gate.

These specific failures were far outnumbered by cases of intermittent and/or erratic failures in flight which were self-correcting, precluding subsequent diagnosis in the laboratory. ARN-21 equipments were in operation for a total of 150 hours, including approximately 30 hours of operation on the test bench.

Failures occurred in the following components of the URN-3 equipment during the course of this evaluation.

1 Cavity short, second doubler.
2 Tube (V-621), Type 2D21W
3. Tube (V-4), Type 8020.
4 Cavity short, quadrupler.
5 Tube (V-103), Type 6AK5W.
6 Tube (V-104), Type 6AK5W.
7 Tube (V-1501), Type 4X150G.
8. Capacitor (C-127).
9 Tube (V-1096), Type 8020
10 Tube (V-1302), Type 4-1000A.
11. Tube (V-1303), Type 371-B.
12. Relay (K-1301).
13 Tube (V-1403), Type JRC-5763

In spite of the longer list of failures for the ground equipment, the URN-3 generally was much more reliable than were the ARN-21 units This statement is justified on these grounds: (1) the URN-3 was operated approximately 2000 hours, and (2) ARN-21 equipments consistently exhibited random and erratic periods of operation which have not been recorded as breakdowns but were caused by general instabilities

During the period the TACAN system was undergoing evaluation at TDC, there were a number of observed phenomena which are worthy of mention

1 At the very beginning of the evaluation program, it was discovered that the modulator of one of the two airborne units had a pulse-repetition frequency very near 135 cps during the time of distance-indicator search This resulted in rhythmic swinging of 8° of the course-deviation indicator Maintenance personnel replaced the modulator subchassis with a new unit and the condition did not recur

2 Early in the flight-evaluation program, it was noted that in areas of very low field intensity the distance indicator would unlock, search, then lock on some signal which always indicated 199 miles, regardless of distance from the ground station. Maintenance personnel corrected the situation and reported that the false distance indication was caused by signals from a 42-Mc crystal-saver oscillator leaking into the ranging circuits of the distance-indicating portion of the airborne unit

3 Scattered throughout the flight evaluation of the TACAN system, there were 11 occasions when the azimuth indicator went into search and then locked at a completely erroneous bearing with no flag-alarm indication In one instance the bearing was in error by 160°, and on the remainder of the occasions it was 40° or 80° in error On each of these occasions the aircraft was in an area of low field intensity and moderate to heavy scalloping.

4 The repeatability of azimuth search on orbital flights was unpredictable in many border line cases Different airborne units and the same unit on different occasions seemed to be able to tolerate various amplitudes of scalloping before going into search. During one orbital

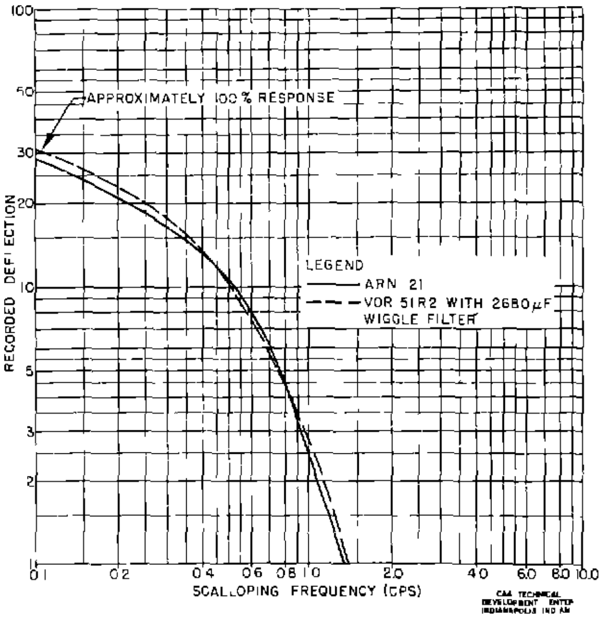

Fig 2 Damping Factor, VOR and ARN-21

flight, the azimuth indicator went into search six different times, the orbit was immediately repeated without a single search When an azimuth search could not be repeated, it was not included in the data presented in this report

Size and Weight

As a matter of general information, the number of tubes, weight, size, and power consumption of the TACAN airborne unit and the VOR/DME airborne units are listed for comparison purposes

TACAN

1 Size, 3/4 air transport rack (ATR) (The width of the unit is the same as a full ATR, but the length is less, hence, the 3/4 ATR rating)
2 Total weight less cables, 72 pounds
3 Power consumption, 17 watts at 28 volts dc and 480 watts at 115 volts ac, 400 cps

VOR/DME

1 VOR (Collins 51R-3)
  A Size, 1/2 ATR
  B Total weight less cables, 52 pounds
  C Power consumption, 127 watts at 27 volts dc
2 DME (Model DIC)
  A Size, 1/2 ATR
  B Total weight less cables, 32 pounds
  C Power consumption, 175 watts at 27 volts dc

The weights, sizes, power, and number of tubes of the TACAN and VOR/DME airborne units may be compared as follows

	TACAN	VOR/DME
Weight, less cables	72 pounds	84 pounds
Size	3/4 ATR	Two 1/2 ATR units
Power	497 watts	302 watts
Tubes	76	60

VOR/DME total weight may be reduced to 76 5 pounds if the Collins Radio Company 51R-3 VOR receiver is replaced with the Collins AN/ARN-19 (XA-1) unit which was developed for the Air Force on Contract No. AF-33(038)-6341 This also would reduce the total power consumption to 284 5 watts, an important consideration in many civil and military aircraft

These considerations are related to the use of a combined azimuth-distance system Thousands of private-flyer aircraft are presently equipped with the VOR azimuth system only, and a large percentage of these probably never will be equipped with distance-measuring equipment for reasons of cost, weight, space, and power consumption. Typical of the VOR receivers used by this class of aircraft are units having the following characteristics which also include air-to-ground voice-communication transmitters

1. Weight, 10 to 20 pounds.
2. Power consumption, 60 to 85 watts d-c.
3 Cost, approximately $500 to $900

At the present time, no TACAN counterpart of a private-flyer VOR receiver is available Development of a TACAN "azimuth only" receiver possessing characteristics equivalent to those enumerated will require years of development and will require the solution of many very difficult engineering problems

In these comparisons, it should be pointed out that the TACAN equipment does not provide any voice-communication service, whereas VOR equipments include this feature

SPECIAL TESTS AND OBSERVATIONS

Indicator Damping

In evaluating fluctuations of the course-deviation indicator (CDI) due to scalloping, it was found necessary to determine the effective degree of mechanical and electrical damping imposed upon the ID-307 indicator (TACAN equivalent of the VOR omnibearing indicator). It is recognized that the degree of damping is a factor which, within limits, is under control of the designer or even the field engineer, however, the optimum amount of damping must take the operational aspect of "flyability" into consideration. In the case of the VOR receiver, essentially all of the damping is accomplished by employing a capacity across the terminals of the CDI On the other hand, damping of the ID-249A (TACAN CDI) is accomplished largely through mechanical means because its deflection is determined by the position of the servo-driven shaft which drives the ID-307 indicator. Only a 1-microfarad (mfd) "wiggle" filter is used for electrical damping at the ID-249A terminals

A number of tests had been conducted previously on VOR receivers to determine the relationship between damping and scalloping frequency In order to obtain equivalent information for the ARN-21, a normal signal from the TACAN simulator was fed into the ARN-21 terminals through a General Radio Company crystal modulator A variable-frequency audio signal was injected into the modulator as a modulating voltage By varying the audio frequency about a center frequency of 135 cps, any desired scalloping frequency could be simulated In Fig 2 the recorded deflection is plotted as a function of scalloping frequency for a constant scalloping amplitude On the same curve is a comparable curve of a Collins 51R-2 VOR receiver with a 2680-mfd wiggle filter The data for the two curves were obtained in a similar manner and reveal almost identical damping characteristics By addition of capacity across the CDI, greater damping can be effected with either TACAN or VOR, however, excessive damping is operationally undesirable, inasmuch as the resultant lag in deflection of the CDI makes it difficult to fly straight courses with accuracy

Phaser Plate Rotations

Previous evaluations by other agencies and the initial tests at TDC revealed the presence in the TACAN system of a characteristic cyclical error, the magnitude of which varies somewhat with different ARN-21 units. Consultation with equipment-manufacturer engineers indicated that these cyclical errors were primarily due to two circuit deficiencies, one in the ground equipment, and one in the airborne equipment In the ARN-21 unit, the output of a circuit operating as a peak-riding detector exhibits a nonlinearity at the time of reception of the reference-pulse bursts These reference pulses occur at a rate substantially higher than the average, causing a periodic change in the duty cycle. The peak-riding detector translates this change in duty cycle to an instantaneous change in the amplitude of the detected envelope. Consequently, a fixed-phase error is introduced into the azimuth-measuring circuits Added vectorially to the variable-phase signal as the aircraft azimuth changes, the resultant error is cyclical in nature.

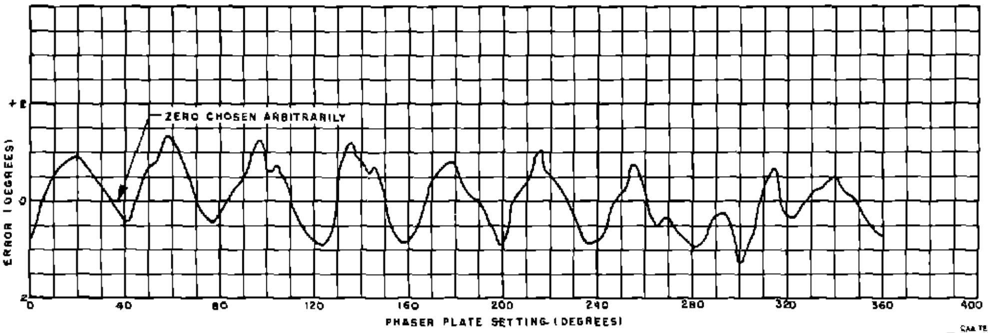

Fig 3 Phaser Plate Rotation, Site No. 1, ARN-21 (Serial No. 52)

In the URN-3 unit, the reference-pulse bursts, with the attendant instantaneous increase in duty cycle, are again responsible for a cyclical error. The modulator-power supply has insufficient filtering, as a result, there is insufficient time for recovery to full voltage between successive pulse pairs of the reference bursts. The effect is amplitude modulation of the r-f energy fed to the antenna, taking the form of a "droop" in the output level occurring during the reference bursts. Since azimuth accuracy of the TACAN system depends upon a constant r-f current being delivered to the antenna, with the only amplitude modulation produced by the parasitic elements in the revolving cylinder of the antenna, again a cyclical error is introduced.

The magnitude of this error may be examined by manual rotation of the phaser plate of the URN-3 antenna This plate controls the time of generation of the reference-pulse bursts Normally, in a ground installation the phaser plate is in a fixed position so that the pickup devices are oriented at the proper places for generation of the reference bursts at 0° magnetic and at 40° intervals therefrom Provision is made for rotation of the phaser plate so that it may be oriented automatically in mobile installations. By manual adjustment of this control, the indicated north of the system may be rotated through a full 360°. If this is done, and if at a remote point the azimuth indications of an ARN-21 are recorded and plotted against the angle of rotation of the phaser plate, the cyclical errors previously described are apparent

An alternate method of obtaining data of this type is through the use of the URN-3 simulator which may be adjusted to simulate any azimuth When using the simulator, the contribution of the URN-3 to the cyclical error obviously is eliminated, as are any discrepancies caused by reflections between the URN-3 unit and the remote receiving point.

Cyclical-error data were obtained by rotating the phaser plate at sites Nos. 1, 2, and 3. The error curves are shown in Figs 3, 4, and 5, respectively. Figure 5 shows the difference between two ARN-21 units The data were obtained at the same site on the same day. Figure 6 shows the cyclical error of an ARN-21 airborne equipment, using the URN-3 simulator as a source of azimuth signal.

It should be noted that the total error spread is approximately 2.5° using the site as a signal source and only 1 5° using the simulator as a source, this indicates an appreciable contribution of the URN-3 to the total error spread Because of the possible effect of reflections between the URN-3 site and the monitoring station, it is believed that the entire degree of improvement is not due to elimination of errors contributed by the URN-3.

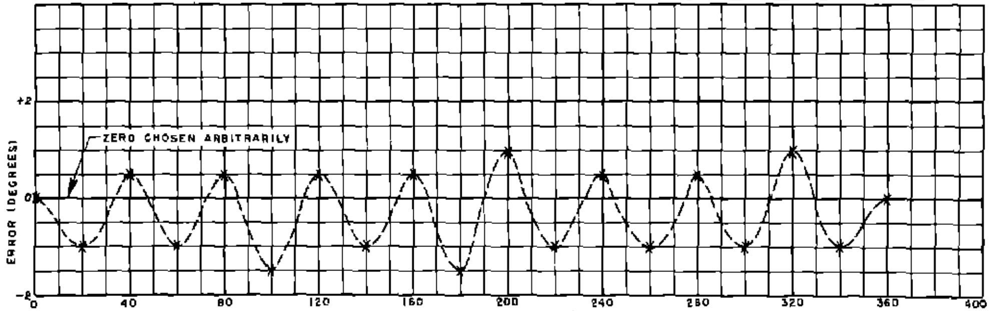

Fig. 4 Phaser Plate Rotation, Site No. 2, ARN-21 (Serial No. 52)

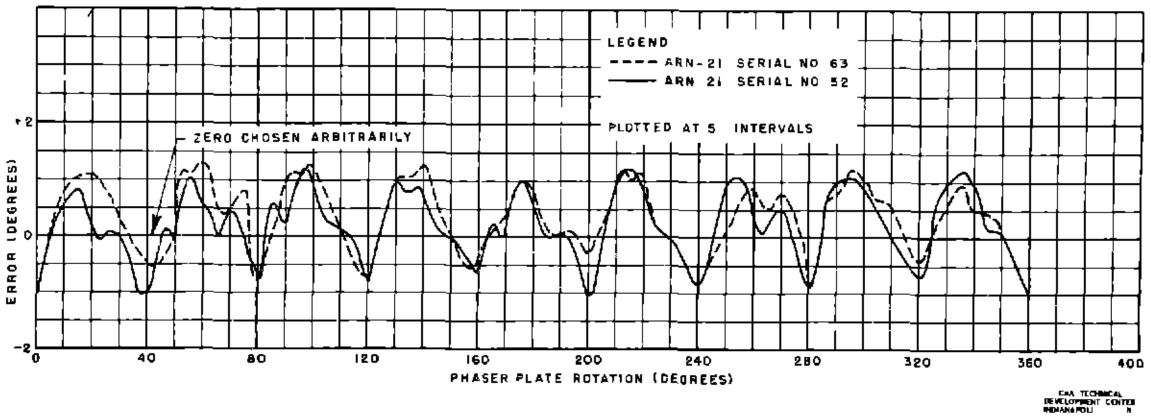

Fig. 5 Phaser Plate Rotation, Site No 3

Distance Accuracy

Recognizing that the distance-measuring principle of TACAN is identical to that employed by civil DME, no particular effort was made to determine the distance accuracy of the particular TACAN equipments under test The few spot checks which were made of TACAN distance accuracy, however, usually revealed distance errors greater than those normally exhibited by civil DME interrogators employing the electromechanical strobe-ranging circuitry similar to that used in the ARN-21. Errors in excess of those which would normally be expected from this type of ranging circuit are believed to be due to hunting and/or sticking of the distance-track motor because instances of both were observed on numerous occasions Both the TACAN system and civil DME are believed to be inherently capable of distance accuracy equal to that required operationally

TACAN-DME Interference

At site No. 1, the URN-3 unit was located approximately 900 feet from a commissioned DME ground facility (transponder). This transponder (Type DTB) was operating on DME channel No. 19 which prescribes a DME-interrogation frequency of 986 Mc (frequency to which the transponder receiver is tuned). The URN-3 was originally tuned to TACAN channel No. 27 which prescribes a transmitting frequency of 988 Mc. The band-pass characteristics of the DTB receiver, coupled with the spectrum characteristics of the URN-3 transmission, plus the difference between the pulse spacing of the TACAN transmission and the pulse spacing acceptable to the DTB, indicated that no interference problem should exist. Transmissions from the DTB were observed at a point approximately one mile distant, using the receiver output of standard Type DID and DIC DME interrogators No abnormal trans- sions were observed from the DTB, indicating that the TACAN was not interrogating the transponder. Furthermore, the DME interrogators successfully latched on the DTB nsponder, and the assumption was made that DTB operation was unaffected by the URN-3 t a later date, CAA maintenance personnel reported intermittent shutdown of the DTB by the built-in monitor A careful examination at the site revealed that although the TACAN transmissions were not triggering the DTB, they were appearing at the DTB receiver output and

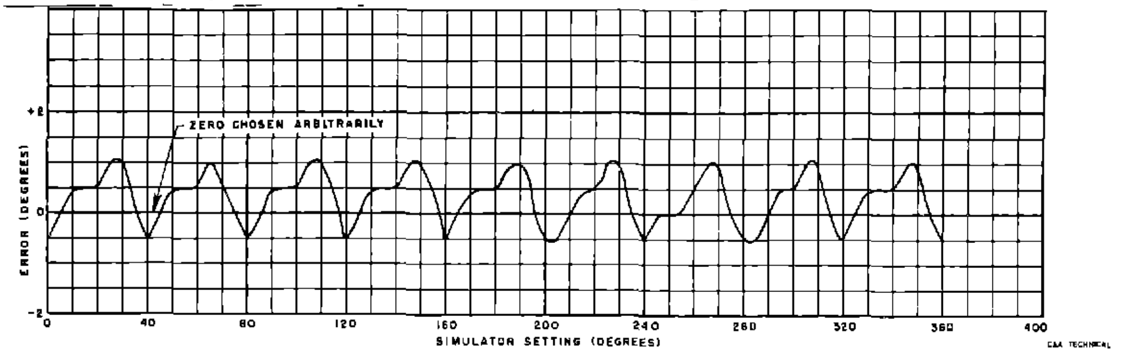

Fig. 6 Error Curve, URN-3 Simulator (Serial No. 52) as Signal Source

were being counted as noise pulses by the DTB-AGC circuit which then automatically reduced the receiver gain Reductions in receiver sensitivity as high as 30 decibels (db) were observed In order to insure that no mutual interference would exist, the URN-3 was retuned to channel No. 37 which resulted in a transmitting frequency of 998 Mc, 12 Mc above the receiving frequency of the DTB. Tests made at this time revealed no derogation of DTB operation, and channel No. 37 or higher channels were employed for the remainder of the tests.

Another DTB transponder, operating on DME channel No 64 (interrogation frequency 973.5 Mc, reply frequency 1203.5 Mc), was located approximately one-half mile from the laboratory which was used for maintenance and adjustment of the ARN-21 equipments For purposes of monitoring, DTB transponders are triggered internally at a random rate of approximately 50 pulse pairs per second. These transmissions at 1203.5 Mc caused intolerable interference with the ARN-21 when it was tuned to channels having receiver frequencies within 2 or 3 Mc of 1203 5 Mc. The interference was exhibited in the form of random and persistent latching of the azimuth indicator on false bearings

It is concluded from these two observations that DME and TACAN cannot be expected to operate satisfactorily with common frequency assignments or without a reasonable guard band assigned between frequencies employed by the two services.

Coverage

Although coverage of the TACAN system in general was shown to extend nearly to radio line-of-sight, on numerous occasions discontinuity of information and consequent azimuth and/or distance search were observed within theoretical line-of-sight This occurred when system-power outputs and sensitivities were normal These discontinuities are believed to be due to one or more of the following causes, occurring either singly or in combination

1 Reduced field strength resulting from unfavorable aircraft attitude (shadowing of the airborne antenna during turns)
2. Flight within null zones in the vertical pattern of the URN-3 antenna
3 Atmospheric anomalies

When considered on a practical basis, the frequency band of TACAN tends to aggravate these conditions

Variations in the horizontal polar pattern of the airborne antenna of 9 db, and in the vertical polar pattern between ±30° (the vertical plane sector of significance) of 18 db, have been established for an antenna installation beneath the fuselage of a DC-3 aircraft Yet, this location has been established as optimum [7]

By far the greatest percentage of flight (particularly in the case of civil-aircraft operations) is carried out below elevation angles of 5° with respect to the ground facility In the case of TACAN, as many as 20 nulls will be found in this flight zone, whereas the lowest VOR null, which has insignificant depth, is at an elevation angle of approximately 20°

In addition, with respect to coverage, the overhead cone of TACAN is approximately 95° wide compared with a width of about 30° produced by a four-loop VOR antenna

The fact that propagation in the 1000-Mc region is characterized by violent and frequent fluctuations of field strength, even at distances well within line-of-sight, has been reported by the National Bureau of Standards in continuous propagation tests of more than a year's duration [8] ". 'fadeouts' or prolonged periods of attenuation often in excess of 20 db below the monthly median level and lasting from a minute up to several hours" were experienced. Simultaneous tests were made at 1046 Mc, 192 8 Mc, and 100 Mc The recordings "illustrate the significant fact that these prolonged space-wave fadeouts are of importance only at the higher frequencies " The fadeouts are shown to be dependent on meteorological

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[7] "Final Technical Report on Phase II of Omni Directional Airplane Antenna Studies," Case 3-12-78, Radio and Radar Components Division, Federal Telecommunication Laboratories, Nutley, New Jersey, September 1953

[8] Bradford R. Bean, "Prolonged Space-Wave Fadeouts at 1,046 Mc Observed in Cheyenne Mountain Propagation Program," Proceedings of the IRE, May 1954

conditions, and in conclusion it is recommended that "when planning UHF navigational systems intended to operate throughout the twenty-four hours of the day in all seasons of the year . the transmitter power should be increased enough to insure the degree of reliability required."

The system sensitivity of TACAN is not adequate to insure reliable line-of-sight coverage in the presence of the previously itemized inherent handicaps, considering also that as a function of frequency, the TACAN system suffers a 20-db loss when compared with a system operating at one-tenth of this frequency

It is recognized that the civil DME system is designed for operation in parts of the same frequency band occupied by TACAN, and is therfore subject to the same deficiencies discussed From an operational point of view, however, the effects are considered much less severe for the following reasons.

1 DME may and does safely employ memory circuits effective up to 20 or more seconds, as desired This memory is adequate to permit continuity of distance information under the great majority of adverse conditions caused by unfavorable aircraft attitudes and by flight through ground nulls and through the cone above the station.

2. The operation of DME is independent of the ratio of reflected- to direct-path energy, which increases in nulls, in the cone, and in unfavorable aircraft attitudes There are no errors in distance indication equivalent to the characteristic "scalloping" errors of the azimuth-measuring systems, including TACAN. The magnitude of these errors increases with the ratio of reflected- to direct-path energy.

3 An azimuth system is of primary value to navigation, distance information, although a valuable asset, is secondary All present-day civil-aircraft operations are based on this philosophy. For this reason, maximum effort should be directed toward implementation and operational usage of a sound and reliable azimuth system.

FLIGHT TESTS

The flight-test data presented were obtained in the course of approximately 120 hours of operational flight evaluation of the TACAN system The TACAN ground station was tested at three different sites. Figure 7 shows the location of the three sites with respect to hangars and runways During the flight-test program, recordings were made of the course-deviation indicator (CDI), distance indicator, and automatic-gain-control (AGC) voltage of the TACAN airborne unit.

The course-deviation-indicator recording was obtained by amplifying the CDI input voltage with a Microsen d-c amplifier, the output of which actuated an Esterline-Angus 2.5-0-2.5-ma recorder In order to obtain reliable data from the airborne unit during a given flight test, a recorder calibration was made prior to each flight test to check recorder deflection and direct conversion to degrees of course displacement In flight-testing the TACAN system, several thousand feet of recordings were obtained. The presentation of course data requires a method of data condensation so that the results of a large number of flight tests may be presented in a manner which is clear, concise, and readily available. The data-condensation methods used in presenting azimuth information on orbital and radial flights follow

Orbital Flights.

In order to obtain a rapid sampling of the courses radiated by the TACAN system, circular flights around the station were made at various radii and altitudes This type of flight was made to obtain data on azimuth accuracy and scalloping. One of the major items for investigation was determination of the effect of siting on the operational performance of the system. The scalloping data obtained on orbital flights were used to determine the location of objects in proximity to the ground station which reflect, shadow, or reradiate energy to produce course scalloping. Scalloping data in this report are presented in graph form. In these graphic presentations the scalloping amplitude is plotted every 10° through 360° of azimuth The scalloping amplitude plotted at each 10° point represents the maximum scalloping encountered at any azimuth within ±5° of the plotted point. When sectors of extreme scalloping or field attenuation were encountered, the azimuth-indicator "search" is shown as a shaded area throughout the sector in which the search occurred. It will be observed that scalloping on successive orbits due to the same reflecting object is not plotted at the same indicated azimuth in all instances This is because the scalloping occurred very near the limit of ±5°. The identification of objects responsible for specific recorded scalloping was determined by analysis of the recordings and the point-by-point data

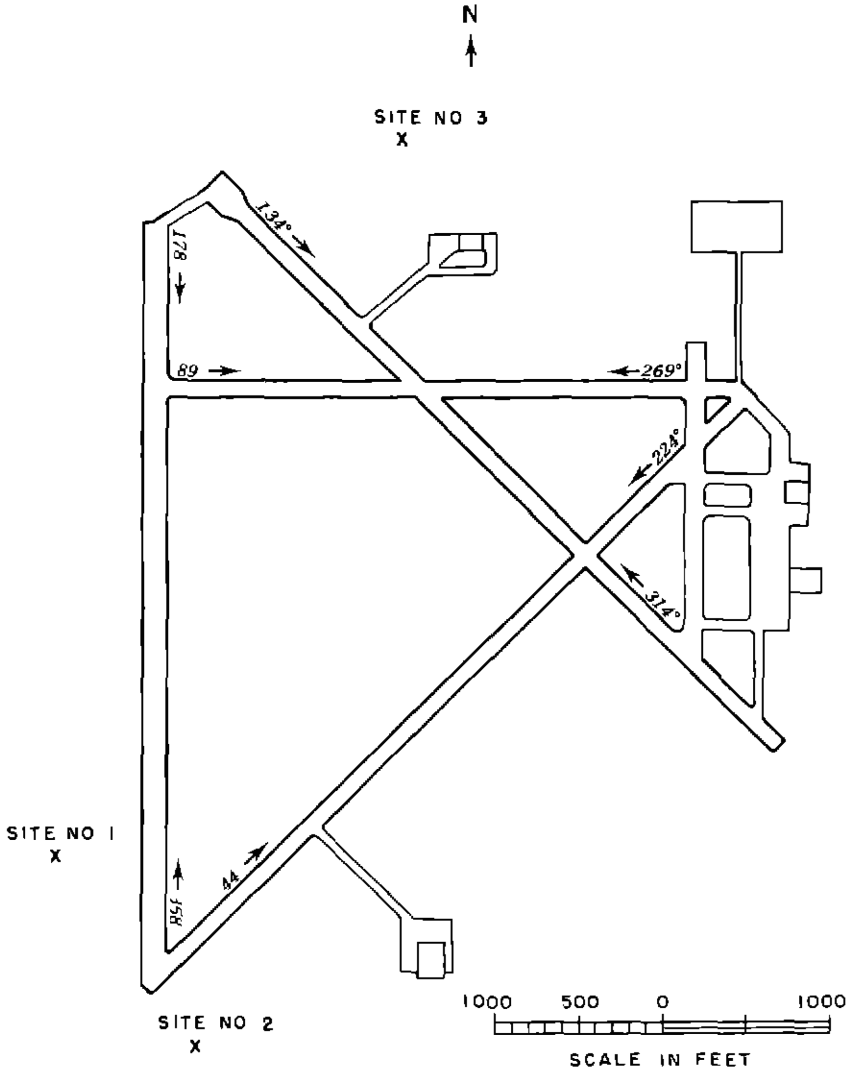

Fig 7 TACAN Sites Location Map

Radial Flights.

The maximum scalloping amplitude recorded during each 5 miles is plotted at the end of the respective 5-mile traverse. For example, if the maximum scalloping amplitude measured between 5 and 10 miles was ±1.1° (CDI deviation) and occurred at 8.5 miles, the 1.1° would be plotted at the 10-mile point on the graph. This method was used when the scalloping amplitude represented near average scalloping for the 5-mile section. Severe and abrupt deviations from the near average scalloping amplitude were plotted point-for-point until uniform scalloping was resumed. Sectors of azimuth search are shown as shaded areas which represent the distance traversed by the aircraft before azimuth information was again available.

During all flight tests, recordings also were made of the automatic-gain-control voltage. An AGC test point on the airborne TACAN unit provided a readily accessible pickoff point for measurement. The normal operating range of this voltage varied from -3 to -5 volts. A 3-volt bucking voltage was inserted in the circuit, and with the aid of a Microsen d-c amplifier, full-scale recorder deflection over this range was obtained. The recordings provided valuable information for use in the data analysis, however, presentation of these data is limited to the radial-flight graphs. On radial flights, as a uniform change in AGC voltage with distance from the ground station was recorded, the voltage at each 5-mile point is plotted. All irregular and abrupt voltage changes were plotted point-by-point.

Recordings of the distance indicator were made on a number of flights. This was done to determine the coincidence of distance-indicator search and azimuth-indicator search. The presentation of distance information on radial-flight graphs is limited to an indication of normal operation or indicator search.

Throughout the flight evaluation of the TACAN system, if at any time it appeared that the operation of either the ground or the airborne equipment was questionable, the flight was immediately suspended and the TACAN maintenance personnel, who were assigned on temporary duty at TDC throughout the evaluation period, were requested to service the equipment before further flight testing was resumed.

Site No. 1, Antenna 15 Feet

The TACAN ground-station equipment was first installed at the south experimental VOR site, on the west side of Weir Cook Municipal Airport, Indianapolis, Indiana. This site is clear of all large obstructions for a radius of 1300 feet. Figure 8 is a plan diagram of the area, showing locations and vertical angles for the trees and buildings. A panoramic photograph of the site taken from the antenna tower is shown in Fig. 9. After completion of the TACAN installation and a preliminary ground check of equipment operation, the flight evaluation of the station was begun. The first flight checks were exploratory to determine general operational characteristics and to compare four airborne antennas in order to obtain optimum performance.

The first series of flight tests consisted of orbits about the station at radii of 6, 12, 20, and 24 miles, at various altitudes. Azimuth-accuracy calibrations were conducted on the 6- and 20-mile-radius flights. The 6-mile-radius calibration was conducted by using the standard CAA theodolite-calibration method in which the system error is determined by comparing the indicated azimuth with the actual magnetic azimuth of the aircraft as determined by a theodolite operator at the ground station. The 20-mile-radius calibration was conducted by a standard CAA method in which specific ground-check points, over which the aircraft is flown during the orbital flight, are marked on the azimuth recording. At the conclusion of the flight, the recording is inserted into an azimuth calculator (an instrument for reproducing the orbital-flight track) for the determination of correct magnetic azimuths. Figure 10 shows curves of the bearing errors observed on these two calibration flights. The bearing-error spreads measured on the 6-mile-radius calibration were 4.8° and 3.8°. The error spread measured on the 20-mile-radius calibration was 3.5°.

The 6-, 12-, and 24-mile-radius orbital flights were conducted with major emphasis on obtaining information relating to the effect of siting on TACAN azimuth indication. The course scalloping amplitudes recorded on this series of flight tests are shown in Figs. 11, 12, and 13.

The major obstruction at the site shown in Fig. 8 was a wooded area located 1500 feet from the station between azimuths 284° and 317°. The effect of this wooded area is revealed by the recorded scalloping centered on an azimuth of 290°, shown in Figs. 11, 12, and 13, and listed in Table I.

TABLE I

RECORDED SCALLOPING DUE TO WOODED AREA

Radius (miles)	Aircraft Altitude (feet)	Over-all Scalloping Amplitude (degrees)
6	1400	4.0
12	2800	3.5
24	1500	3.3
24	3100	2.9

A second wooded area with a pronounced operational effect on the TACAN system at site No. 1 was located 2000 feet from the station between azimuths 142° and 157°. This wooded area produced scalloping centered on an azimuth of 150° for the flights at 6 miles radius at 800 feet altitude, 12 miles radius at 1600 feet altitude, and 24 miles radius at 1500 and at 3100 feet altitude. The maximum scalloping spread recorded was 3° on the 24-mile-radius orbit, however, the azimuth indicator went into search on both the 6- and 24-mile-radius orbits

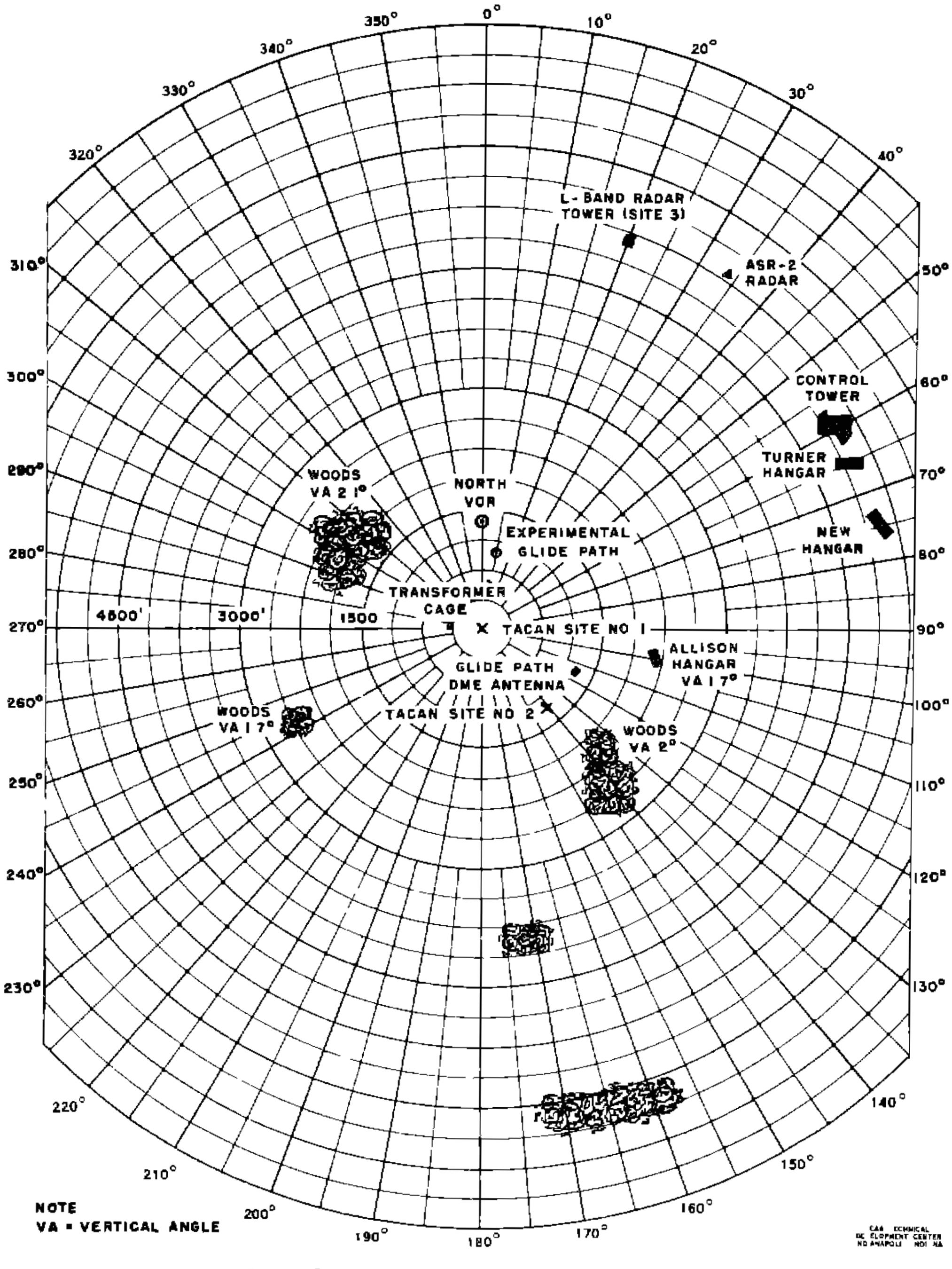

Fig 8 TACAN Siting Plot, Site No. 1

An aircraft hangar is situated on the south side of the airport 2300 feet from the station between azimuths 107° and 113°. This hangar produced course disturbances at two widely different azimuths A shadow effect caused course scalloping at 100° azimuth at 6 miles radius and altitudes of 800, 1000, and 1400 feet, 12 miles radius and 1600 feet altitude, and 24 miles radius at 1500 and 3100 feet altitude, with a maximum scalloping spread of 4° on the 24-mile radius at 1500 feet altitude Reflected energy from the hangar caused a maximum course-scalloping spread of 5.5° and azimuth-indicator search at 250° azimuth as shown on the curve for 24 miles radius at 3100 feet altitude This particular course disturbance is a good example of the complex nature of the TACAN siting effect This is a

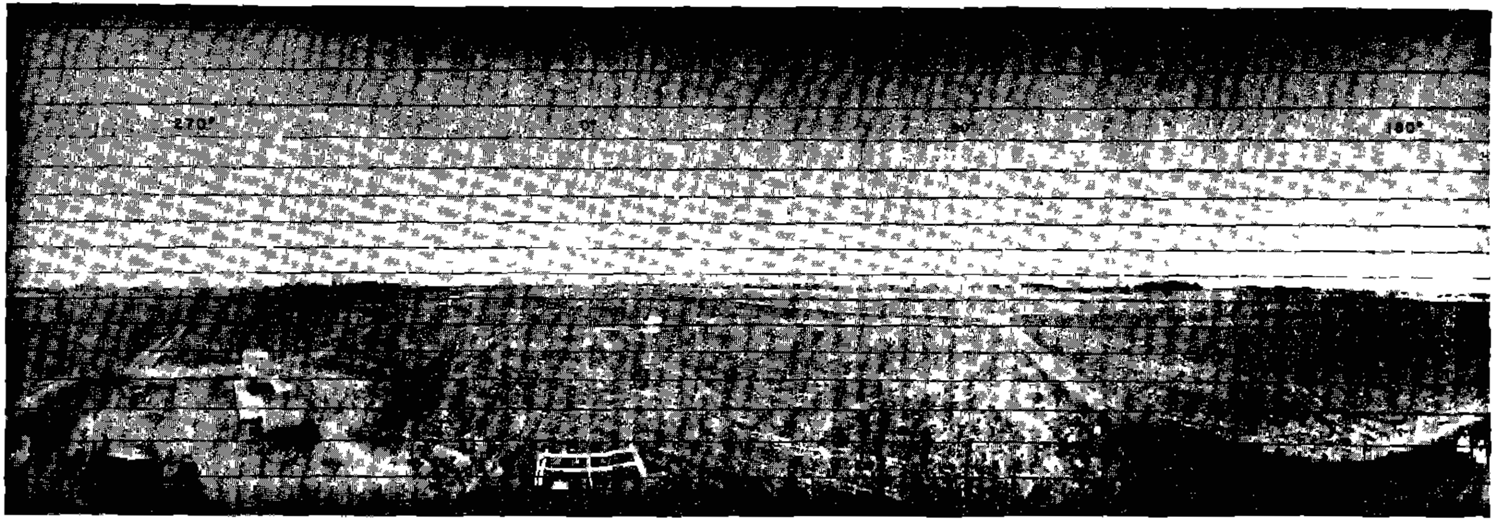

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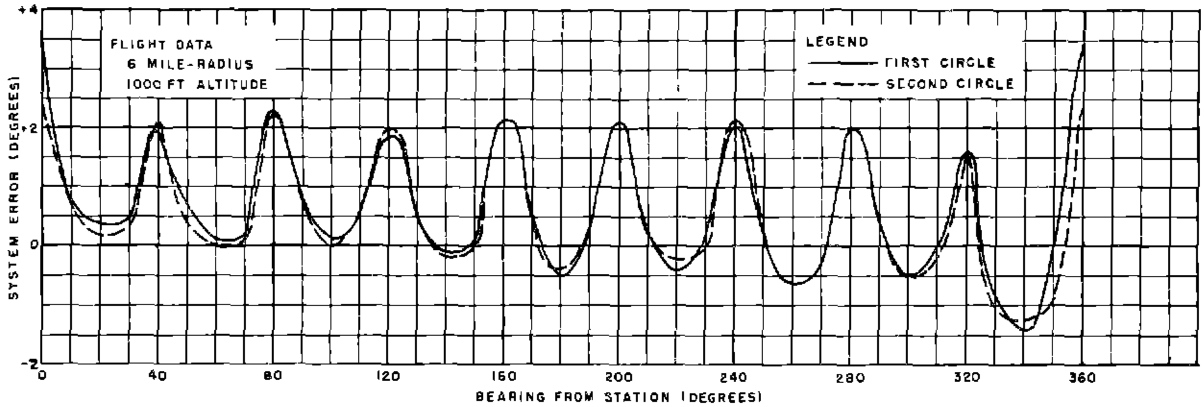
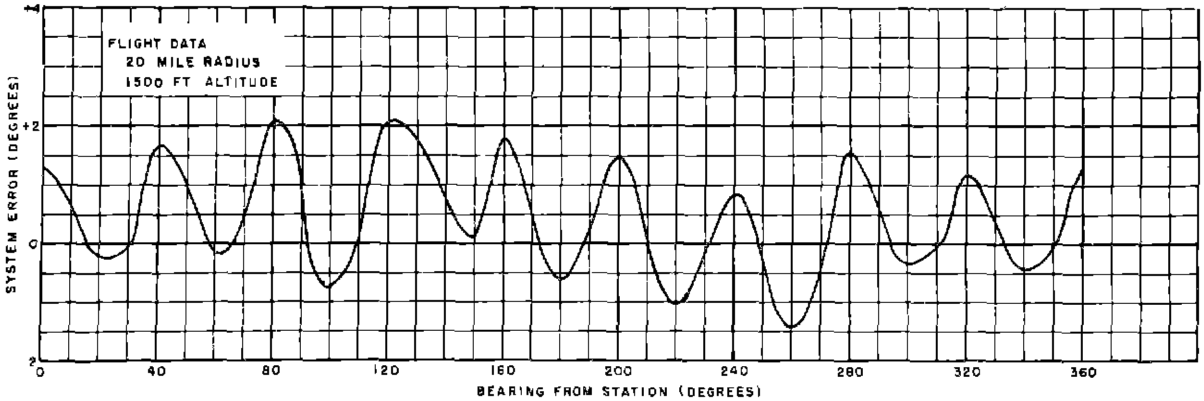
Fig. 9 Panoramic Photograph, Site No. 1



(A) THEODOLITE CALIBRATION



(B) AZIMUTH CALCULATOR METHOD

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Fig 10 Flight Calibration Error, Site No. 1, Antenna 15 Feet High

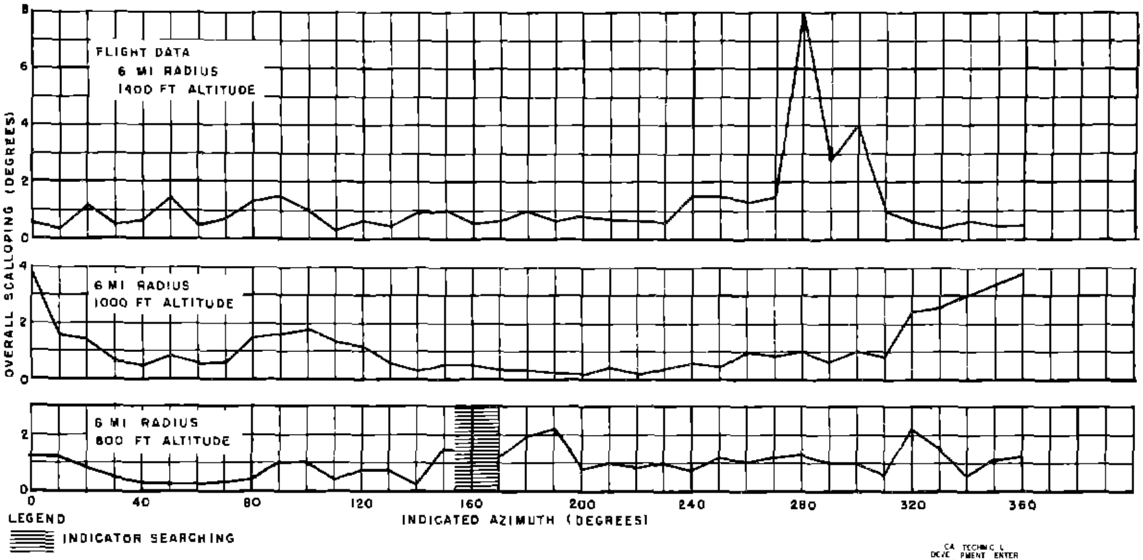

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Fig 11 TACAN Scalloping Graph, Site No. 1, Antenna 15 Feet High

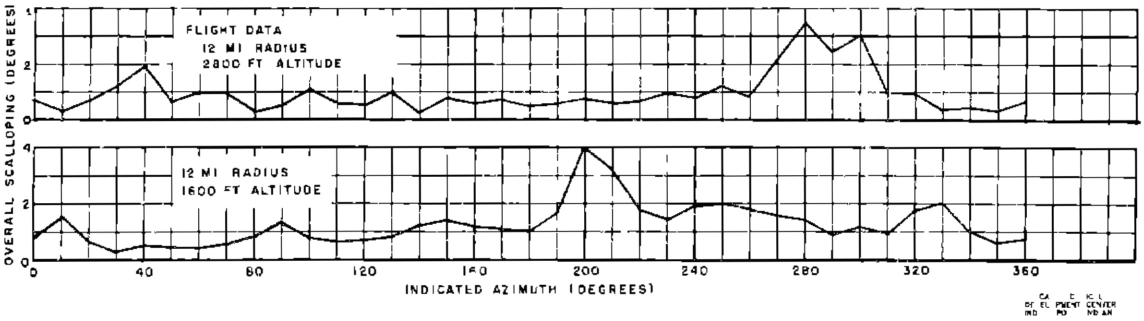


Fig 12 TACAN Scalloping Graph, Site No 1, Antenna 15 Feet High

case in which a course disturbance was detected and its cause was determined accurately to be due to reflected energy from the hangar This disturbance was apparent on only 1 of 8 orbits at various altitudes and radii, indicating that the reflected energy was contained in a narrow beam

A flight-test program of many hours could have been conducted to investigate thoroughly the deteriorating effect of this one particular object on the operational performance of the TACAN system In a flight-test program totaling 120 hours and covering three transmitter sites, however, it was not possible to investigate the complete effect of all sources of course disturbance Therefore, upon positive identification of the source of a course disturbance from the resulting amplitude and frequency of scalloping, the flight testing proceeded to the next phase

Moderate course disturbances were recorded on the orbital flights between 80° and 100° azimuth as shown in Figs 11, 12, and 13 The source of this disturbance was determined to be reflected energy from a 4 by 4 by 6-foot chain-link fence around the power transformer at the TACAN site This transformer cage was located 235 feet from the station at an azimuth angle of 274° The recorded scalloping due to the transformer cage is listed in Table II This cage also caused severe scalloping of 8° spread at an azimuth of 280° as shown on the curves for flights at 6-mile radius at 1400 feet altitude, and 3 4° spread at 12-mile radius at 2800 feet altitude.

To investigate further the effect of small objects in close proximity to the TACAN station, a reflective screen constructed of 1/2-inch hardware cloth, 9 feet high and 16 feet

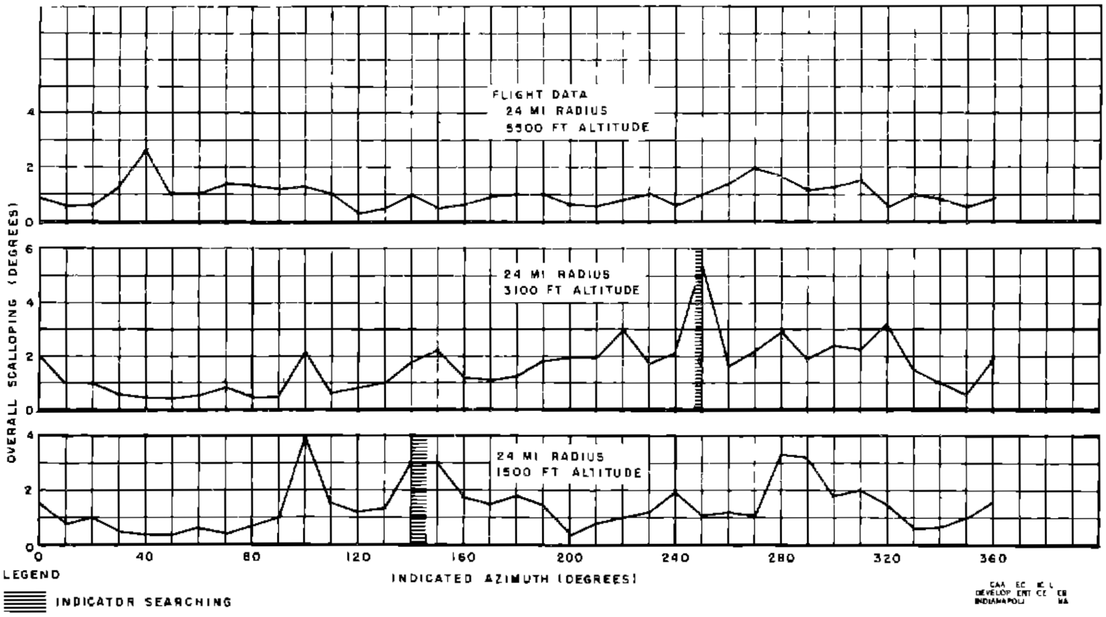


Fig 13 TACAN Scalloping Graph, Site No 1, Antenna 15 Feet High

TABLE II

RECORDED SCALLOPING DUE TO TRANSFORMER CAGE

Radius (miles)	Aircraft Altitude (feet)	Over-all Scalloping Amplitude (degrees)
6	800	1.0
6	1000	1.8
6	1400	1.3
12	1600	1.3

long, was installed vertically in front of the transformer cage and oriented so as to direct the reflected energy toward the 40° azimuth with respect to the ground station. This resulted in an area of scalloping shown in the graphs for flights at 12 miles radius at 2800 feet altitude, with a maximum scalloping spread of 2.6°. Samples of the recordings obtained at 40° azimuth with and without the transformer screen are shown in Fig. 14.

The TDC VOR station is located 1350 feet north of TACAN site No. 1. At this site a four-loop VOR antenna is installed on a standard 35-foot-diameter counterpoise 10 feet above ground. On the flight at 6 miles radius at 1000 feet altitude, scalloping with a maximum spread of 3.8° was recorded between azimuths 320° and 20°. This scalloping was attributed to the VOR station. This VOR station was reaffirmed as a source of field disturbance in later tests when the TACAN antenna was raised to 30 feet.

A series of flight tests was conducted for the purpose of recording radial-course scalloping. The radials selected for investigation were chosen to sample the areas of no scalloping, moderate scalloping, and heavy scalloping as revealed by the data obtained on the orbital flights. Figure 15 shows the scalloping amplitudes recorded at 1500 feet altitude during flight tests of one radial of small scalloping, three of moderate scalloping, and two of severe scalloping. These data were obtained at distances up to approximately 30 miles. The 144° radial exhibited the most severe course scalloping, ±4°, and azimuth-indicator search caused by the wooded area previously described in the section concerning orbital-flight tests.

Two flight tests were conducted at higher altitudes ranging from 10,000 to 12,000 feet above ground on the 90° and 270° radials to obtain data on course characteristics and coverage. Data obtained during these flights, plotted in Fig. 16, show a maximum scalloping amplitude of ±2° and several areas of azimuth-indicator search in the nulls of the vertical plane pattern of the ground antenna.

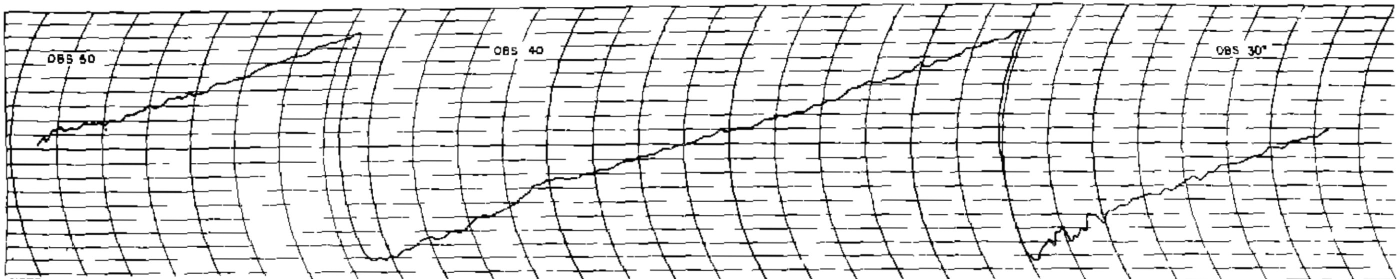
Site No. 1, Antenna 30 Feet

At the conclusion of the first series of flight tests, the TACAN antenna was raised from 15 feet to 30 feet above ground. Flight tests conducted on this installation were confined to orbital and radial flights to determine possible reduction in siting effects. The orbital flight data are presented in Fig. 17. These data do not show any substantial reduction in siting effects over those noted when the antenna was 15 feet high. The observed effect of the transformer cage was worse than that obtained when the antenna was 15 feet above ground, as may be seen on the curve for 12-mile-radius flights at 1300 feet altitude. The maximum scalloping spread recorded was 6°, which was accompanied by azimuth-indicator search.

The effect of this specific reflective object was further investigated by flying a series of arcs between 70° and 120° azimuth, 12 miles from the station. These arcs were flown at altitudes of 1000, 1300, 1600, 1900, 2200, and 2500 feet above ground. The most severe scalloping was recorded at the 1300- and 2200-foot altitudes as shown in Fig. 18, with a maximum spread of 2.6°.

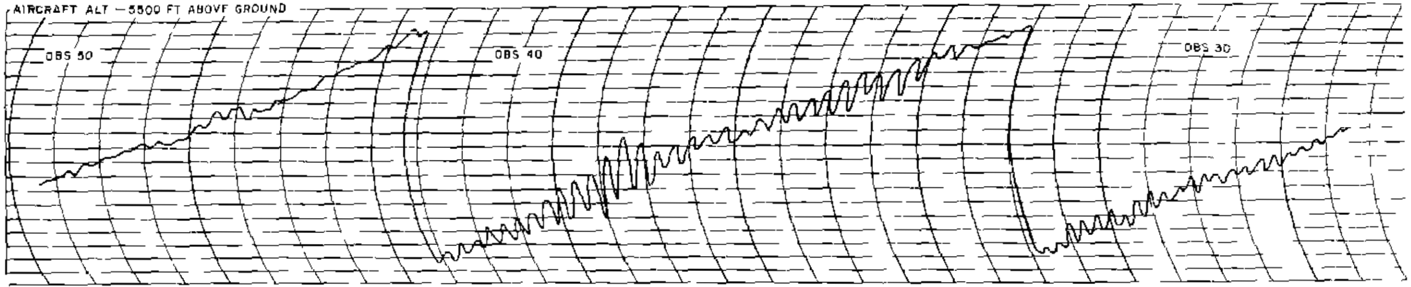
The effect of the north VOR station again was exhibited by azimuth-indicator search in a sector 12° wide, centered on 4° azimuth on the 12-mile-radius orbit at 1300 feet altitude. A scalloping spread of 3.3° was observed at 180° on the 24-mile-radius orbit at 1000 feet altitude, this was believed to be caused by reflection from the VOR.

The radial flights conducted on this installation consisted of a series of flights on the 144° radial, which is the azimuth of a heavily wooded area, and the 324° radial. The 144° radial was flown at altitudes of 1000, 2000, 4000, 8000, and 12,000 feet above ground. The data obtained on these flights are shown in Figs. 19 through 22 and show the improvement of distance range with increase in altitude.



NOTE
24 MI RADIUS ORBIT
AIRCRAFT ALT — 5500 FT ABOVE GROUND

(A) SITE NORMAL



(B) SCREEN INSTALLED AT TRANSFORMER CAGE

Fig. 14 Sample Orbit Recordings

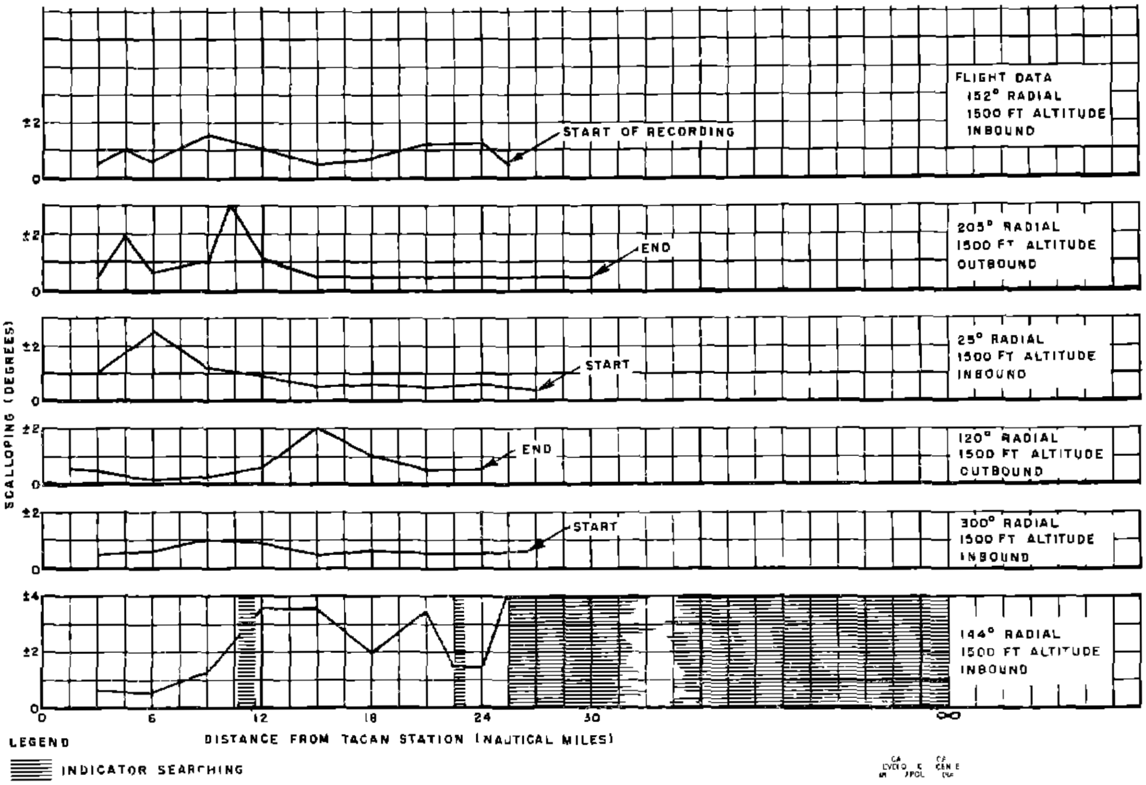


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Fig 15 Radial Scalloping Graph, Site No. 1, Antenna 15 Feet High

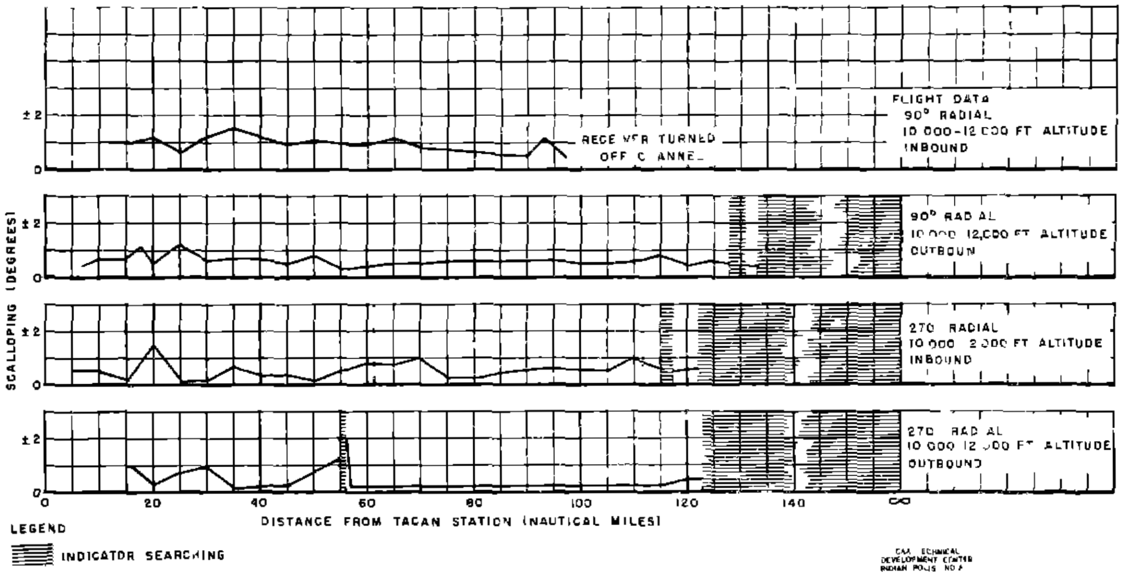

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Fig 16 Radial Scalloping Graph, Site No. 1, Antenna 15 Feet High

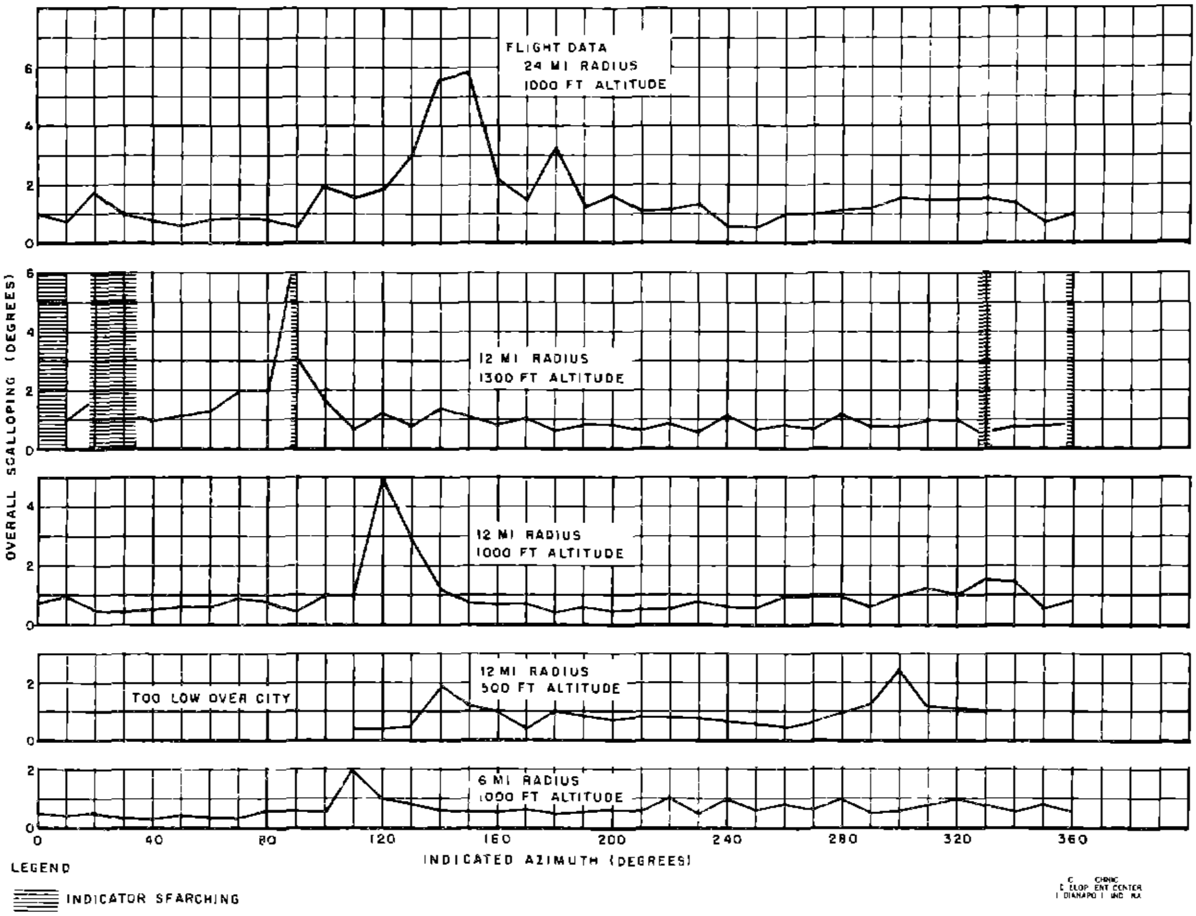
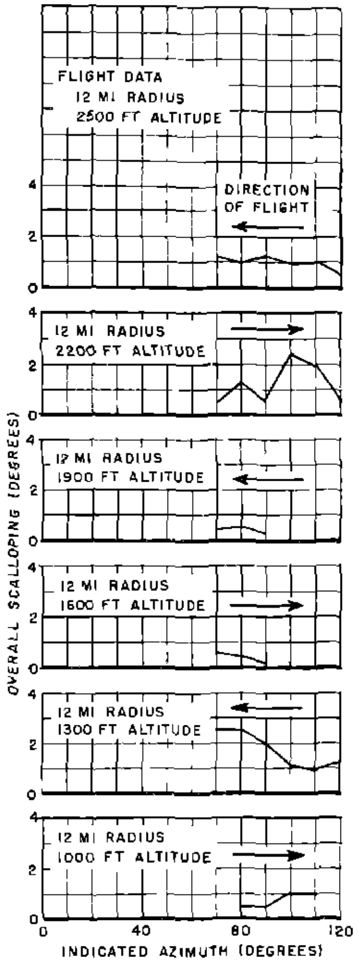


Fig. 17 TACAN Scalloping Graph, Site No. 1, Antenna 30 Feet High

Site No. 2, Antenna 30 Feet

Site No 2 was selected to bring the TACAN ground station closer to a grove of trees and a hangar in order to evaluate the effect of these obstructions more readily Figure 23 is a plan diagram of the site and surrounding obstructions A panoramic view of the site is shown in Fig 24 The flight tests were conducted with major emphasis on obtaining scalloping and coverage information The first series of flight tests consisted of orbits about the station at radii of 6, 12, and 24 miles, at various altitudes The course-scalloping amplitudes recorded on this series of flight tests are presented in Figs 25, 26, and 27 These graphs show that trees and other reflecting surfaces cause a minimum amount of scalloping and indicator search on the 6-mile-radius circle because of the high field strength The 12- and 24-mile-radius circles show the increased effect of signal scattering and attenuation caused by the trees and centered on approximately 140° azimuth The true value of scalloping amplitude in areas of severe scalloping actually could not be measured The azimuth circuits of the airborne unit were unable to track during periods of rapid and extreme course excursions, resulting in azimuth-indicator search It was further observed that different airborne units, or the same unit under different conditions, exhibited varying degrees of tolerance to scalloping before going into search

A DME antenna was located 600 feet from the TACAN station at 38° azimuth at an elevation angle of 1 4°. The scalloping due to this object was very pronounced at and near this angle of elevation, as shown in Figs 25, 26, and 27, for flights at 6 miles radius at 750 feet altitude, 12 miles radius at 1500 feet altitude, and 24 miles radius at 3000 feet altitude The curve for 6-mile-radius circles at 750 feet altitude shows that the scalloping was so severe that the azimuth indicator went into search.



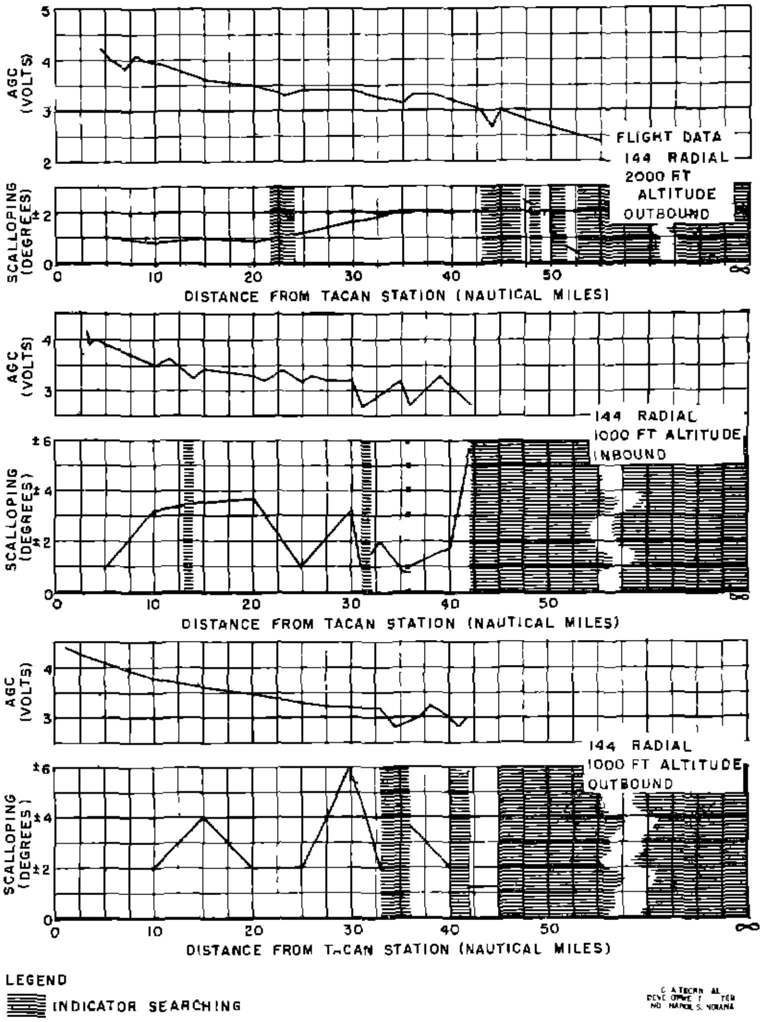


Fig. 18 TACAN Scalloping Graph, Site No 1, Antenna 30 Feet High, 90° Area

Fig. 19 TACAN Radial Data, Site No. 1, Antenna 30 Feet High

The hangar located on the south side of the airport and 1470 feet from the station was centered at an azimuth of 63° at a maximum elevation angle of 1.8° This object produced operational effects at two azimuths Shadowing effects are shown on the graphs for the 12-mile-radius circles at 500- and 1000-foot altitudes and on the 24-mile-radius circles at 1000- and 2000-foot altitudes See Figs 26 and 27. At both radii the airborne equipment went into search at the lower altitudes and displayed a maximum scalloping spread of 3 7° at the higher altitudes Reflection effects were observed at 6-mile radius at 500 feet altitude, 12-mile radius at 1000 feet altitude, and 24-mile radius at 2000 feet altitude, as shown in Figs 25, 26, and 27. This effect resulted in azimuth search and maximum scalloping spread of 4.3° between 280° and 290° azimuth.

The main obstruction near site No. 2 was a grove of trees centered at an azimuth of 140° and located 640 feet from the station at the nearest point The effect of these trees on the operational use of the TACAN system is clearly shown in the curves for the 6-, 12-, and 24-mile-radius flights. The 6-mile-radius plots, Fig 25, show the scalloping effect of these trees with one area of search at 147° at 500 feet altitude, and an improvement in performance at the higher altitudes On the 12- and 24-mile-radius orbits, large areas of indicator search were observed in which no azimuth information was derived from the system Improvement was obtained at increased altitudes

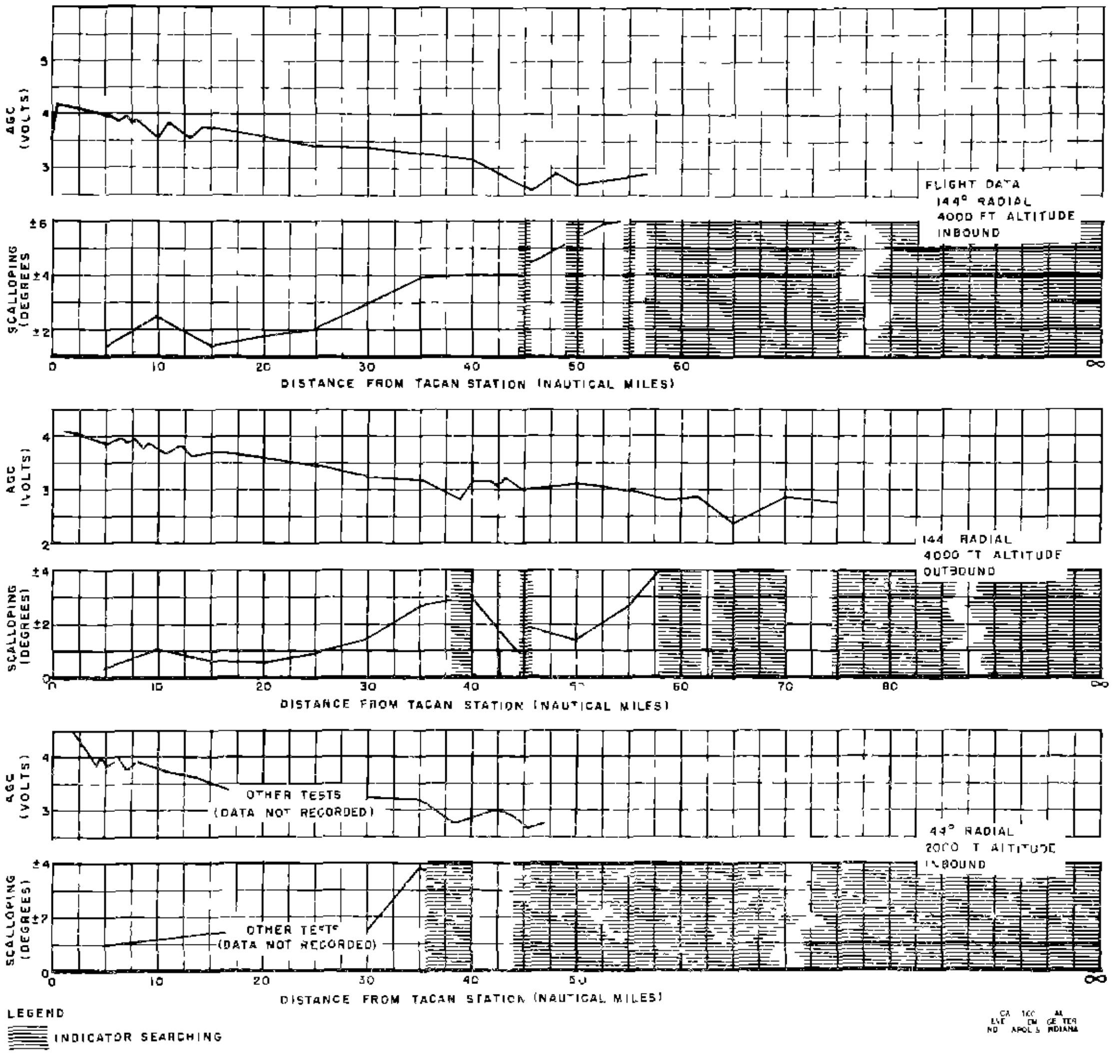


Fig. 20 TACAN Radial Data, Site No. 1, Antenna 30 Feet High

On the second series of flights, radial-course scalloping and distance range were recorded. A number of radials were flown at an altitude of 1000 feet above ground in sectors where scalloping had been recorded previously on the orbital flights and where the scalloping was caused by reflected signals from the hangar. The radials flown were 287°, 290°, and 293° azimuth. Figure 28 shows plots of the course-scalloping amplitude recorded on the radial flights. It also indicates distances at which interruptions to azimuth and distance information occurred. These plots show that the most severe course disturbances occurred in the first 15 miles from the station, indicating that the reflected energy from the hangar causes course disturbances at angles of elevation above 0.6°.

Other radials were flown at 60°, 65°, and 68° azimuth in the shadow area produced by the hangar. Figure 29 shows the extreme attenuation of the field due to the hangar on the 65° and 68° radials where a distance range of 18 miles was obtained, in contrast to 43.5 miles on the 60° radial which clears the hangar by 1°.

The effect of the grove of trees was investigated by flying the radials 150°, 140°, 135°, and 125° azimuth. The plots in Fig. 30 show the effective breakdown of the system due to the presence of the trees which effectively limited the range of the system to distances of 9.5 to 15 miles. The flight data obtained on the 80° and 330° radials shown in Fig. 31 portray TACAN operation under optimum conditions for a ground antenna height of 30 feet. The maximum scalloping observed on these radials was ±1.3°.

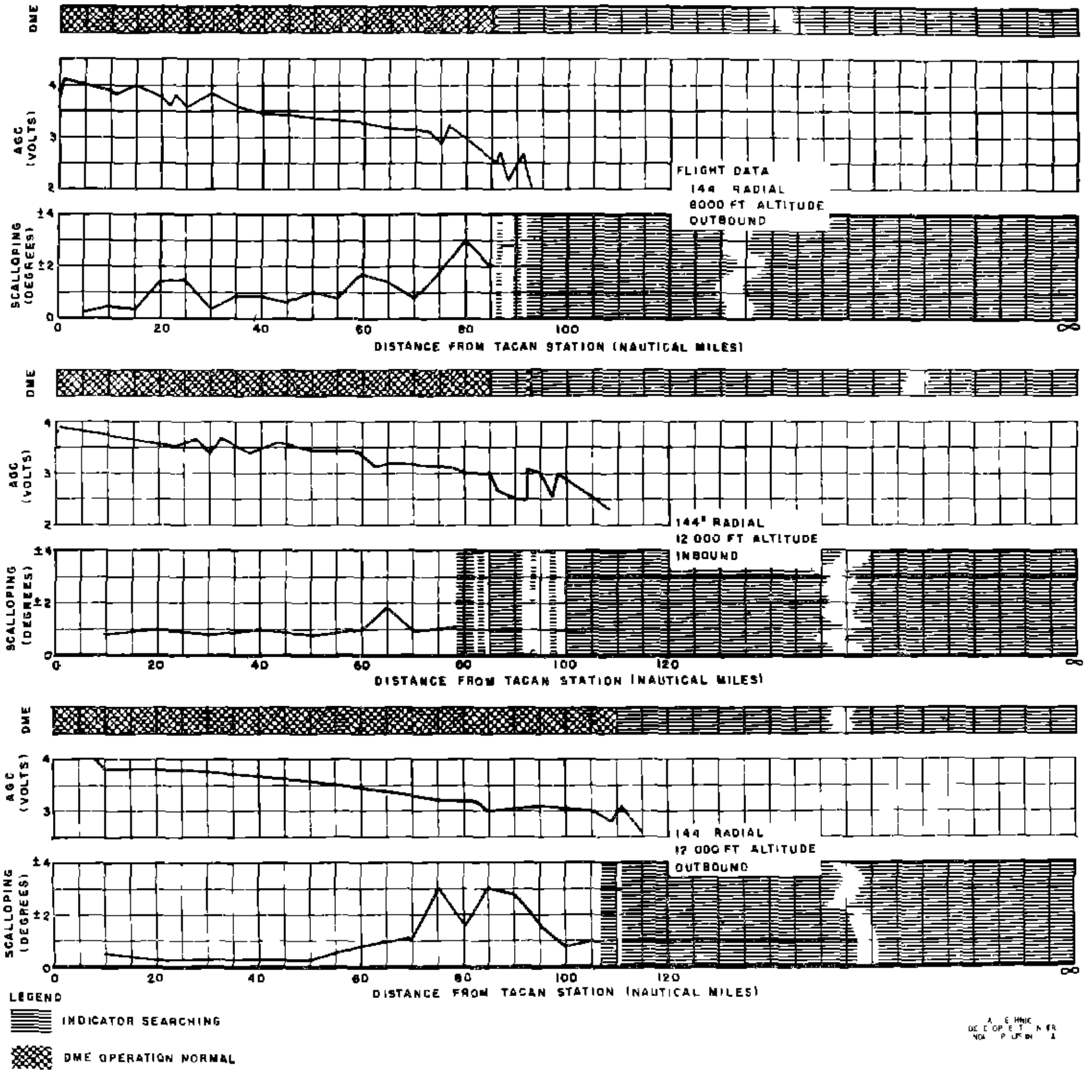


Fig 21 TACAN Radial Data, Site No 1, Antenna 30 Feet High

The next series of radial flights was conducted at an altitude of 12,000 feet above the station Plots of the data obtained on the 129° radial during the flights outbound and inbound to the station are shown in Fig 32 The effect of the grove of trees again resulted in a maximum of ±5° course scalloping and a very limited service range Figure 33 shows graphs of the data obtained on the 330° radial and again portrays TACAN operation under optimum conditions The effect of a null in the vertical plane-radiation pattern of the TACAN ground-station antenna may be seen by the increase in scalloping of maximum amplitude of ±4 5° and azimuth search encountered at approximately 75 miles from the station

Site No 3, Antenna 95 Feet

The TACAN ground equipment was installed in the TDC Radar Laboratory, and the antenna and wooden tower previously used at site No 1 were placed on the top of an ASR-1 radar tower This placed the center of the antenna 95 feet above ground A photograph of this installation is shown in Fig 34 Figure 35 is a panoramic view taken from the tower

The 12- and 24-mile-radius circles which were flown around the No 2 site were repeated at the No 3 site The data obtained are presented in Figs 36 and 37 These figures show reduced siting effect as a result of the increase in antenna height The scalloping between 100° and 130° azimuth on the 12-mile-radius circle at 2000 feet altitude, and on the 24-mile-radius circles at 4000- and 8000-foot altitudes, is attributed to an

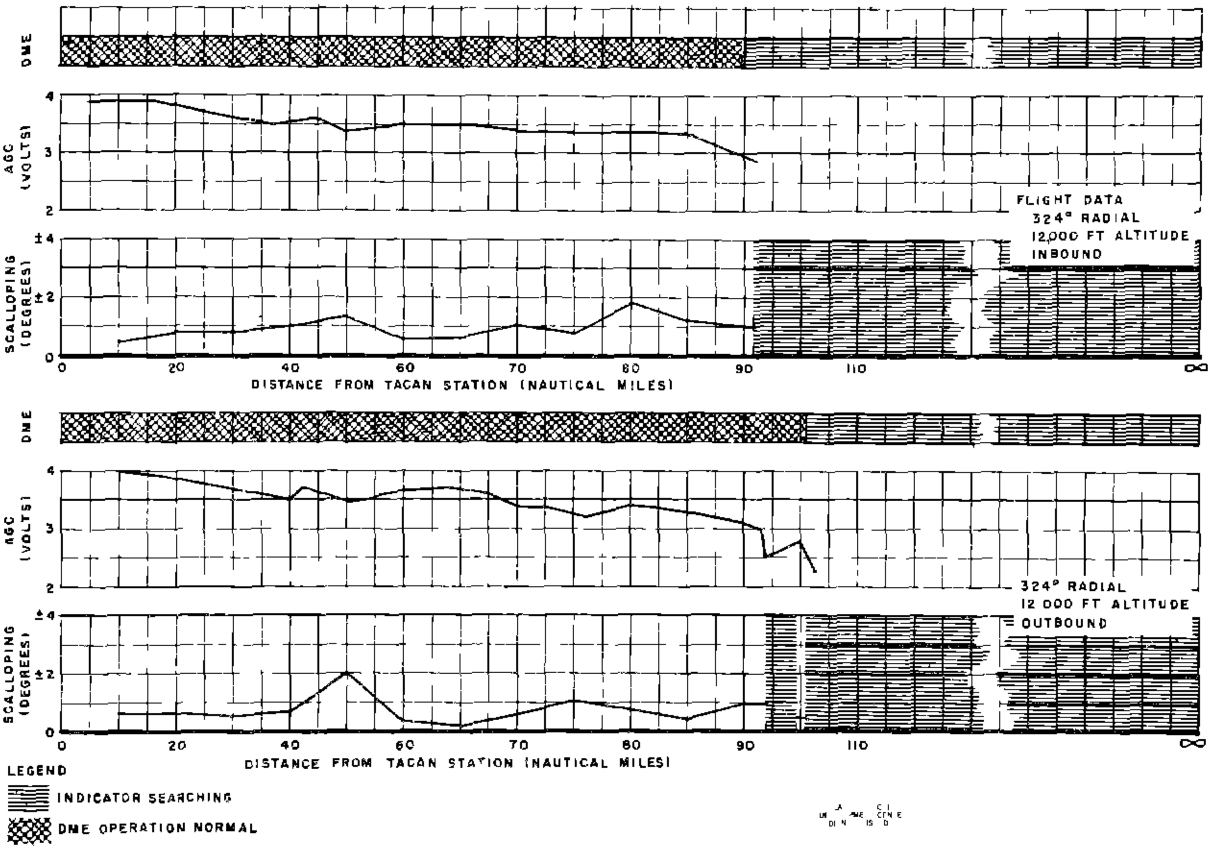


Fig 22 TACAN Radial Data, Site No 1, Antenna 30 Feet High

ASR-2 radar tower 60 feet high located 1000 feet distant at an azimuth of 110° This tower caused a maximum spread of scalloping of 3°

Radial flights were conducted at altitudes of 1000 feet and 12,000 feet to determine course scalloping and distance range The 1000-foot-altitude radials were flown at 184°, 270°, and 327° azimuth The data obtained on these flights are presented in Figs 38, 39, and 40, and show distance ranges varying from 40 to 57 miles with a maximum course scalloping of ±1 7°. The 330° radial was flown at an altitude of 12,000 feet above ground. The data obtained on this flight are presented in Fig 41, and show a distance range of 141 miles with a maximum course scalloping of ±1 2°

During the evaluation of the TACAN system at sites Nos 1 and 2, and during a part of the evaluation at site No 3, Type RG-17/U transmission line was used between the transmitter and the antenna The transmission line was then changed to a Stvroflex cable The new cable reduced the transmission-line power loss approximately 4.5 db This was evidenced by increased distance ranges averaging from 42 miles to 54 miles, at 1000 feet above ground Also, subsequent to the evaluation of the TACAN system at site No 3, a new modified transmitter was installed A theodolite flight calibration conducted on the station, using the new transmitter, provided data for the error curves shown in Fig. 42 with errors of ±1 25° and ±1 0°

Comparison of the data obtained with the TACAN antenna 30 and 95 feet above ground reveals increased distance range and reduced siting effect when the antenna was 95 feet high

Vertical Plane Radiation Patterns

Figures 43 through 48 show relative vertical plane field-strength patterns of the TACAN antenna when it was mounted 15, 30, and 95 feet high In Figs 43, 45, and 47, the patterns are plotted in rectangular co-ordinates for a clearer presentation of minimums and maximums at the lower angles, Figs 44, 46, and 48 show the patterns in polar co-ordinates

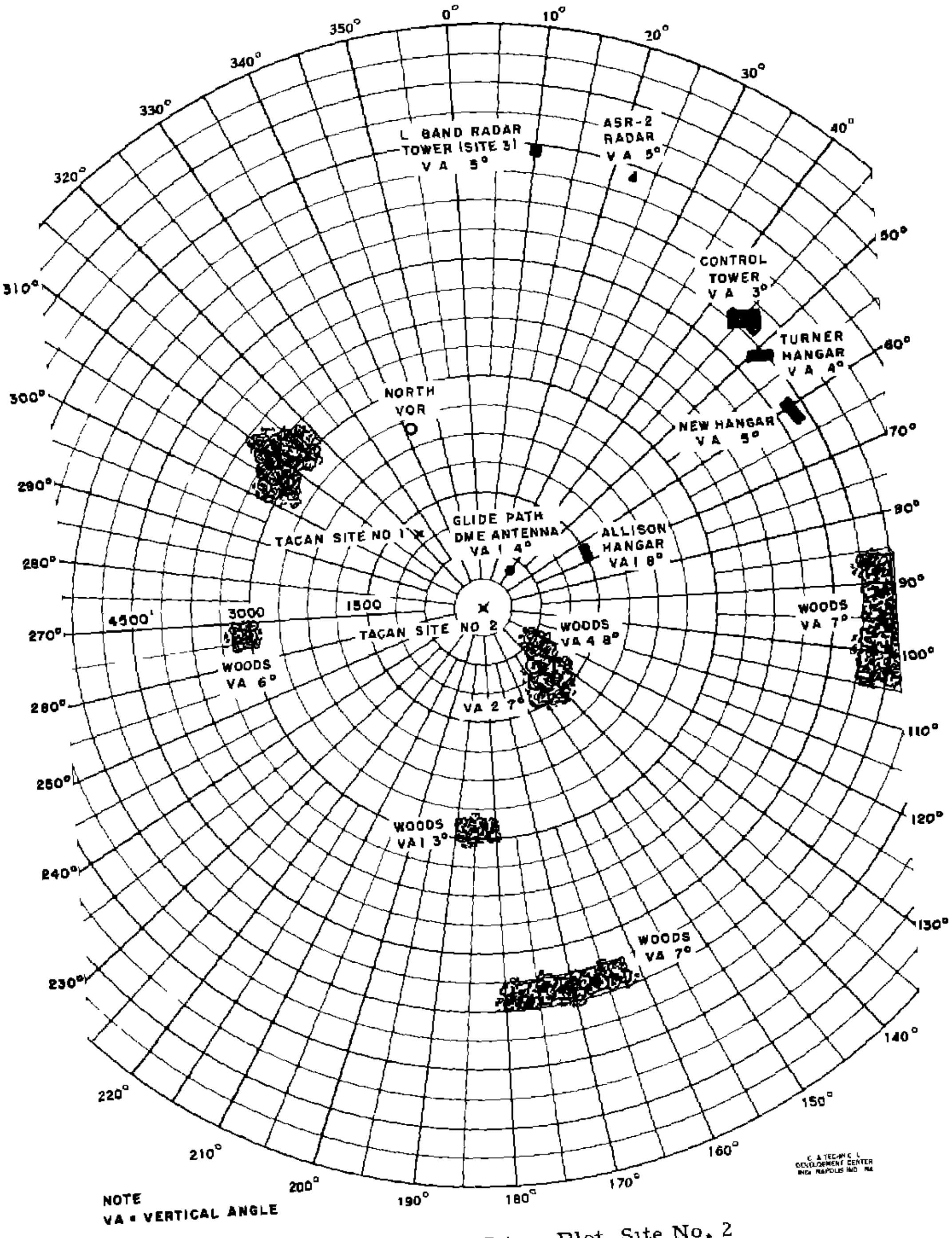


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Fig. 23 TACAN Siting Plot, Site No. 2

These patterns were computed from the AGC recordings obtained on radial flights at an azimuth of 330° which previous orbital and radial flights had shown to be free of siting effects The recordings were obtained on inbound flights at an altitude of 12,000 feet

Cone Width.

Cone-width measurements were made in a manner similar to that used in measuring cone width of VOR stations. The CDI recording on a radial pass over the station indicates

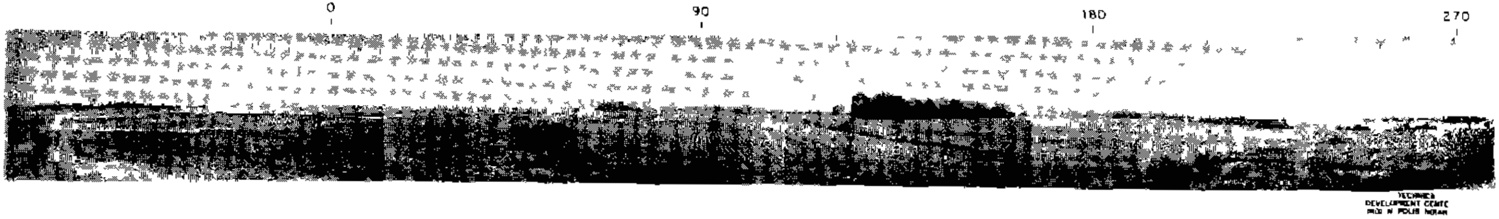

Fig 24 Panoramic Photograph, Site No. 2

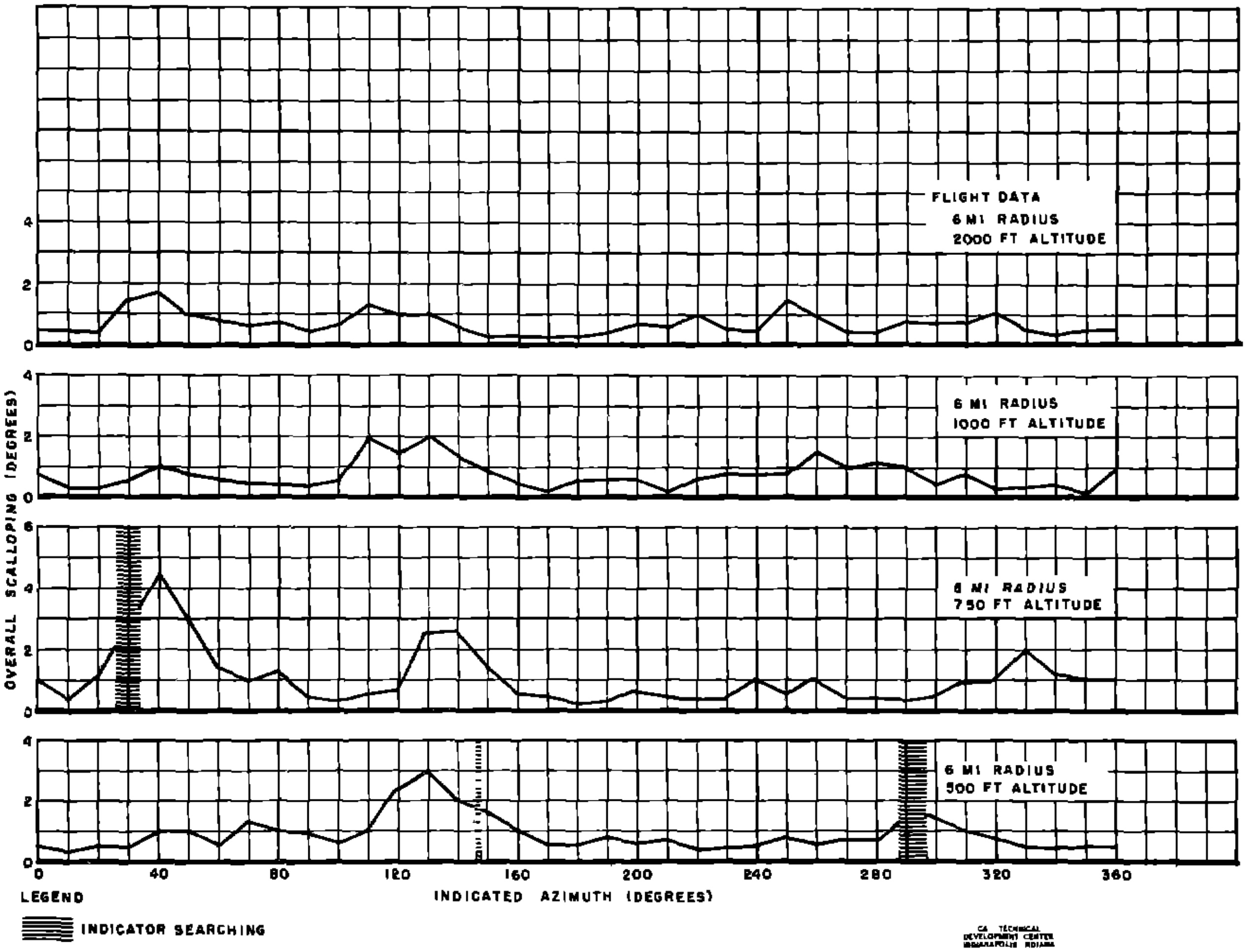

Fig 25 TACAN Scalloping Graph, Site No 2, Antenna 30 Feet High

the period of time during which incorrect azimuth information is received. The cone is considered entered when the CDI deviates more than 2° and when this deviation is due to normal course disturbances above the station The cone is left at the 2° deflection point as the straight-line-course indication is resumed after passing the station

The width of the cone was 156° measured at 1600 feet altitude when the antenna was 15 feet high, 97° measured at 8000 feet altitude when the antenna was 30 feet high, and 95.2° at altitudes above 8000 feet when the antenna was mounted 95 feet high.

One cone measurement when the antenna was 95 feet high was 161.6° at an altitude of 1000 feet This was due to the long time required for the airborne equipment to search Approximately 18 seconds are required for one complete search of azimuth. When flying through the cone, the course changes 180°. This requires one-half revolution of the azimuth indicator, or a minimum time of 9 seconds for passage through the cone. If the amplitude modulation containing azimuth information (15 and 135 cps) has not returned within 9 seconds, however, the azimuth indicator must make a complete revolution requiring an additional 18 seconds It follows, therefore, that the period during which azimuth information is unavailable in the cone occurs in odd multiples of 9 seconds 9, 27, 45, 63 seconds, and so forth.

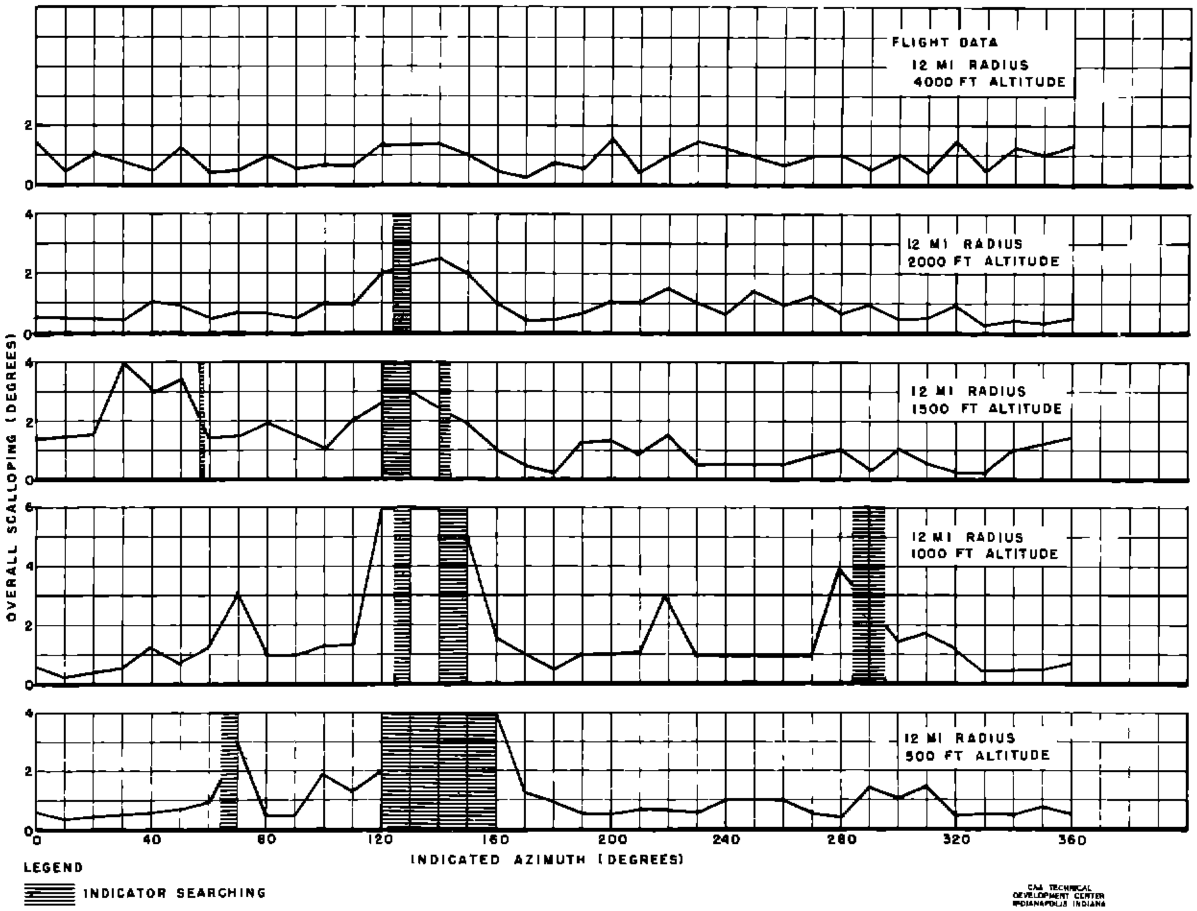

Fig 26 TACAN Scalloping Graph, Site No 2, Antenna 30 Feet High

CONCLUSIONS

As a result of the evaluation of the TACAN system, it is concluded that

1 The TACAN equipment has not demonstrated sufficient reliability for civil use

2 TACAN is subject to siting errors comparable to those of the VOR, although of a somewhat different nature

3 The azimuth portion of TACAN is much more susceptible to shadowing effects than is the VOR

4 When the TACAN antenna was situated 15 and 30 feet above ground, the airborne indicator went into search in the lowest null of the vertical plane-radiation patterns at an altitude of 12,000 feet

5 When the TACAN antenna was placed at a height of 95 feet above ground at a poor site, siting errors were practically eliminated.

6 The distance accuracy of the TACAN system is comparable to that of the civil DME.

7 The best theodolite flight calibration revealed an error of ±1.0° when the antenna was feet above ground and a modified transmitter was used. The best theodolite VOR-system libration obtained at TDC was ±0 6° using a four-loop VOR antenna

8 The operational characteristic of azimuth-indicator search caused by course alloping leads to discontinuity of azimuth information and loss of confidence in the system the pilot

9 The TACAN cone of silence subtended an angle of approximately 95° compared to 30° r the VOR.

10. The distance-indicator coverage of TACAN is comparable to that of DME.

11. The azimuth coverage of TACAN is less than that of VOR for equal antenna elevations

12. TACAN and DME cannot operate satisfactorily on common frequencies, and adequate guard bands between the two services are required

13 One of the greatest limitations of the TACAN airborne equipment is that no voice communications are provided for air-traffic control and weather broadcasts.

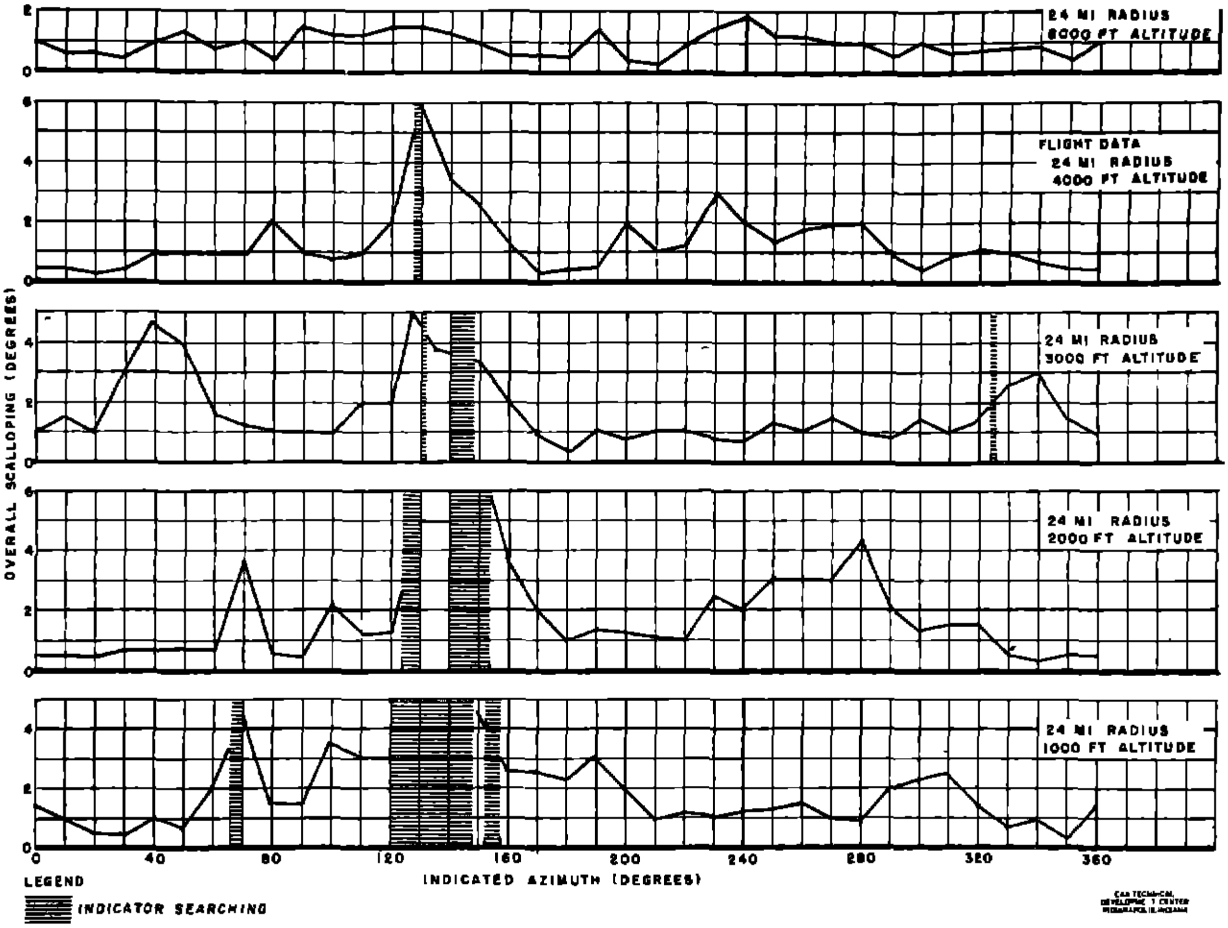

Fig. 27 TACAN Scalloping Graph, Site No. 2, Antenna 30 Feet High

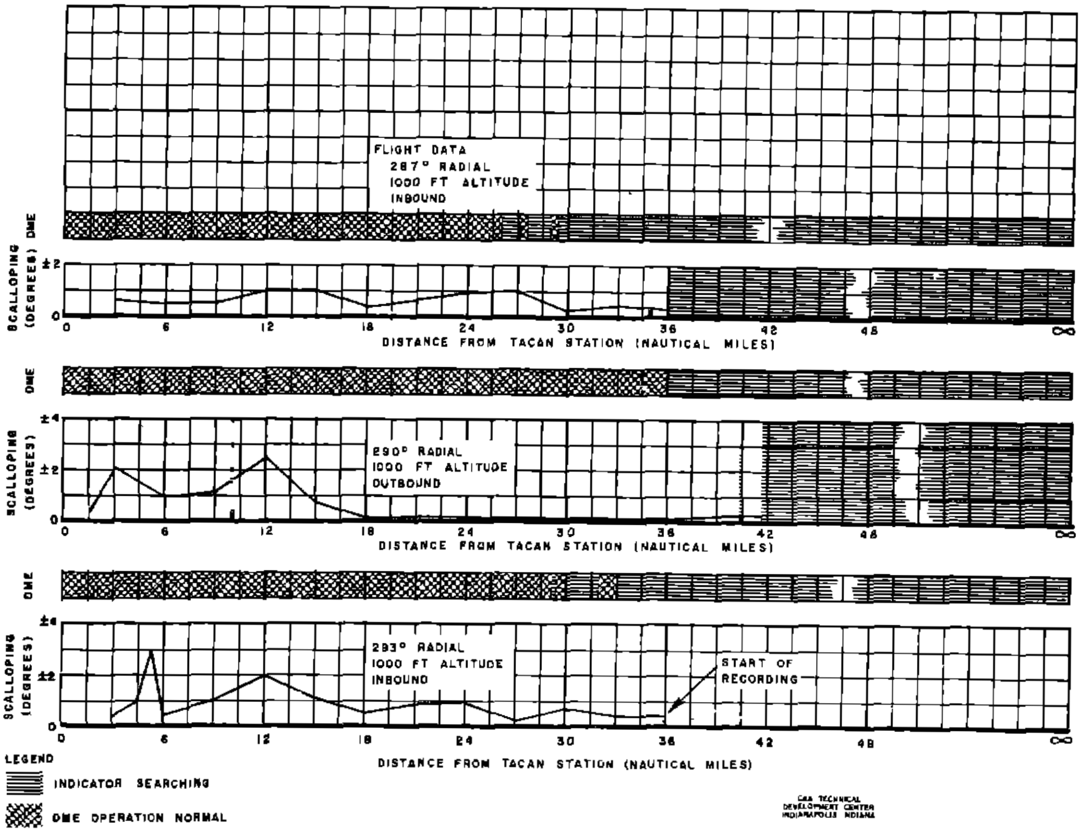

Fig. 28 TACAN Radial Data, Site No. 2, Antenna 30 Feet High

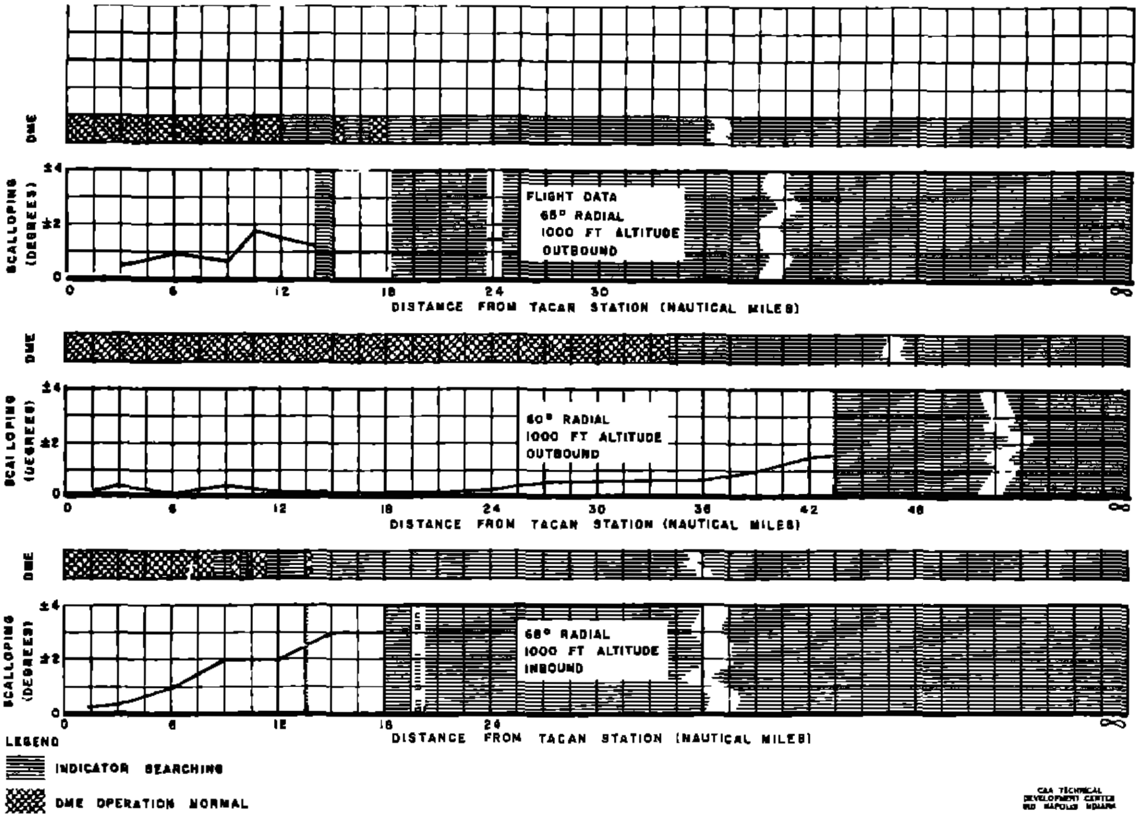

Fig. 29 TACAN Radial Data, Site No. 2, Antenna 30 Feet High

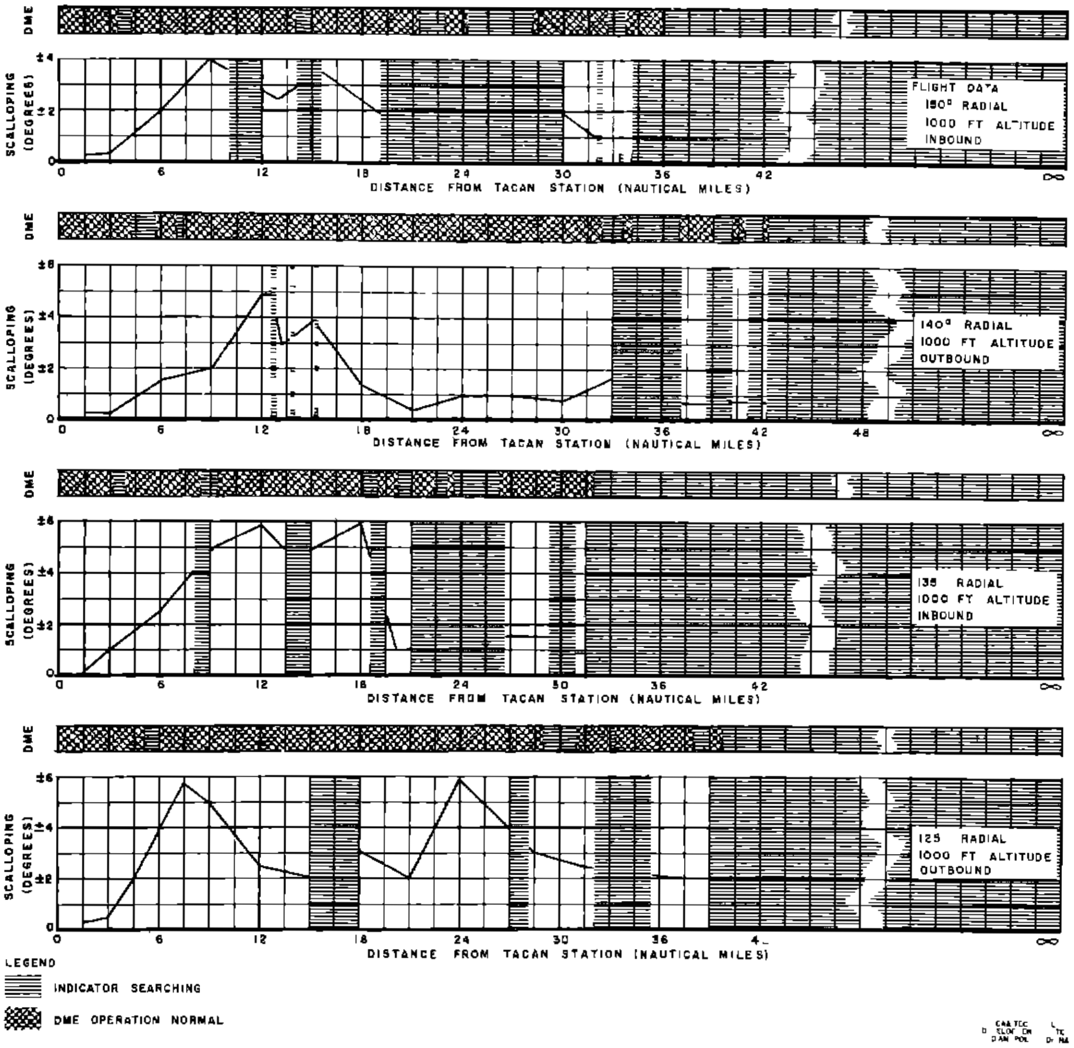

Fig. 30 TACAN Radial Data, Site No 2, Antenna 30 Feet High

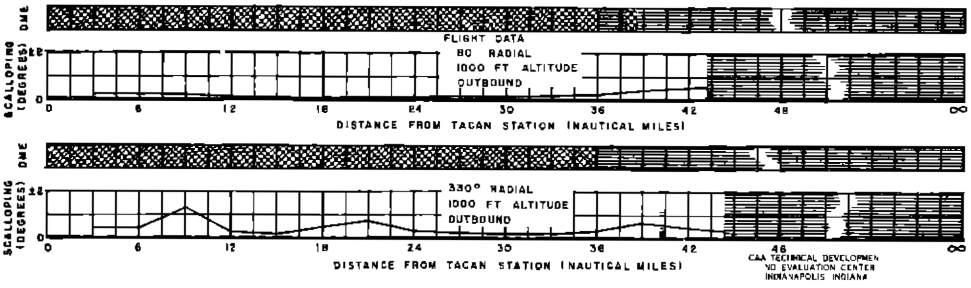

Fig. 31 TACAN Radial Data, Site No. 2, Antenna 30 Feet High

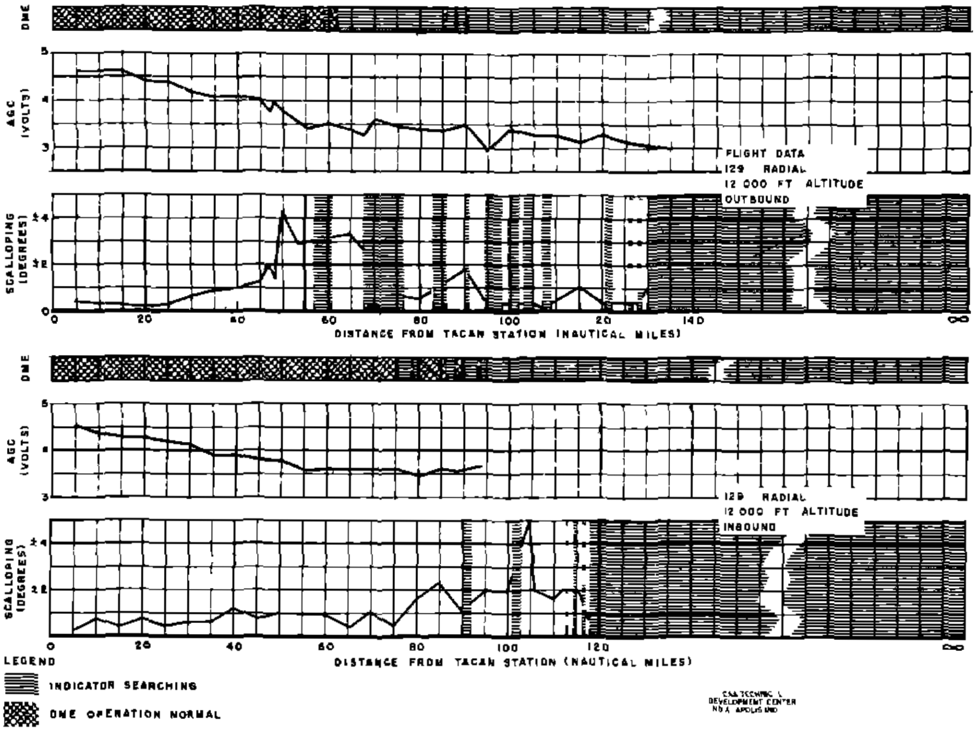

Fig 32 TACAN Radial Data, Site No 2, Antenna 30 Feet High

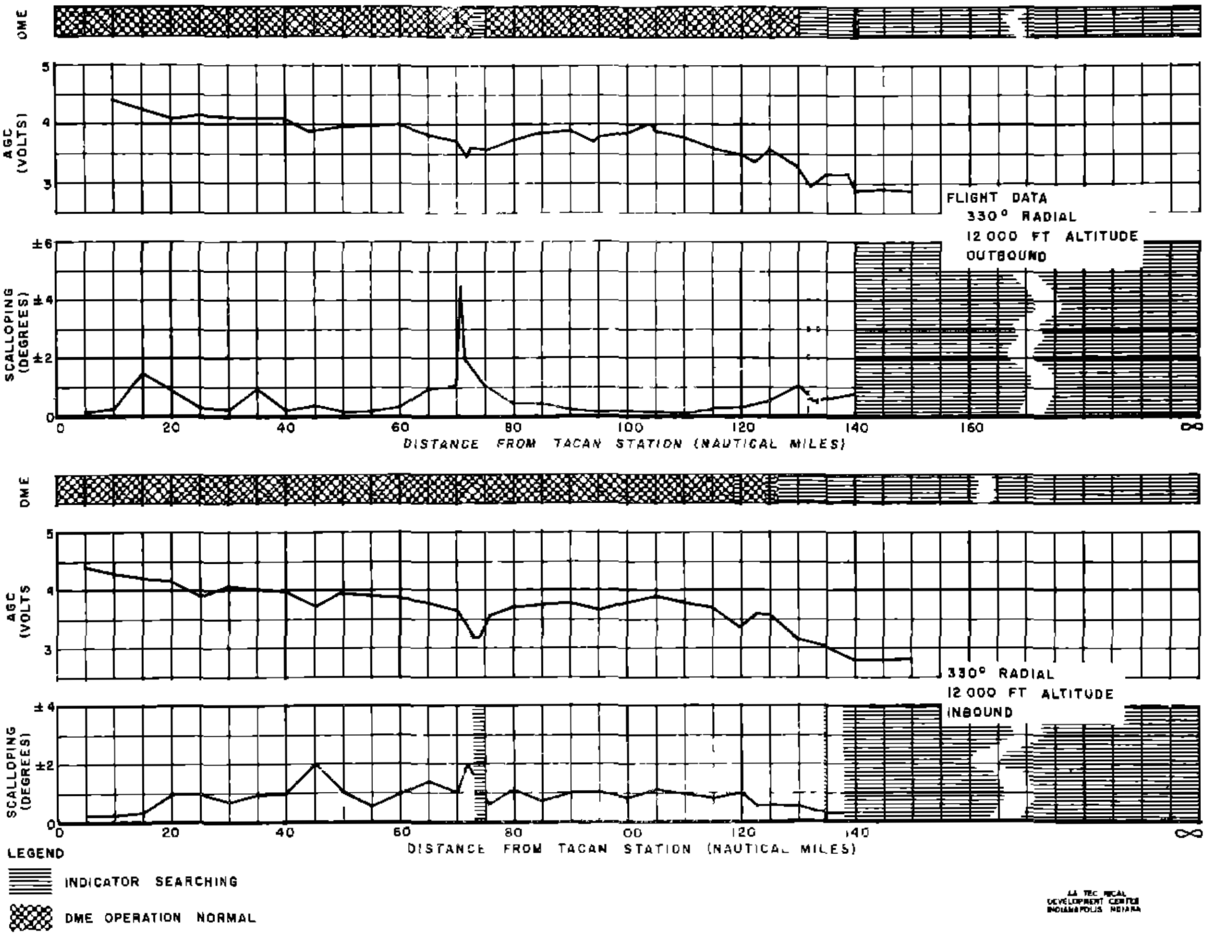

Fig 33 TACAN Radial Data, Site No. 2, Antenna 30 Feet High

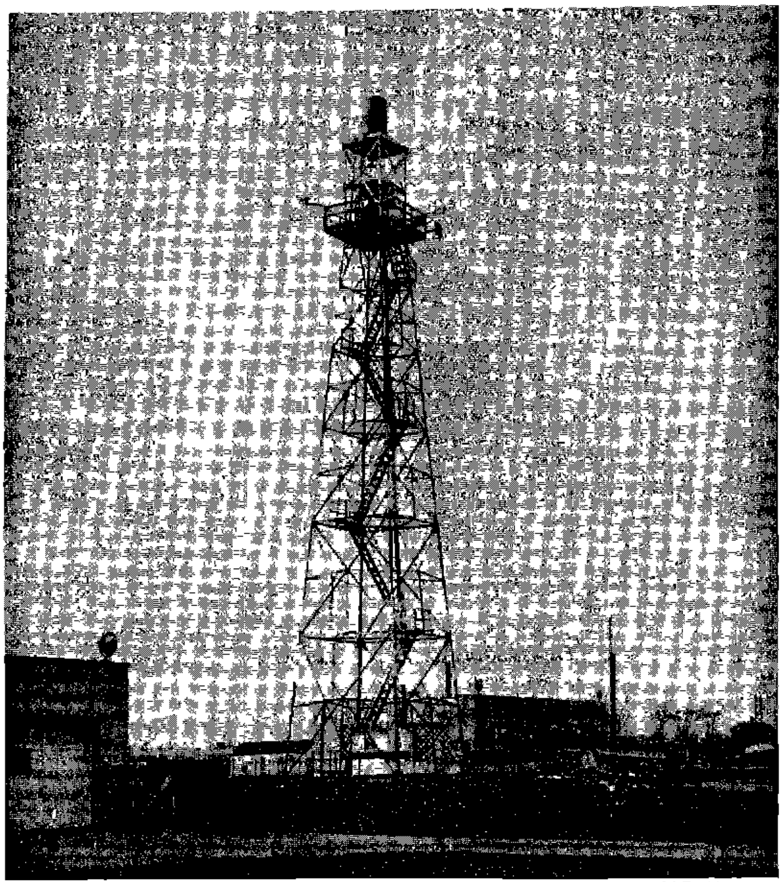

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Fig 34 TACAN Antenna Installation, Site No. 3

Fig 35 Panoramic Photograph, Site No. 3

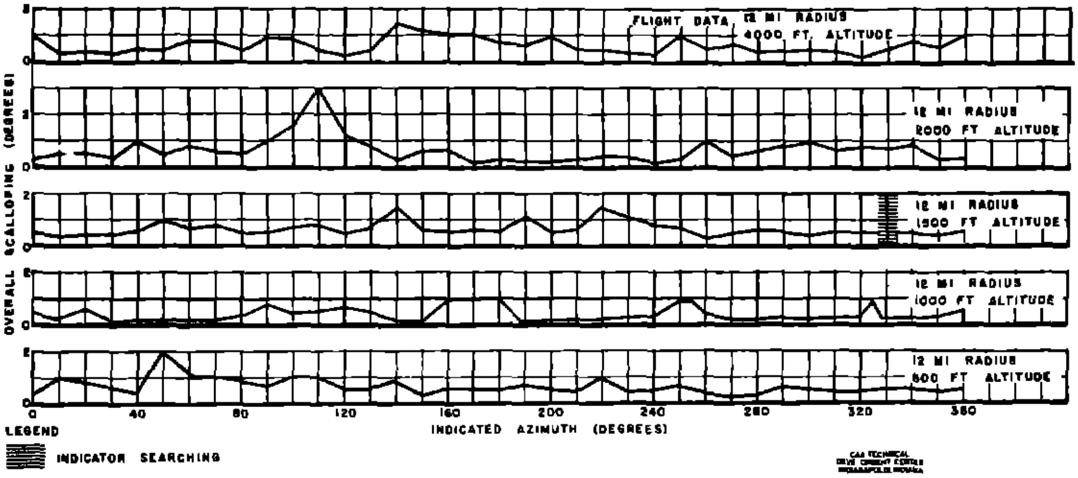

Fig. 36 TACAN Scalloping Graph, Site No. 3, Antenna 95 Feet High

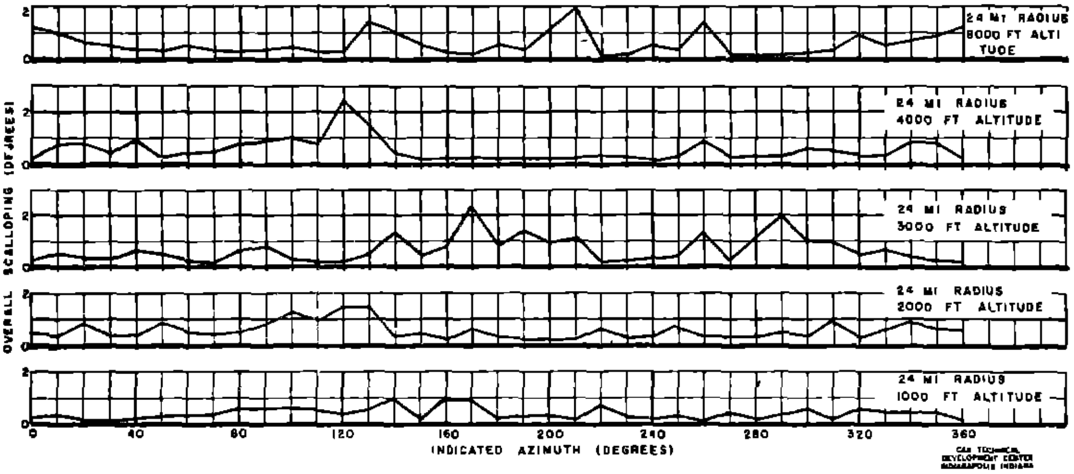

Fig 37 TACAN Scalloping Graph, Site No. 3, Antenna 95 Feet High

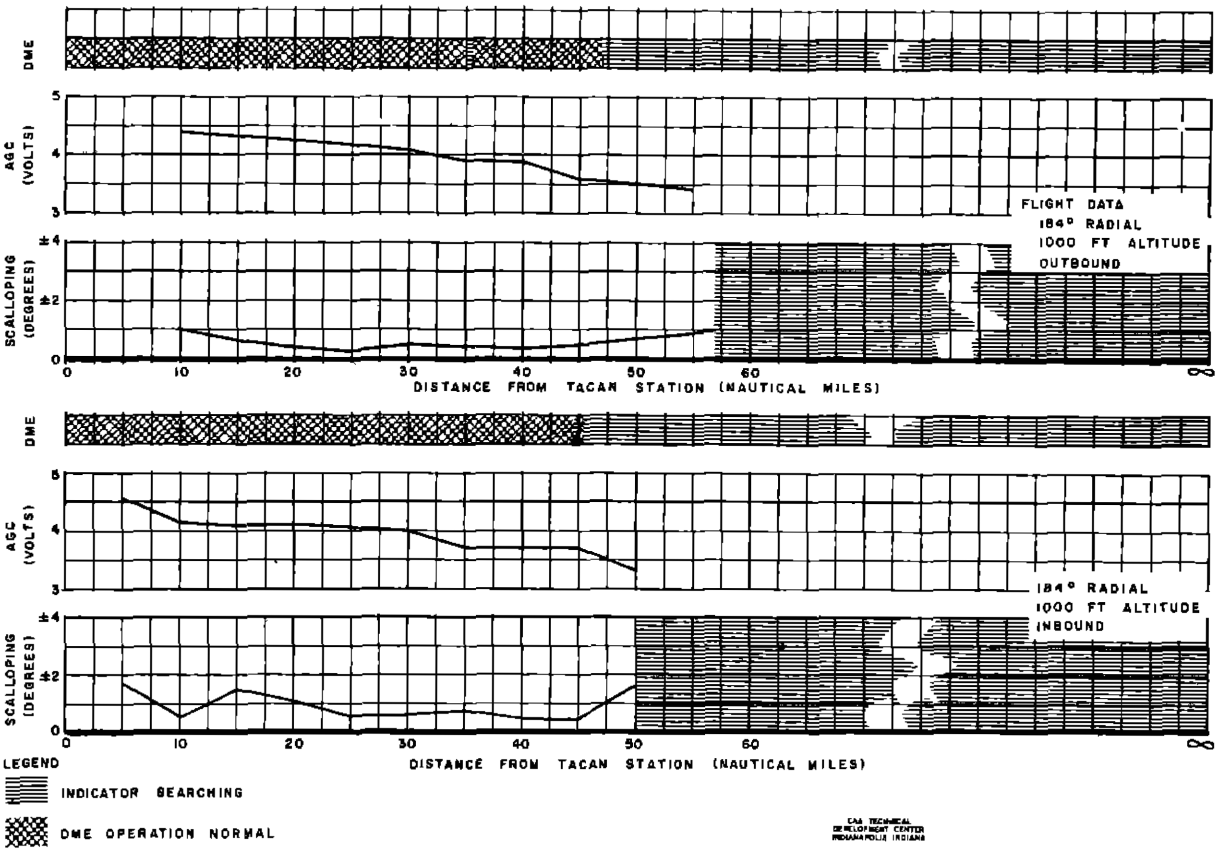

Fig 38 TACAN Radial Data, Site No. 3, Antenna 95 Feet High

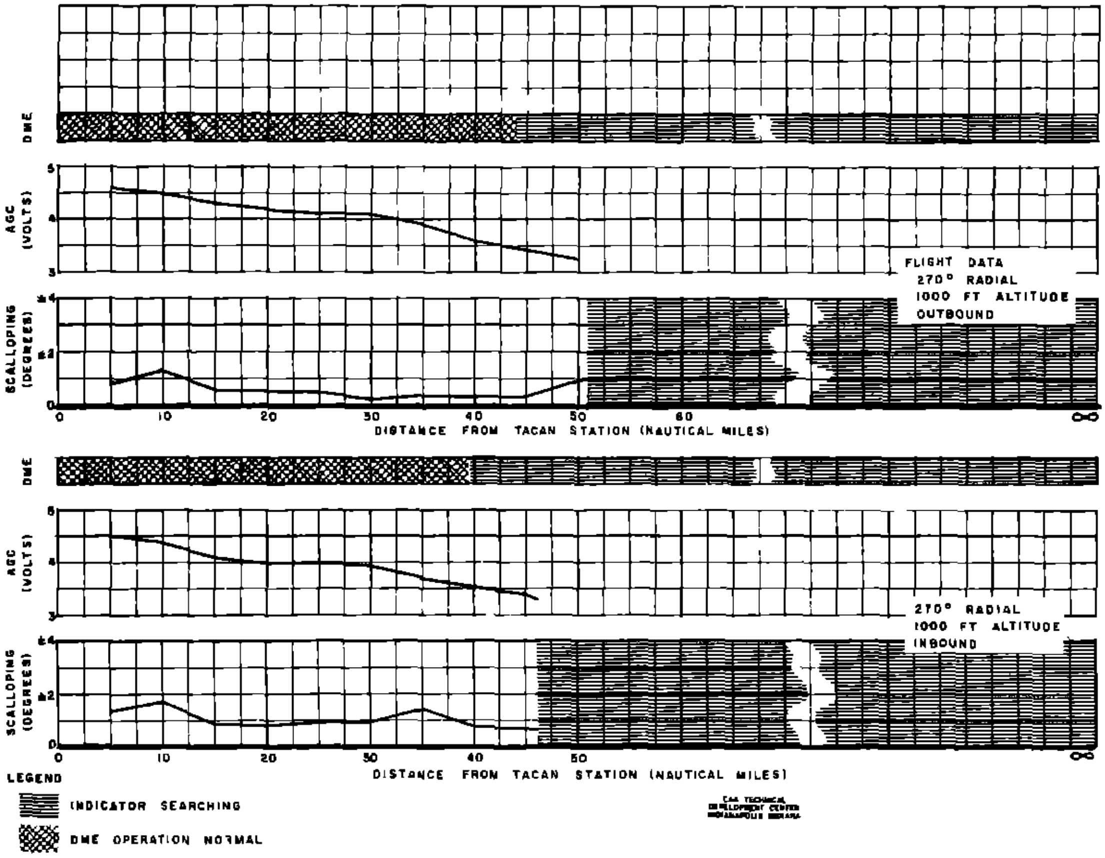

Fig 39 TACAN Radial Data, Site No 3, Antenna 95 Feet High

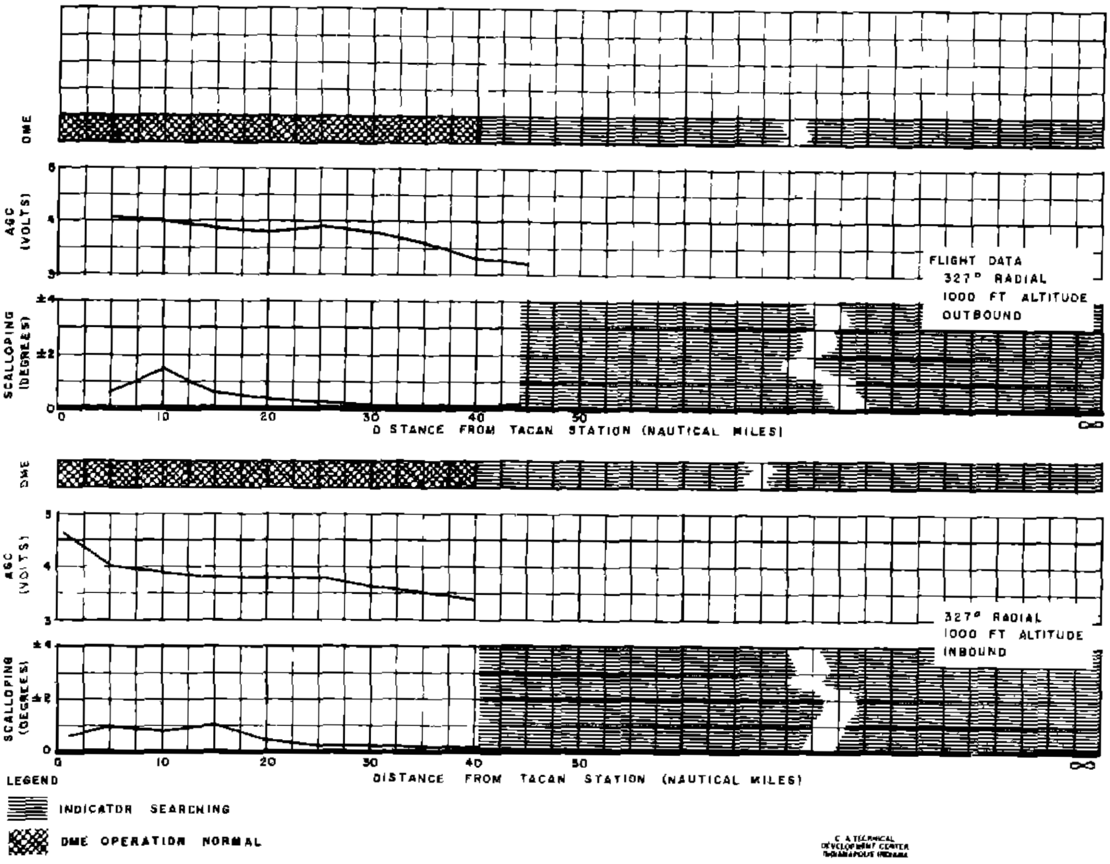

Fig 40 TACAN Radial Data, Site No 3, Antenna 95 Feet High

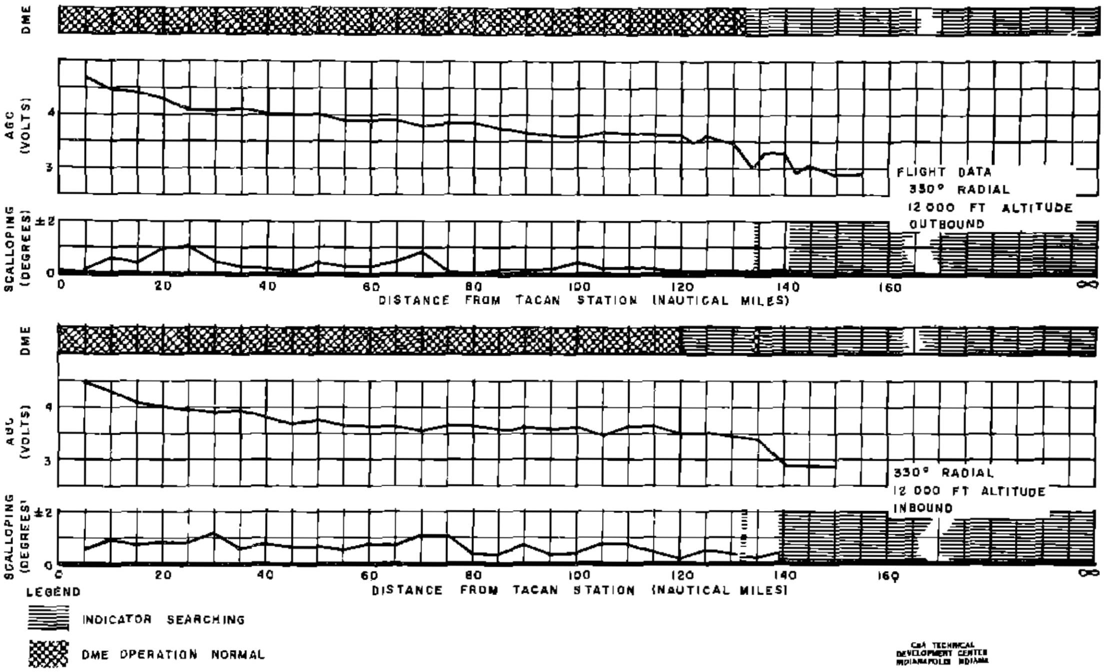

Fig 41 TACAN Radial Data, Site No 3, Antenna 95 Feet High

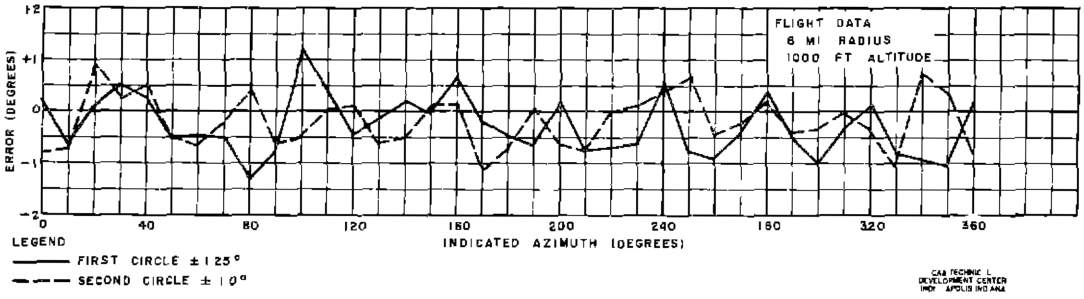

Fig. 42 TACAN Theodolite Flight Calibration, Site No 3, Antenna 95 Feet High

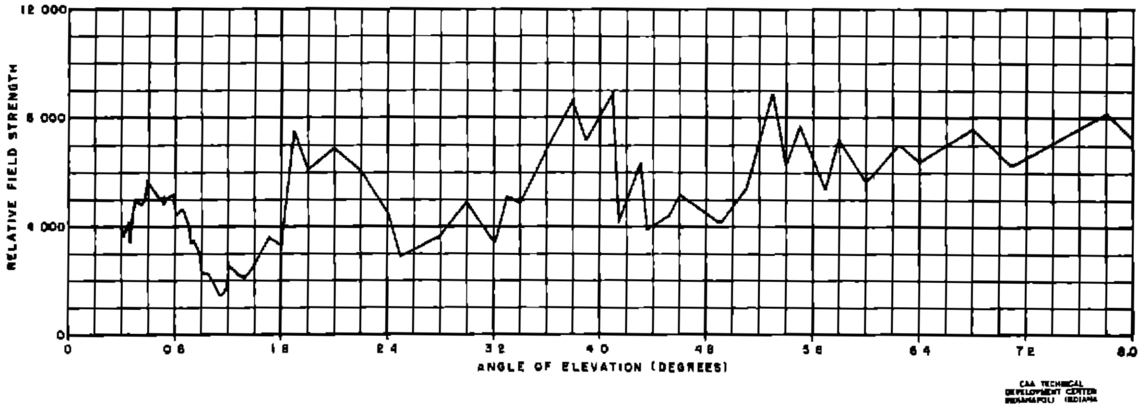

Fig 43 Vertical Plane Pattern, TACAN Antenna 15 Feet High (0°-8° Plot)

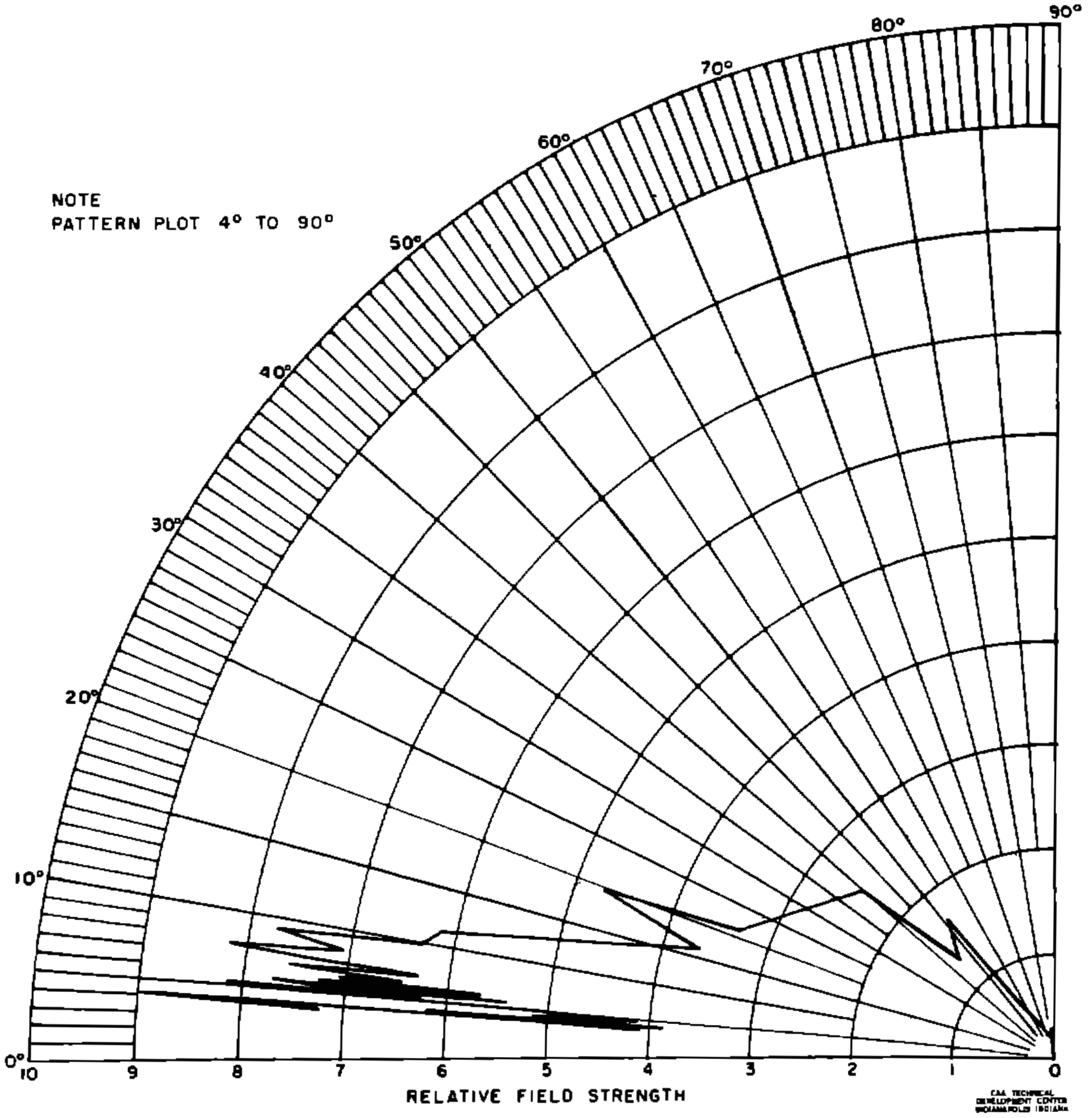

Fig 44 Vertical Plane Pattern, TACAN Antenna 15 Feet High

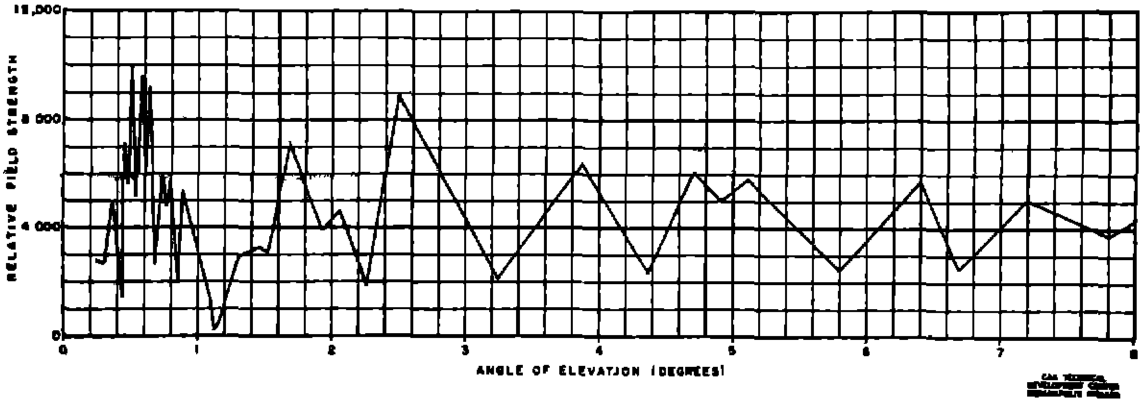

Fig 45 Vertical Plane Pattern, TACAN Antenna 30 Feet High (0°-8° Plot)

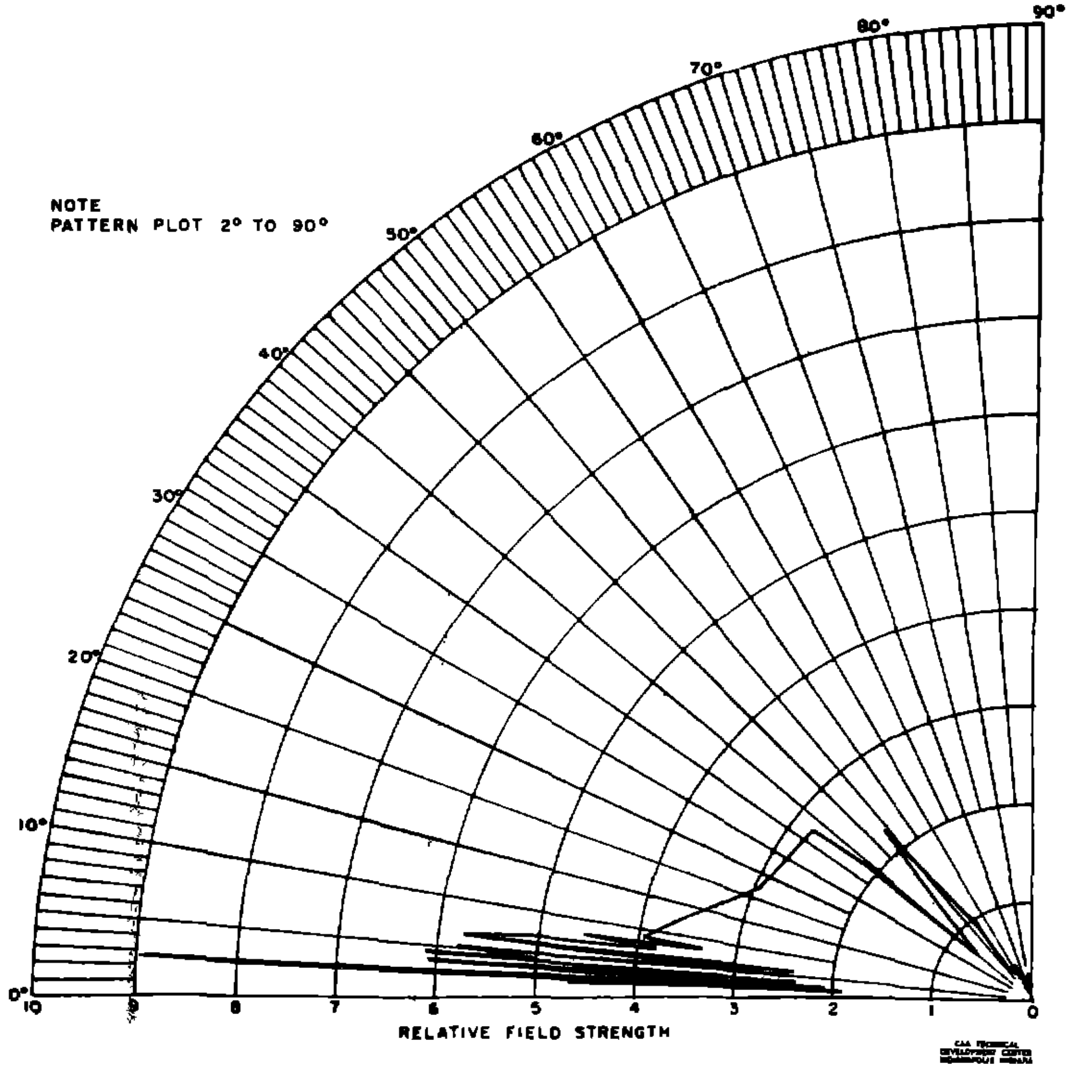
NOTE
PATTERN PLOT 2° TO 90°

Fig. 46 Vertical Plane Pattern, TACAN Antenna 30 Feet High

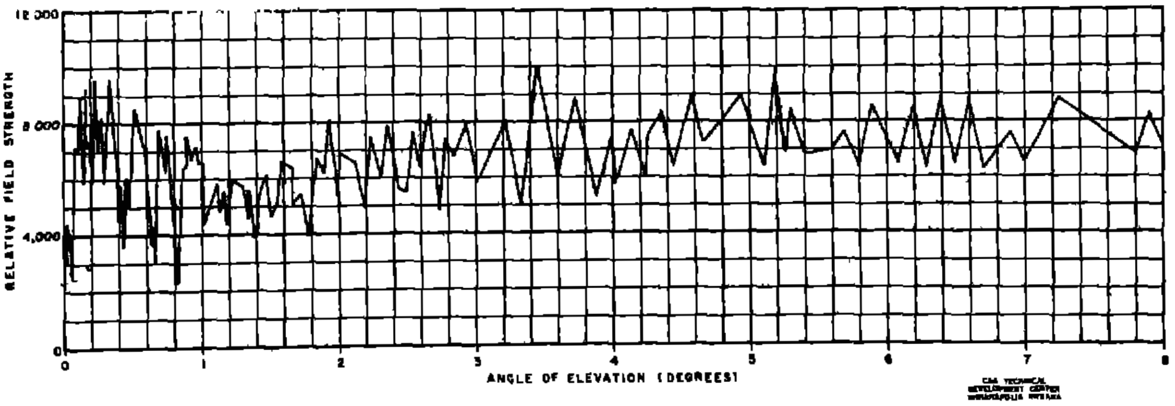

Fig 47 Vertical Plane Pattern, TACAN Antenna 95 Feet High (0°-8° Plot)

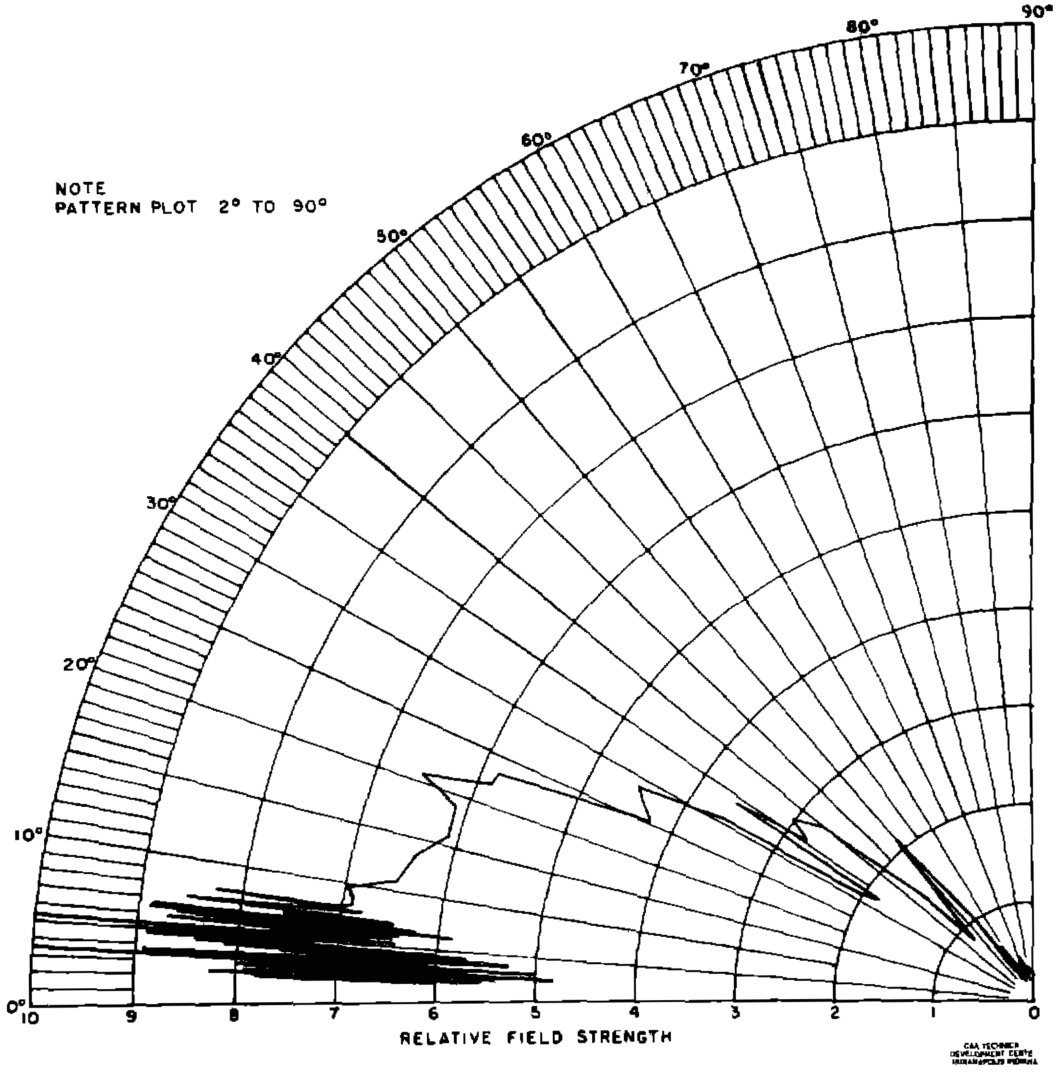

Fig 48 Vertical Plane Pattern, TACAN Antenna 95 Feet High