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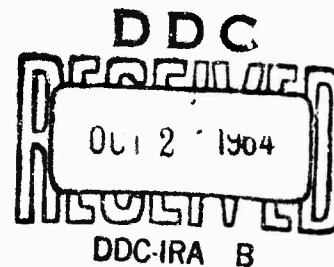

RADAR CROSS SECTION TARGET SUPPORTS -
METAL COLUMNS AND SUSPENSION DEVICES

TECHNICAL DOCUMENTARY REPORT NO. RADC-TDR-64-382
June 1964

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Space Surveillance and Instrumentation Branch
Rome Air Development Center
Research and Technology Division
Air Force Systems Command
Griffiss Air Force Base, New York

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Project No. 6503

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FOREWORD

In order to meet the need for a National Radar Reflectivity Range, Rome Air Development Center (RADC) awarded a development contract on 29 June 1962 to General Dynamics/Fort Worth (GD/FW) to design, fabricate, and develop the Radar Target Scatter Site (Project RAT SCAT) on the Alkali Flats, Holloman AFB, New Mexico, (Contract AF30(602)-2831). The operational RAT SCAT Site was delivered to the Air Force on 30 June 1964.

The RAT SCAT facility was developed for full-scale radar cross section measurements. In the pursuit of this development, an R&D Program was undertaken to provide for the specific needs of Project RAT SCAT as requirements appeared in the implementation of the function of the Site. A significant portion of this work was subcontracted. Emphasis was placed on those areas thought to be most promising in achieving measurement objectives. The presentation of the results of the R&D Program is covered in eight reports which were prepared as RADC Technical Documentary Reports.

This report (General Dynamics/Fort Worth Report No. FZE-222-5) is No. 5 in the series. It contains a description of the results of the investigations of two types of target support techniques used in making radar cross section measurements, i.e., shielded metal column and suspension target support techniques. The material on the shielded metal column was prepared by Dr. C. C. Freeny of General Dynamics/Fort Worth. The material on suspension target supports was prepared by Mr. R. A. Ross of Cornell Aeronautical Laboratory, Inc., under subcontract to General Dynamics/Fort Worth.

The contents of this report and the abstract are unclassified.

ABSTRACT

The shielded metal column program was devoted specifically to the investigation of errors in cross section measurement resulting from the use of a large, hydraulically actuated metal target support at the RAT SCAT Site. The analytical model used and the factors taken into consideration in arriving at a test program for use in evaluating shielding techniques for the metal target support are described in this report. The suspension target support program was an experimental program carried out by Cornell Aeronautical Laboratory. A scale ground plane range was used to simulate low-frequency operation on the RAT SCAT range. Most of the measurements made were for the purpose of determining the cross section return of such conventional suspension target supports as nylon. The parameters of primary concern were size and the polarization of the transmitter and receiver. This report is No. 5 in a series of 8 RAT SCAT Research and Development Program reports.

PUBLICATION REVIEW

This report has been reviewed and is approved. For further technical information on this project, contact

Approved: DONALD M. MONTANA
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SECTION 1

INTRODUCTION

One of the more important items to be considered in the
static measurement of the radar cross section of aerospace ve-
hicles is the target support mechanism. It is imperative, for
accurate measurement, that the selected vehicle support device
produce a negligible effect on both the incident and reflected
electromagnetic fields. Two basic approaches to the solution of
the support problem are commonly employed on present radar cross
section ranges. The first approach is to use materials in the
construction of support devices which are characterized by an
impedance closely matched to that of air and therefore produce
a negligible effect on the electromagnetic field. Such supports
are commonly fabricated from plastic materials. The second ap-
proach is to construct support devices which are, for the most
part, outside of the electromagnetic field and/or are designed
to divert both the incident and reflected energy in such a man-
ner that the target field will not be significantly disturbed.
Target supports constructed on the basis of the latter approach
are commonly fabricated from heavy nylon cables or from metals
and are capable of supporting extra heavy targets.

At the initiation of the RAT SCAT R&D program, both ap-
proaches to the solution of the target support problem were con-
sidered worthy of investigation. Accordingly, in the first
phase of these two investigations, subcontracts were awarded for
theoretical and limited experimental studies covering both ap-
proaches.

A subcontract was awarded to The University of Michigan for
the study of scattering properties of cellular plastic materials.
The results obtained from this study and studies made by General
Dynamics/Fort Worth may be found in Technical Documentary Report
No. RADC-TDR-64-381.

A subcontract was awarded to Cornell Aeronautical Laboratory
for a study of suspension target supports. The results obtained
from this study and studies by General Dynamics/Fort Worth on the
application of shielded metal columns to the support of radar
cross section targets are contained in this report. The final
suspension support subcontract report from Cornell Aeronautical
Laboratory is presented verbatim in Section 3 and the Appendix
except for the format changes necessary for proper presentation
of the combined results.

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It will be noted in this report that both studies culminated in recommendations for implementation of the program at the RAT SCAT Site. Such implementation was not carried out because of a diversion of contract funds to more promising R&D areas. However, documentation is provided herein that will provide a base line for the continuation and completion of the radar cross section target support investigation.

SECTION 2

SHIELDED METAL COLUMN

INVESTIGATION

GENERAL

The RAT SCAT R&D shielded metal column task was undertaken to develop methods for making cross-section measurements with a high degree of confidence when a metal column is used as a target support. It was anticipated that the theoretical and experimental results of the work could be used as a guide in specifying a useful shield for the 1.5-foot diameter, 30-foot-long hydraulically actuated, metal target support at the RAT SCAT Site. This Technical Documentary Report contains a definition and discussion of the measurement errors considered prevalent in the use of a metal target support. Shielding techniques for reducing these errors are also discussed, and an outline is presented for an experimental program designed to obtain information for evaluating various shielding techniques.

MEASUREMENT ERRORS INTRODUCED BY METAL SUPPORTS

The cross section measurement errors arising from the use of a metal target support can be classified in the same manner as the errors associated with cellular plastic or any other support system. The main distinction in the use of a metal support is that the potential magnitudes of the errors are much greater than those encountered in using cellular plastic supports of a comparable size. A general classification and discussion of target support errors will be presented. This material will then be used in a discussion of metal supports in which it will be assumed that the only pertinent measurement errors are those resulting from the target support system (i.e., measurement errors, such as equipment nonlinearities, RFI, target misalignment, will be considered negligible). A measurement error E caused by a given target support system may be defined as

$$E = \frac{\sigma_m - \sigma_t}{\sigma_t} \tag{1}$$

where

σ_m = cross section of target plus the target support system

σ_t = cross section of target.

The cross sections used in Equation 1 may be either monostatic or bistatic, as well as a function of target orientation and/or polarization. However, since the target support error classifications are independent of these parameters, the above factors will not be used in indexing the appropriate parameters. In general, Equation 1 is only of academic interest since E, σ_m, and σ_t are usually unknown; but subject to various assumptions, it can be used to estimate either E, σ_m, or σ_t. The most generally used assumption is that σ_m can be determined by comparing the return of the target with the return from an object whose cross section is known (e.g., that of a sphere). In other words, the system can be so calibrated that a negligible resultant error is obtained because the power level seen by the receiver has been converted to dbsm in an erroneous manner. In the evaluation of a support system, such as a metal column, this assumption should be quite valid. For example, use of a sphere, mounted on a Styrofoam column or hoisted by a balloon, should enable the calibration of the system to at least an order of magnitude better than the errors associated with σ_t because of the metal target support. Hence, in

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the remaining discussion, σ_m will be taken as a measurable quantity in terms of dbsm. If σ_m is known, then confidence limits on E can be obtained by using a target with a known cross section. In turn, these confidence limits can be used in measuring a target when its cross section is known only to an order of magnitude. The latter situation constitutes the practical application of Equation 1; whereas the former case is useful in any attempt to establish confidence limits for E. Since the establishment of confidence limits for E is the objective set for this program, the cross sections of the targets to be used in the experimental program will be taken as known quantities (e.g., the targets may be measured in the manner suggested for calibration).

To estimate the error represented in Equation 1, individual sources of error and their relationship to the total error will be formulated. The reason for the use of this approach, rather than the direct use of Equation 1, is that "representative" targets have not been defined; consequently, an estimate for the total error E is not as meaningful as estimates for components of E, i.e., targets are available and experiments can be designed for the investigation of the individual errors which contribute to the total error.

The individual errors which contribute to the total error may be divided into three types. These errors will be defined by using the following nomenclature along with the earlier definitions:

σ_s = cross section of target support system without target and without cancellation.

σ_s' = cross section of target support with target and without cancellation.

σ_s'' = equivalent cross section of cancellation signal.

σ'_t = cross section of target as modified by the target support system.

$\emptyset$ (with appropriate indexes) = phases associated with the appropriate cross section returns.

The first type of error is considered in terms of a ratio between the cross section of the target support system and the cross section of the target which is being measured. This error factor will be denoted by E_b and is defined as

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$$E_b = \frac{\sigma_s}{\sigma_t} \qquad (2)$$

The second type of error represents a measure of the reduction of the E_b type of error which is achieved through cancellation. This error will be denoted by E_c and is defined as

$$E_c = \left| 1 - \sqrt{\frac{\sigma_s''}{\sigma_s'}} \, \epsilon^{\; i(\phi_s'' - \phi_s')} \right|^2 \qquad (3)$$

The third type of error is a measure of the potential error introduced by coupling between the target and the target support. This error will be divided into two terms, as suggested, from consideration of a system of only two scatterers. The first coupling error will denote the cross section change of the support caused by the target and will be denoted by E_{ts}. The second coupling error will denote the influence of the support on the target cross section and will be denoted by E_{st}. These two errors are defined as

$$E_{ts} = \left| 1 - \sqrt{\frac{\sigma_s'}{\sigma_s}} \, \epsilon^{\; i(\phi'_s - \phi_s)} \right|^2 \qquad (4)$$

$$E_{st} = \left| 1 - \sqrt{\frac{\sigma_t'}{\sigma_t}} \, \epsilon^{\; i(\phi'_t - \phi_t)} \right|^2 \qquad (5)$$

To relate the above error factors to the total error, the target support cross section, σ_m, can be expressed in terms of σ_t', σ_s', and σ_s'' as

$$\sigma_m = \left| \sqrt{\sigma_s'}\epsilon^{\; i\phi'_s} - \sqrt{\sigma_s''}\epsilon^{\; i\phi_s''} + \sqrt{\sigma_t'}\epsilon^{\; i\phi_t'} \right|^2 \qquad (6)$$

By solving Equations 3, 4, and 5 for the appropriate terms indicated in Equation 6, σ_m can be expressed in terms of the measurable quantities σ_s and σ_t, along with the errors E_c, E_{st}, and E_{ts}. With these substitutions, σ_m is expressed as

$$\sigma_m = \left| \sqrt{\sigma_s}\,\epsilon^{\; i\phi_s}\,(1 - \sqrt{E_{ts}}\epsilon^{\; i\phi_{ts}})\,\sqrt{E_c}\,\epsilon^{\; i\phi_c} + \sqrt{\sigma_t}\,\epsilon^{\; i\phi_t}(1 - \sqrt{E_{st}}\epsilon^{\; i\phi_{st}}) \right|^2$$

$$(7)$$

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By using Equation 7, along with Equations 1 and 2, the total error E can be expressed as

$$E = \left| \sqrt{E_b E_c} \, (1 - \sqrt{E_{ts}} \, \epsilon^{\, i\emptyset_{ts}}) \, \epsilon^{\, i(\emptyset_{st}\emptyset_c)} + \epsilon^{\, i\emptyset_t}(1 - \sqrt{E_{st}} \, \epsilon^{\, i\emptyset_{st}}) \right|^2 - 1 \tag{8}$$

Equation 8 indicates the manner in which the three types of errors are vectorially related to form the total error. However, even though the individual coupling errors help to provide a physical picture of the problem, they cannot be separated by experiment (except for the trivial case of complete independence). Hence they are combined for evaluation, as suggested by Equation 8. This combined coupling error will be denoted by E_{TS} and is defined as

$$E_{TS} = \left| \sqrt{E_b E_c E_{ts}} \, \epsilon^{\, i(\emptyset_s + \emptyset_c + \emptyset_{ts})} + \sqrt{E_{st}} \, \epsilon^{\, i(\emptyset_{st} + \emptyset_t)} \right|^2 \tag{9}$$

By using Equation 9 in Equation 8, the total error can be written as

$$E = \left| \sqrt{E_b E_c} \, \epsilon^{\, i(\emptyset_s + \emptyset_c - \emptyset_t)} - \sqrt{E_{TS}} \, \epsilon^{\, i(\emptyset_{TS} - \emptyset_t)} + 1 \right|^2 - 1 \tag{10}$$

Expanding Equation 10 into an incoherent (amplitude only) and coherent (amplitude and phase) term gives

$$E = E_b E_c + E_{TS} + 2 \left[- \sqrt{E_{TS} E_b E_c} \, \cos(\emptyset_s + \emptyset_c - \emptyset_{TS}) \right.$$
$$\left. + \sqrt{E_b E_c} \, \cos(\emptyset_s + \emptyset_c - \emptyset_t) - \sqrt{E_{TS}} \, \cos(\emptyset_{TS} - \emptyset_t) \right] \tag{11}$$

If it is assumed that the amplitude and phases in Equation 11 are independent and the phases are distributed uniformly over 2π, then the average error is given by

$$\bar{E} = E_b E_c + E_{TS} \tag{12}$$

Although the assumptions used to obtain Equation 12 are valid only when a large class of targets and/or repeated measurements are considered, this equation can be used to show that a positive average error tends to exist. Actually, because of the quasi-fixed

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relationship between the target and support (limited target shapes, measurement frequencies, and spacing between target and support) in the test program, a somewhat biased average coupling error may be obtained. To indicate that a value of average coupling error is determined from a limited test program, the average coupling error will be denoted by $\bar{E}_{TS}$.

In the case of conditions commonly achieved by using Styrofoam supports, errors calculated from Equations 11 and 12 are compared by using the maximum positive error obtained from Equation 11. The maximum positive error will be denoted by E_M and defined by

$$E_M = E_b E_c \div E_{TS} + 2(\sqrt{E_{TS}E_b E_c} + \sqrt{E_b E_c} + \sqrt{E_{TS}}) \tag{13}$$

Two conditions are often encountered in outdoor pulse ranges when Styrofoam columns are used as target supports: $E_c = 1$ (no cancellation is used), and $E_b - .01$ (i.e., the target support is at least 20 db down from the target to be measured). In the case of the above conditions, it is observed that σ_m is never more than 1 db larger than σ_t when Equations 13 and 1 are used and the coupling error, E_{TS}, is neglected. If the conditions used in the above example are imposed on the average errors represented by Equation 12, it is observed that the average measured cross section level, $\bar{\sigma}_m$, differs from the cross section level, σ_t, by only 0.43 db. Similar conditions are often assumed for indoor ranges, except that $E_c \neq 1$ and $E_b E_c$ are taken as $\lesssim .01$ since cancellation is usually necessary on an indoor range. On both types of ranges, where Styrofoam or other low dielectric material target supports are used, the coupling errors are usually neglected. However, for the case of metal target supports, the coupling error may present a major difficulty in achieving accurate cross section measurements. The remainder of this note is devoted to the discussion of methods for reducing the errors encountered when metal supports are used.

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SHIELDING TECHNIQUES FOR USE WITH METAL SUPPORTS

From the previous analysis, it is evident that a technique for shielding a metal support should be evaluated in terms of the errors E_b, E_c, and E_{TS}. In addition, other factors, such as cost, installation and storage time, maintenance problems, etc., need to be considered. Before techniques for shielding the hydraulic ram at the RAT SCAT Site are considered, several facts concerning the ram are discussed.

An advantageous feature of the ram, relative to the error E_c, is that the ram does not rotate. Target rotation will be accomplished by a rotator on top of the ram. However, the rotator will probably be larger in diameter than the column itself; consequently, E_b will tend to increase. A disadvantageous feature, relative to cancellation, is that the ram will be used to raise the targets to the required measurement heights. Hence, to use cancellation, any shield which is attached to the ram must be so designed that its geometrical relationship relative to the ram can be controlled quite accurately. Another factor which will tend to increase E_b, and especially E_{TS} and E_c, is that the target will not be appreciably elevated above the top of the metal rotator by any low dielectric support, such as Styrofoam. Consequently, the rotator will be illuminated with the same intensity wave as the target. Normally, these errors are reduced by raising the target several feet above the rotator with a support, such as Styrofoam. However, because of the target weights anticipated for the hydraulic ram, this approach is not feasible.

A desirable operational feature would be the capability for operating the ram from several heights (e.g., 10, 20, 30 feet). To attain this operational capability, the shield would also have to be devised to include this capability. Another desirable operational feature is the ability to use the ram for bistatic as well as monostatic cross section measurements. Hence a technique for shielding the ram should be considered relative to its bistatic as well as its monostatic properties.

Three shields are considered for reducing the measurement errors to be encountered in connection with the use of the hydraulic ram. These were chosen after consideration of the two basic methods used in cross section reduction of any target. The two basic methods are (1) use of materials placed on the target, such as absorbers and (2) shaping of the target. A combination of target shaping and absorber materials can be considered as a third method. These three reduction techniques will be investigated by evaluating the shields shown in Figure 2-1 in terms of the errors and operational features discussed earlier.
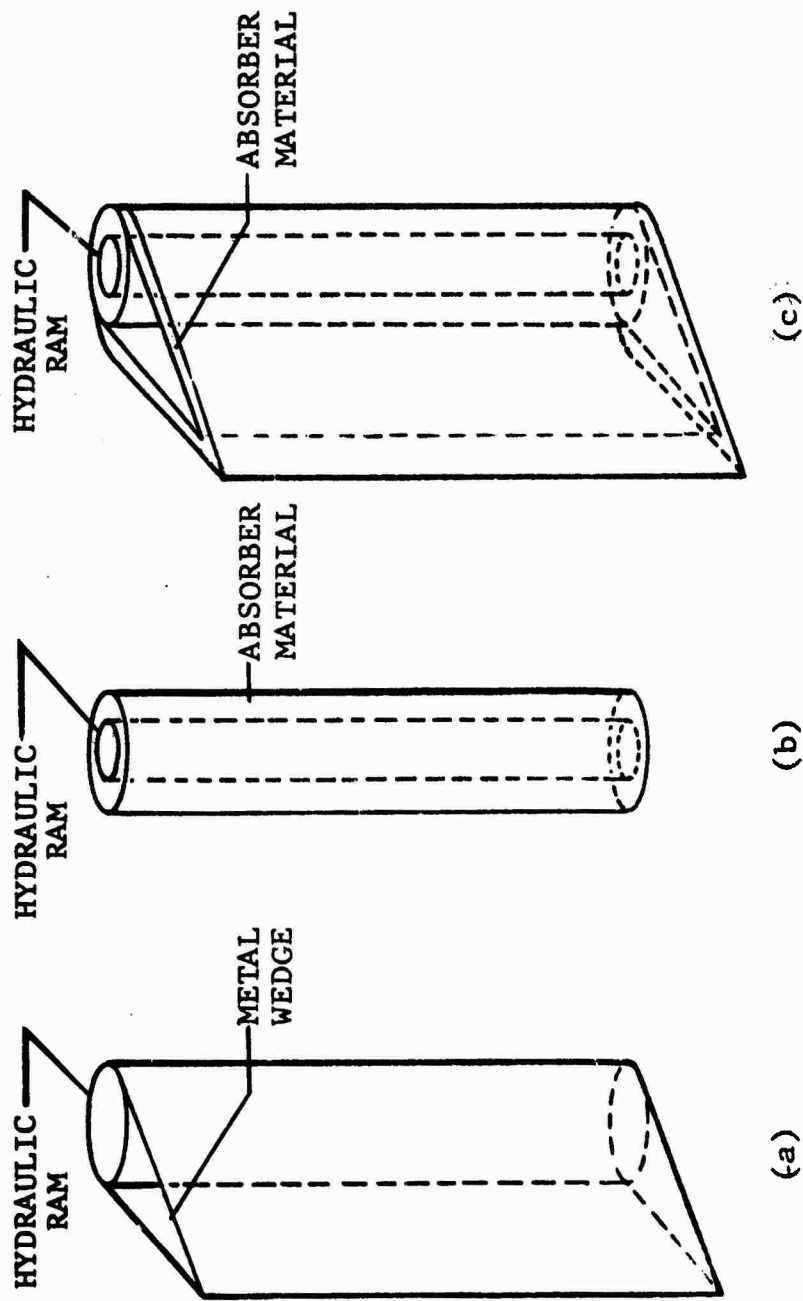
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Fig. 2-1 HYDRAULIC RAM SHIELD CONFIGURATIONS

(a) — HYDRAULIC RAM, METAL WEDGE

(b) — HYDRAULIC RAM, ABSORBER MATERIAL

(c) — HYDRAULIC RAM, ABSORBER MATERIAL

The wedge shield without absorber is representative of a metal shield shaped to reduce the cross section from that of the metal cylinder (configuration a in Figure 2-1). When this type of shield is used, simple analysis (physical optics) indicates the target support return at small bistatic angles can possibly be made 30 to 50 db lower than the return obtained from the metal cylinder.

Shield configuration b, shown in Figure 2-1, is representative of the application of pure absorber techniques. Although the target support return will probably be somewhat larger than that obtained by use of the metal shield, application of the technique shown in configuration b appears to provide the best operational characteristics of all techniques considered. Shield configuration c, shown in Figure 2-1, represents a combination of Shield configurations a and b.

Although the shields shown in Figure 2-1 may not represent the ultimate design obtained by use of the shielding concepts discussed heretofore, they should be sufficient to obtain a relative indication of the technique which can be used to show the least measurement error. Hence if there are no significant differences in the measurement errors encountered in measurement of the basic shields illustrated in Figure 2-1, the recommended shielding techniques for RAT SCAT should be based on considering cost and other operational characteristics of the shield.

The wedge shields may be constructed from two 2/8-inch sheets of 3- by 8-foot plywood. The surface seen by the radar may be covered with aluminum foil to simulate the metal wedge shown as configuration a in Figure 2-1. To obtain the absorber-covered wedge shown in configuration c, the plywood wedge may be covered with absorber. The wedge may be installed on wooden supports which lift the bottom of the wedge approximately 1 foot from the ground. The front support should be adjustable so that the tilt angle of the wedge can be adjusted. The wedge half angle should be that needed to obtain a "cone-sphere" type of matching between the wedge and cylinder boundaries

The metal cylinder covered with absorber can be constructed by using the 16-inch diameter, 10-foot long metal cylinder which has been shipped to RAT SCAT for use in the Range Geometry and Accuracy Investigation Program. The cylinder may be covered with 2- by 2-foot VHP absorber which is available at the Site. Since the circumference of the cylinder is slightly over 4 feet (4.16 feet), 10 pieces of available absorber will cover the cylinder.

The length of the shields was chosen on the basis that the shields would be relatively inexpensive to construct yet of sufficient length to enable conservative estimates of the measurement error which can be expected from longer shields. The only expected difference between the measurement errors obtained by evaluating 10-foot-long shields and that obtained from longer shields is the difference in magnitude of the error E_b. In other words, the coupling errors are assumed to be "localized" within a region extending 10 feet from the target.

TEST PROGRAM FOR EVALUATING SHIELDING TECHNIQUES

An average coupling error $\overline{E}_{TS}$ may be estimated for the three types of shields by using the data obtained when frequency stepping is used. Although frequency stepping is only available at band 7, it seems reasonable to assume the test results will be indicative of test results from similar experiments at bands 4, 5, and 6 because of the large (compared to wavelength) size of shield and targets being considered. A test program is outlined below in steps 1 through 9.

Measurement Procedure

1. Band 7 is set up to operate at a stepped frequency between 8.8 and 9.8 gigacycles.

2. A 36-inch sphere is mounted on a Styrofoam column 10 feet in length and 19 inches in diameter, and the antennas are adjusted for a target height of 10 feet. The phase average return is recorded for horizontal and vertical polarizations for 36-, 24-, and 12-inch spheres, along with the return from a 80-inch, 16-inch diameter cylinder mounted horizontally.

3. A 4-foot saddle is then placed on top of the column, and returns from off-center rotation of three spheres are recorded for both vertical and horizontal polarizations.

4. The Styrofoam column is then replaced by an absorber-covered cylinder. The cylinder is rotated and the return for both polarizations is recorded.

5. Step 3 is then repeated.

6. The 80-inch cylinder is placed on top of the column and the return for both polarizations is recorded. This step is then repeated for the 16-inch cylinder.

7. The absorber is removed from the cylinder support and the conducting wedge is placed in front of the cylinder. The return at zero azimuth angle is recorded for tile angle settings of 0, 5, 10, and 15 degrees for both horizontal and vertical polarizations.

8. The wedge tilt angle is then set at zero, and Steps 3 and 6 are repeated by rotating the 80-inch cylinder saddle and sphere saddle manually. The return of the 80-inch

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cylinder is recorded at azimuth angles of 0 through 90 degrees in 10-degree increments. These steps are then repeated for the 16-inch cylinder. The return from the spheres is recorded from 0 through 100 degrees in 20-degree increments for both horizontal and vertical polarizations.

9. Absorber material is then placed over the conducting wedge, and Steps 7 and 8 are repeated.

By using the test data obtained from the tests outlined above, an average coupling error $\overline{E}_{TS}$ may be computed for each of the three shields. The procedure to be used in computing $\overline{E}_{TS}$ is described in the next paragraph.

Data Analysis

At each azimuth angle, the phase-averaged return obtained in step 2 is denoted by $\overline{\sigma}_t$ for each target. Likewise, the phase-averaged return of the shield is denoted by σ_s. An estimate of E_b, say $\overline{E}_b$ maximum, can then be obtained by using $\overline{\sigma}_t$ and $\overline{\sigma}_s$ in Equation 2. $\overline{\sigma}_m$ is used to denote the phase-averaged return of the target plus shield; the average error $\overline{E}$ can then be estimated as indicated by Equation 1. To obtain $\overline{E}_{TS}$, Equation 11 can be written in the form suggested earlier as

$$\overline{E} = \overline{E}_b + \overline{E}_{TS} \tag{14}$$

in order to indicate that the coupling error term may be biased either positively or negatively. When $\overline{E}$ and $\overline{E}_b$ of Equation 14 are estimated as outlined above, for each of the five targets, $\overline{E}_{ST}$ can then be estimated at each azimuth by averaging $\overline{E}$ and $\overline{E}_b$ relative to the five targets. Plots of $\overline{E}_{TS}$ can then be made as a function of azimuth for use in rating the three shielding methods.

A rating of the three shields, relative to the error E_b, can be made from similar plots. However, since the use of cancellation is contemplated in order to reduce the error E_b, comparison of the shielding techniques should be made relative to $E_b E_c$ rather than E_b. Cancellation is not used in the test program since it is not practical with frequency stepping; nevertheless, the estimate obtained for the average coupling error is indicative of the potential effectiveness of using cancellation. For example, if $\overline{E}_{TS}$ approaches zero in the case of one shield and approaches $-\overline{E}_b$

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in the case of a second, cancellation can probably be used to in-
crease the measurement accuracy in the first case, while the meas-
urement accuracy is likely to be decreased in the second case
(i.e., the first case is indicative of independence between tar-
get and support whereas the second case is indicative of a high
degree of coupling, such as shielding of the target support). The
error E_C will also be influenced by the common stability problems
associated with maintaining correct amplitude and phase of the
cancellation signal $\sqrt{\sigma_s''}\ \epsilon^{i\phi_s''}$. Ideally, the cancellation signal,
$\sqrt{\sigma_s''}\ \epsilon^{i\phi_s''}$, is set equal to the support return without target,
$\sqrt{\sigma_s}\ \epsilon^{i\phi_s}$. However, several factors influence the degree to which
the ideal condition can be approached. The degree of stability re-
quired for useful cancellation is discussed in the RAT SCAT R&D
Report on discrimination techniques. This referenced report
(General Dynamics/Fort Worth Report No. FZE-222-8, dated July 1964)
is documented as an RADC Technical Documentary Report. The perti-
nent stability problems presently under consideration are those
associated with removal and replacement of a shield and its wind
characteristics. In both respects, the absorber shield configura-
tion b illustrated in Figure 2-1 appears to be the best design.

SECTION 3

SUSPENSION TARGET SUPPORT

INVESTIGATION

GENERAL

The investigation of suspension target supports described in this section was conducted by Cornell Aeronautical Laboratory, Inc. under subcontract to GD/FW as part of the RAT SCAT R&D Program. The Cornell material is presented verbatim with the exception of the changes needed to ensure uniformity of format of the overall report. An examination of the results obtained by Cornell has revealed the following in terms of applicability to RAT SCAT:

1. The reduction in the return from a suspension support tower should be significantly less than the 70 db stated herein because the intermediate system will ring for a significant period of time after the onset of a received pulse. A receiver design with a range gated local oscillator could be used to reduce this effect significantly although other features which commonly reduce the theoretical range resolution of pulsed radar may then become significant. This comment can be interpreted in terms of tower and line load requirements, i.e., at the distance between the tower and the target necessary to achieve a high degree of reduction by range gating, the tower load and line size requirements may be excessive.

2. The off-normal relationship between the target rotation axis and the radar boresight can be small, as suggested. The angular error is about 30 and 20 minutes from the local horizontal in the respective cases of Pits II and III. This tilt angle does not exceed that specified for the accuracy of the azimuth angle. It is suggested that this tilt error may be further reduced by utilizing a small cellular plastic column to bear a small percentage of the target load; in addition, this configuration may aid in reducing any tendency of the target to oscillate in the tilt or azimuth planes.

3. A null of suitable extent and depth above the main lobe, in which to place the main suspension line, may be difficult to realize in the case of certain range

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configurations and frequencies. This effect has been observed experimentally and shown theoretically for large D/λ antennas.

4. Operational nulling equipment is not available at the RAT SCAT Site although R&D experimental background subtraction equipment for Band 4 (1 to 2 gigacycles) has been implemented and may be of value in analytically reducing the effective level of portions of the suspension support configuration.

THE CONVENTIONAL SUSPENSION SUPPORT

One of the most difficult problems encountered in the measurement of radar cross section, especially on full-scale ranges, is a suitable means of target support. The desired support scheme has negligible radar cross section compared with the radar cross section of the target, and, in addition, does not appreciably modify target scattering characteristics. The target support problem has generated two solutions in common use on present day ranges: the suspension support and the pedestal or rigid-tower support. While much effort has been expended in minimizing the cross section of certain physically large bodies, comparatively little parallel work is being directed towards attainment of compatible support schemes for these targets. This study is confined to the applicability of "conventional" suspension supports to the RAT SCAT range. However, specific shortcomings of suspension support components are mentioned. **The conventional suspension support is shown in Figure 3-1.**
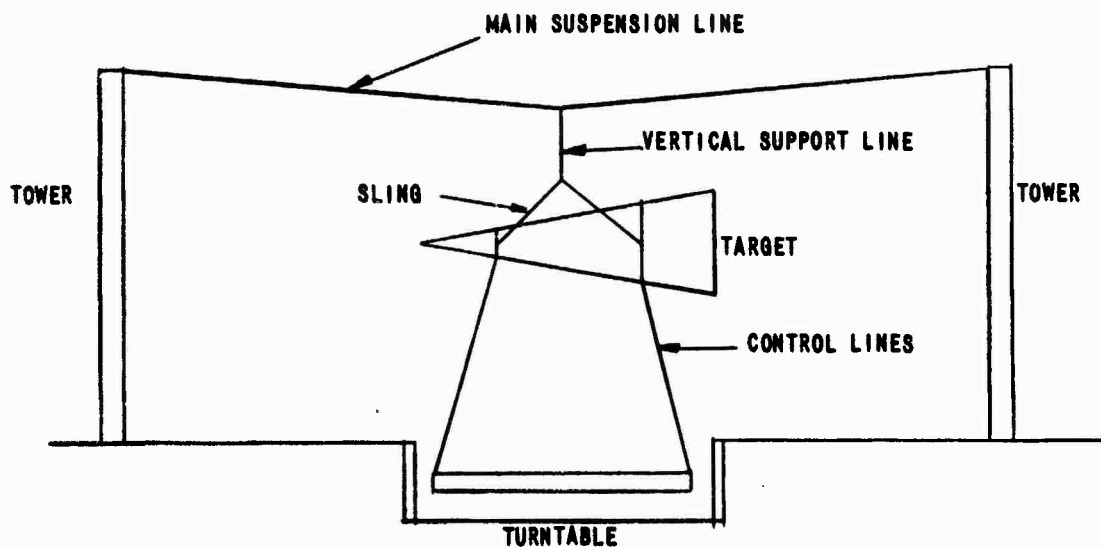

Fig. 3-1 CONVENTIONAL SUSPENSION SUPPORT

Suspension Support - General Considerations

The conventional suspension-type target support illustrated in Figure 3-1 consists of towers (usually two), a main suspension line, a vertical support line, a target sling and target control lines. Cross-section accuracy is maintained by

1. Minimizing tower effects through shaping, absorber materials, location of towers in nulls of the field pattern, and range gating techniques,

2. Reducing main suspension-line interactions by means of aspect control and placement above the main beam.

Three components remain in the main beam of the radar. Because control lines consist of smaller-diameter guy ropes, they do not warrant consideration compared to the vertical support line and target sling, although care in selection of these ropes and their placement may be necessary for targets having very small cross sections. Proper design of the latter two components insures a range capable of high-precision cross section measurements.

The usual suspension line is nylon, a low loss dielectric material chosen for its relatively high tensile strength and relatively low dielectric constant (3). Figure 3-2 relates line breaking strength to line diameter for nylon, steel cable, and a relatively new product, bundled glass fibers.

Although nylon has excellent strength properties (roughly 50% of steel cable), complications arise with the use of nylon through cold creep and stretch. Creep allows a change in target position as a function of time, until the line takes a "set," while stretch, behaving as a spring, allows dynamic errors in target positioning. The spring constant is independent of load, with approximately 100% increase in line length noted before ultimate strength is reached.

Two other materials have recently been introduced to replace nylon as a support line because of superior mechanical properties. One, Dacron, has electrical performance similar to nylon (dielectric constant approximately 3) and almost equal tensile strength. However, maximum elongation before ultimate strength is limited to 5%. The other material, polypropylene, has a lower dielectric constant (2 - 2.5), a slightly lower ultimate strength (about 50% of nylon) and an elongation of about 5% before breaking. For equivalent strengths, polypropylene and nylon have almost identical radar cross sections.
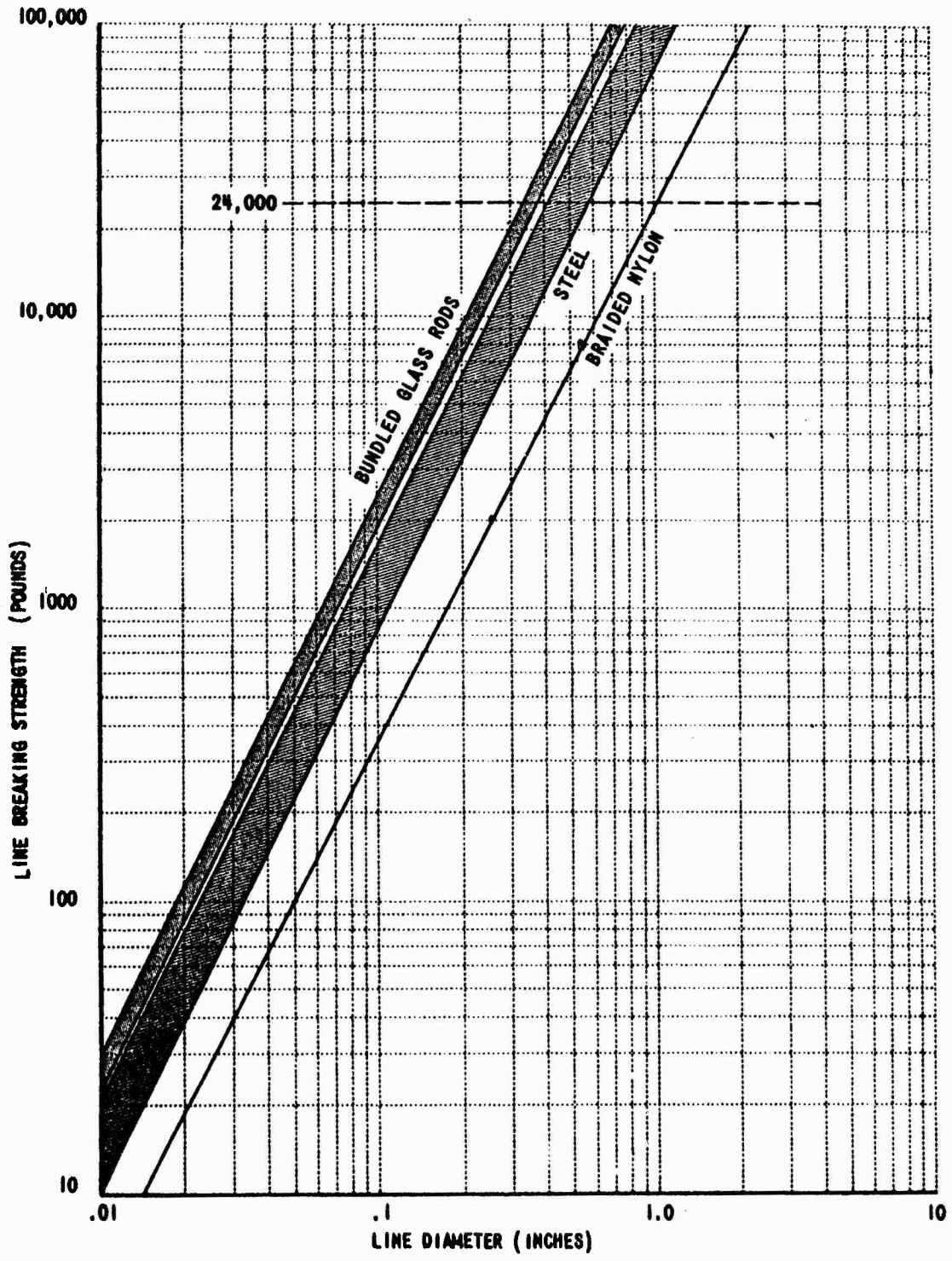
20

Fig. 3-2 SUPPORT LINE BREAKING STRENGTH VS. DIAMETER

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Of the three materials, polypropylene exhibits the finest environmental and aging behavior. While both nylon and Dacron deteriorate under prolonged exposure to ultraviolet, becoming brittle and losing strength, polypropylene remains relatively un- affected. Furthermore, it is less hygroscopic, retaining about 1% moisture after prolonged submersion, compared to the 10 to 15% noted for nylon. The surface of polypropylene is also easier to maintain in terms of dust and grime accumulation; while nylon can retain a coat of foreign matter, it is almost impossible to "stick" a coat of anything to polypropylene.

A recent development that may replace all three plastics as a support line is bundled glass fibers. With a dielectric con- stant of 3.5 and an ultimate strength of roughly 10 times nylon, it is apparent that such lines will have a cross section 10 db less than a nylon line of equivalent strength. Unfortunately, present glass lines are easily damaged, since small nicks and scratches drastically modify ultimate strength, and thus re- quire extreme care in handling. It is expected that they will become practical when suitable protective coverings are developed.

Line fastenings should, in the case of multistrand lines, follow accepted practice of eye-knots or equivalent to retain strength capability. A 50% loss in load capacity can be noted through improper fastening. In those cases where the line must pass over a pulley or roller, the pulley diameter must be as large as possible to relieve localized stress.

RAT SCAT Capabilities and Suspension Supports

RAT SCAT range characteristics pertinent to this discussion include ground-plane operation, use of range-gating techniques, bistatic-cross section measurement capability, and proposed meas- urements at discrete frequencies throughout a broad frequency in- terval. The first two characteristics promise ease of support construction and measurement accuracy; the latter two capabilities can impose definite limitations on the application of suspension supports to RAT SCAT.

Aspects Easing the Suspension Support Problem

Ground-plane-range operation allows the upper null of the first lobe of the field to be about 50 feet about the ground plane. Placement of a sagged main suspension line in this null thus can be accomplished with towers less than 150 feet high.

The use of pulse gating techniques on the RAT SCAT range

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provides additional reduction of tower and main suspension line disturbances. Towers may be located such that direct reflection and bistatic interactions from towers are effectively eliminated. Range gating will also reduce the main suspension line contribution to measurement errors.

Aspects Complicating the Suspension Support Problem

A problem that arises with a suspension support used in conjunction with either an oblique range or a ground plane range is the off-normal relationship between target rotation axis and radar boresight. The "soft" control afforded by lines does not allow effective target rotation about axes other than that parallel to the local "g" vector, so that rotation axis intersects boresight axis at 90° plus boresight elevation angle. Compensation for this condition can be accomplished through data reduction, although the error introduced in most cases is of secondary importance.

The application of suspension supports to cross-section ranges contemplating bistatic measurements can limit the utility of the range. Unrestricted bistatic capability in azimuth requires moveable towers or a portable transmitter-receiver configuration. It is concluded that suspension supports have limited application to such ranges. In the following analyses it is assumed that measurements are performed monostatically or at small bistatic angles (less than 10 degrees).

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SUSPENSION SUPPORT FOR THE LOW-FREQUENCY
RAT SCAT RANGE

Tower Study

Figure 3-3 illustrates the situation to be found on the RAT SCAT range, where a 100μ sec transmitted pulse and a 100μ sec range gate are employed. Area ① of the figure shows the equal range region, where time differentiation between true target and spurious responses cannot be accomplished. Area ② is the region where bistatic interference occurs between the true target and environment, and is again impossible to gate out.

By placing the towers outside areas ① and ② a large measure of tower discrimination is possible. For example, assume a gate discrimination capability of 70 db. Then the signal scattered from the towers will be reduced in the receiver by at least 70 db. Since this signal occurs outside the time interval for reception of target signal, it need only be slightly less than target signal. Thus, for a -60 db/square meter capability, tower cross section, if illuminated by the main beam, could be as much as 10 db/square meter. Quite fortunately, the towers could be located in antenna side lobes and, assuming at least a -30 db two way side lobe level (well designed antennas should yield 60 db), tower cross section can be as high as 40 db/square meter. It thus appears no special tower treatment is required (such as placement of radar absorber) in order to achieve effective direct return reduction.

Bistatic interference effects are not quite as simple to predict analytically, although the 70 db reduction is still achievable through range-gating. In order to obtain firm data on bistatic interaction, a simulation program was conducted on CAL's scale ground plane range, with results shown in Figures 3-4 through 3-7.

Here towers were simulated by two 5/8 copper pipes 10" high, corresponding to 150' towers 12' in diameter at 200 mcs. A one inch flat plate was used as a target since it exhibits a well understood and large bistatic cross section.

Comparisons between free space cross section and those obtained with the pipes in place at 21" and 8" respectively from the target are shown in Figures 3-4 to 3-7. From these data it can be seen that the main bistatic interaction is at the 8" separation (100' full scale) and is approximately 20 db below the peak cross section value. As a consequence, the maximum bistatic

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270' TOWER SEPARATION AT 200 Mc

① ② TARGET ✗ RADAR
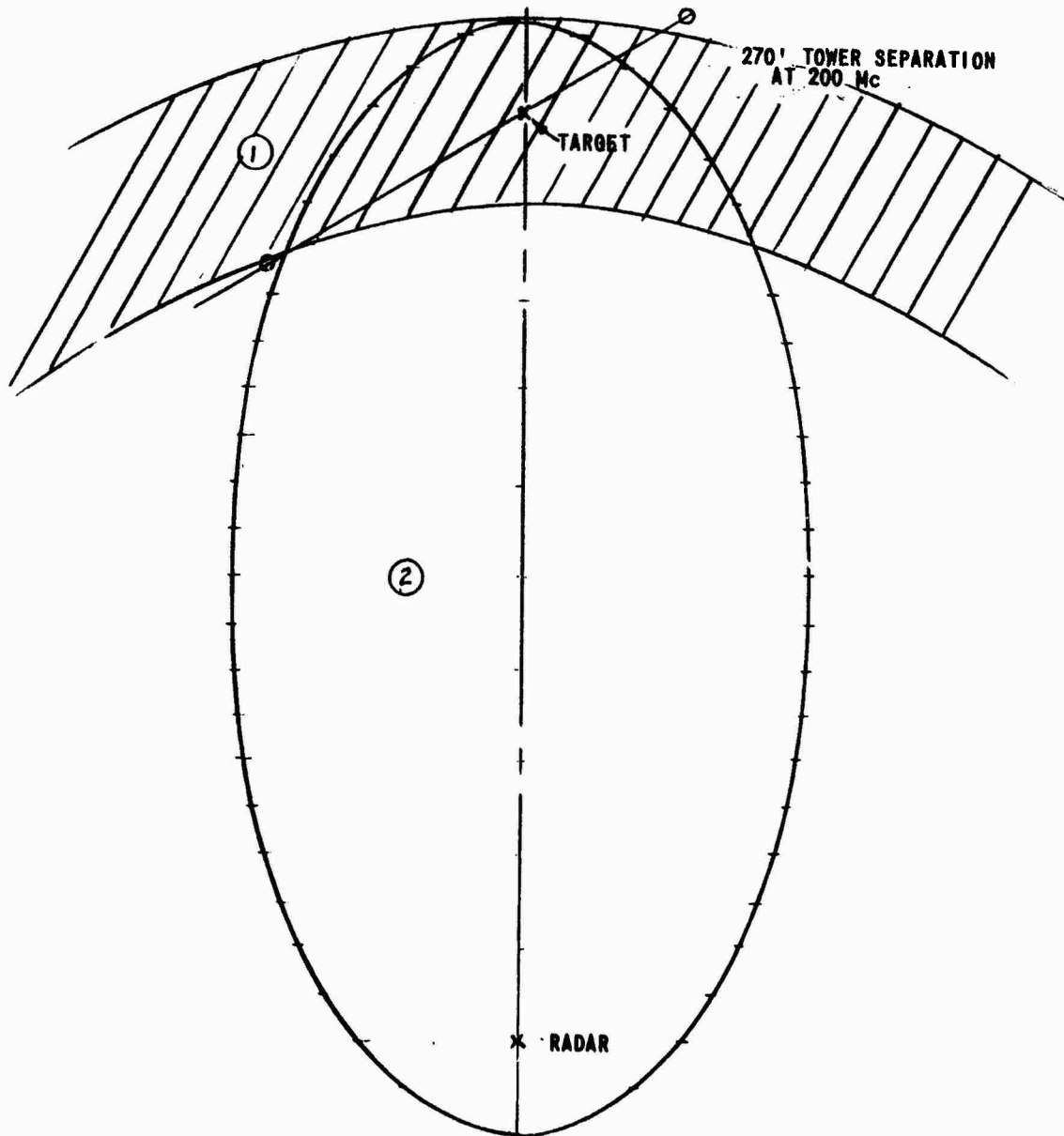
Fig. 3-3 TOWER PLACEMENT BASED ON RANGE GATING CONSIDERATIONS
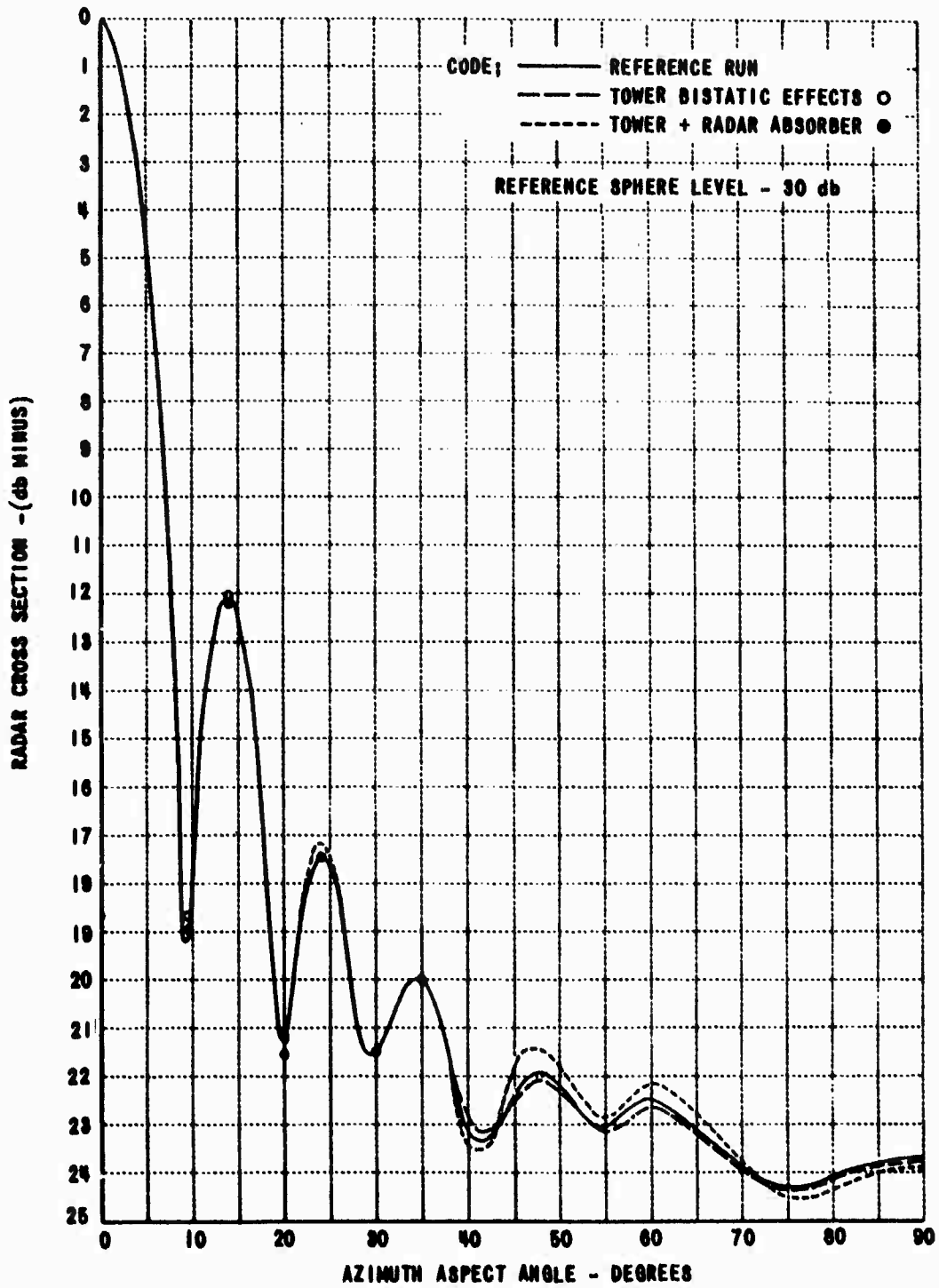
Fig. 3-4   TOWER BISTATIC EFFECTS, VERTICAL POLARIZATION,
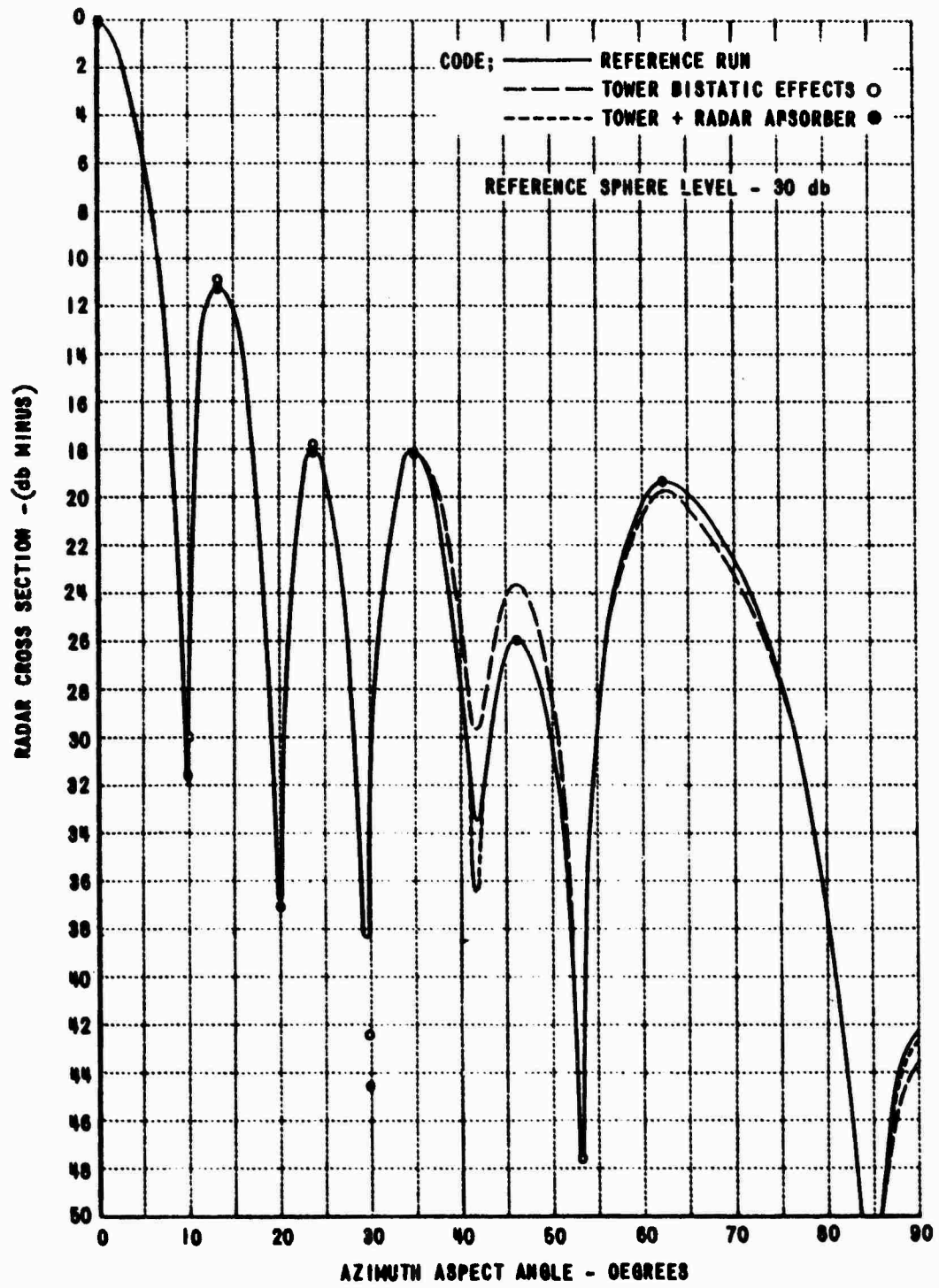21-INCH TOWER - TARGET SEPARATION

Fig. 3-5   TOWER BISTATIC EFFECTS, HORIZONTAL POLARIZATION,
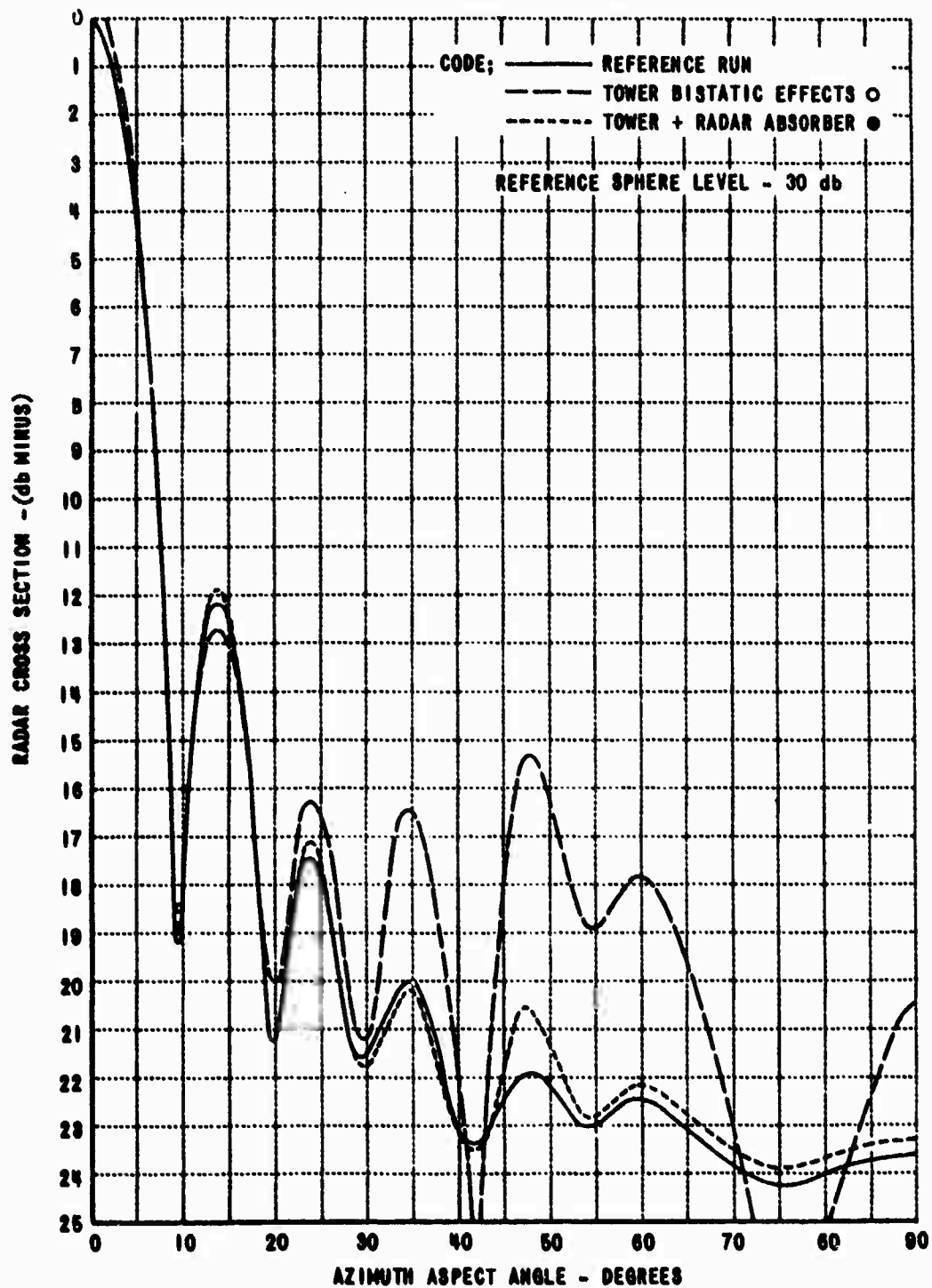21-INCH TOWER - TARGET SEPARATION

Fig. 3-6 TOWER BISTATIC EFFECTS, VERTICAL POLARIZATION,
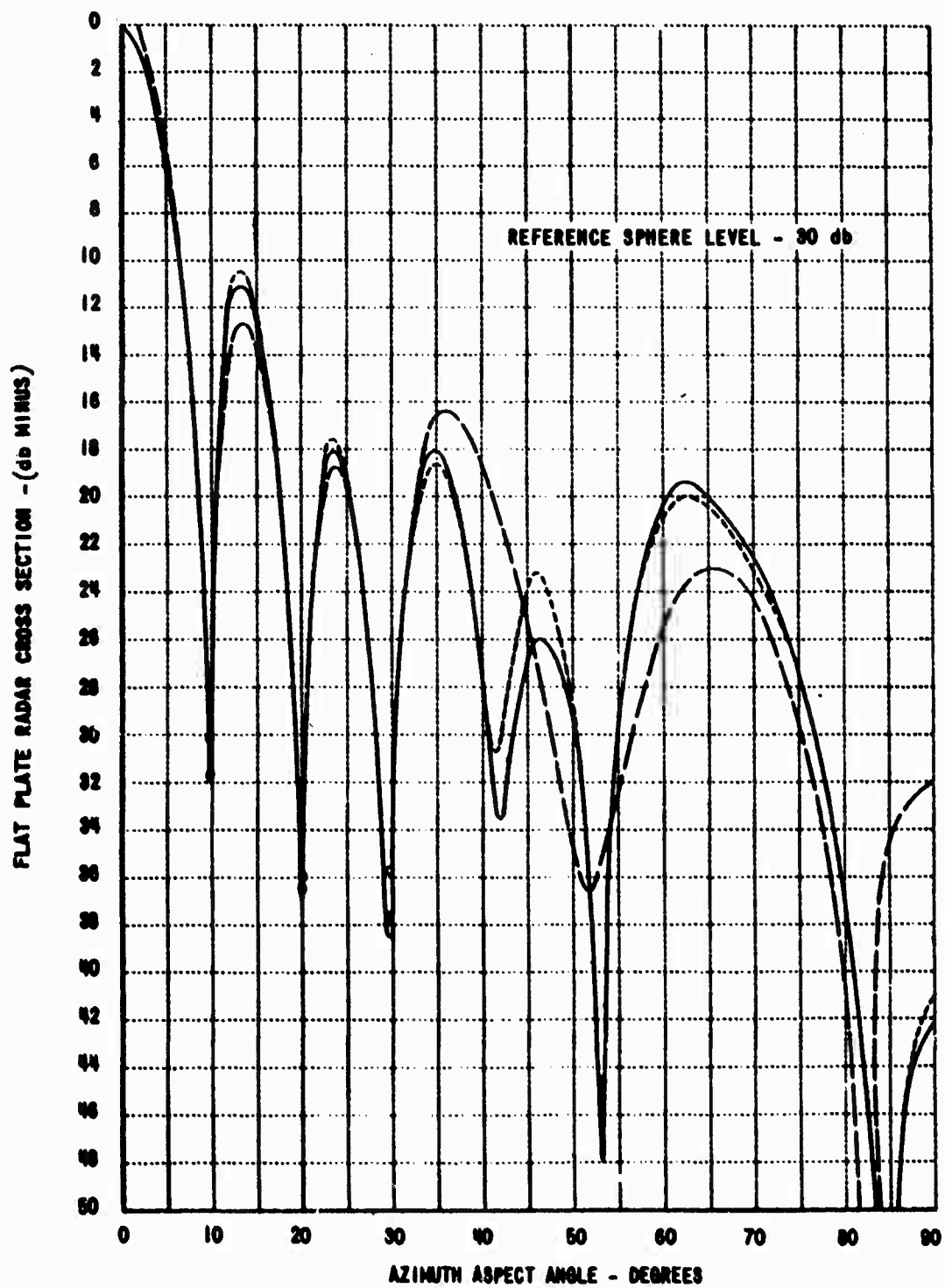8-INCH TOWER - TARGET SEPARATION

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Fig. 3-7 TOWER BISTATIC EFFECTS, HORIZONTAL POLARI-
ZATION, 8-INCH TOWER - TARGET SEPARATION

effect noted on a full scale gated system should be approximately 90 db below the peak monostatic cross section value. Allowing 10 db/square meter for maximum target cross section, it can be seen that bistatic effects should prove negligible.

In order to verify the efficacy of absorbent in reducing bistatic interference, both posts were covered with a 20 db absorber. As expected, the interference was reduced by about 20 db. It thus appears certain that towers can be built that will meet the RAT SCAT requirements.

Main Line Suspension Study

Two procedures exist by which the direct return from a conventional main suspension line can be reduced. First, main line azimuth orientation can be chosen such that a cross section minimum is produced in the back scattered direction. Second, main line height can be chosen such that the line lies essentially in a null of the vertical field pattern.

Two programs were run on the scale ground plane range to evaluate the return from the conventional main line. The first was concerned with azimuth aspect dependence of the line cross section, the second treated the resultant cross section of realistic configurations under minimization conditions.

The cross section of nylon lines at RAT SCAT frequencies was determined through model tests of nylon rods at a frequency of 35 Gc. Such tests are valid provided the lines have essentially the same dielectric constant at the scale frequency as at the full scale frequency. Under this condition, the full scale line diameter is given by:

$$D_o = \frac{\lambda_o}{\lambda_m} D_m \tag{14}$$

where λ_m is the wave length used in measurement, D_m is the actual diameter of line measured, λ_o is full scale wavelength and D_o is full scale line diameter, while full scale cross section is given by:

$$\sigma_o = (\lambda_o^2/\lambda_m^2) \sigma_m \tag{15}$$

where σ_m is measured cross section.

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Preliminary Study of Main Line Radar Cross Section

Initial estimates of main line cross section were obtained from measurements of nylon rods at the two principal polarizations. The rods were located in the main beam of the scale ground plane range (2-1/4 inches above the ground plane), with their longitudinal axes maintained in a horizontal plane. Cross sections were then measured as a function of azimuth aspect angle from the specular or broadside view to an angle 45° off specular.

The rods were 8 feet long with diameters of 0.035, 1/8, 1/4, 1/2, 5/8 and 3/4 inches respectively, and, with the exception of the 0.035 diameter line, constructed of Nylon 101. Line material was nylon of standard formulation for fish line or rope purposes. Because of rod length, support effects were negligible, so that recorded results are a function of aspect angle, rod diameter and antenna pattern only.

Results are shown in Figures 3-8 and 3-9 for the two principal polarizations, horizontal and vertical. Since actual line diameter to be used on the full scale range will depend upon the weight and shape of the vehicle, these data are plotted as a function of λ^2, allowing, with the aid of Figure 3-2, an extrapolation to cross section versus load carrying capacity at a particular frequency. For example, let 24,000 pounds be required of the line. From Figure 3-2, a one-inch line is necessary, hence data taken on the 1/4 inch rod corresponds, from equation 14, to a frequency 1/4 of the measurement frequency, or approximately 9 Gc. From Figures 3-8 and 3-9, the cross section is given for specular return, as 17 db and 19 db above λ^2 respectively, or 0.05 square meters and 0.08 square meter full scale, since λ^2 is approximately 10^{-3} square meter.

From Figures 3-8 and 3-9, it can be seen that at least a 20 db reduction from specular cross section is afforded by orienting the line at 45 degrees from the radar. Further reductions of 24 and 18 db for horizontal and vertical polarizations respectively are possible by location of the line in the first minimum of the vertical field pattern (see Figure A-2). The corresponding line cross sections, full scale, for a one-inch line are given in Table 1.

At frequencies below 1,200 Mc, line cross section can be assumed not to exceed the above figure, with a high probability of reduction below 1,200 Mc.
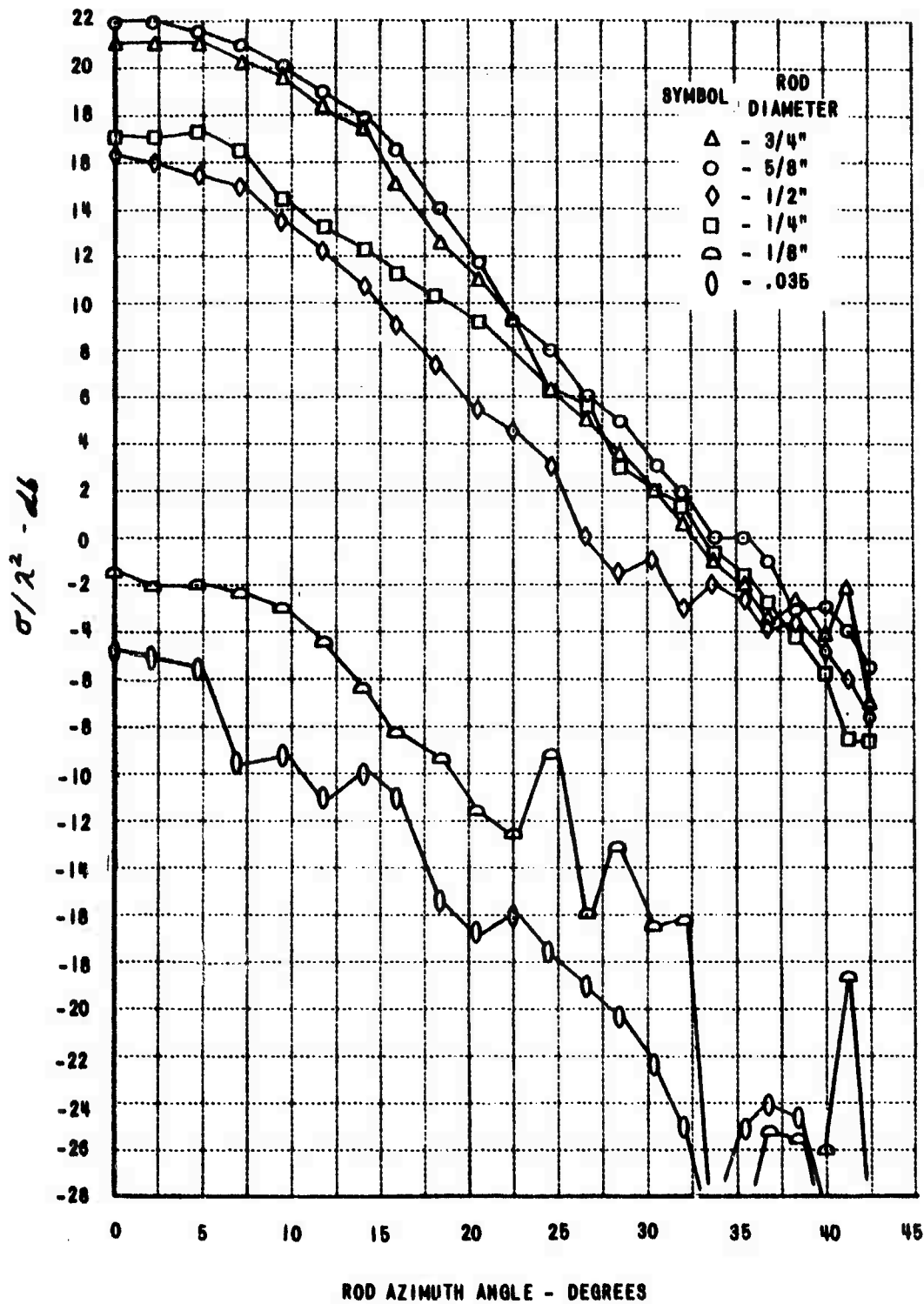
31

Fig. 3-8 RADAR CROSS SECTION OF HORIZONTAL RODS,
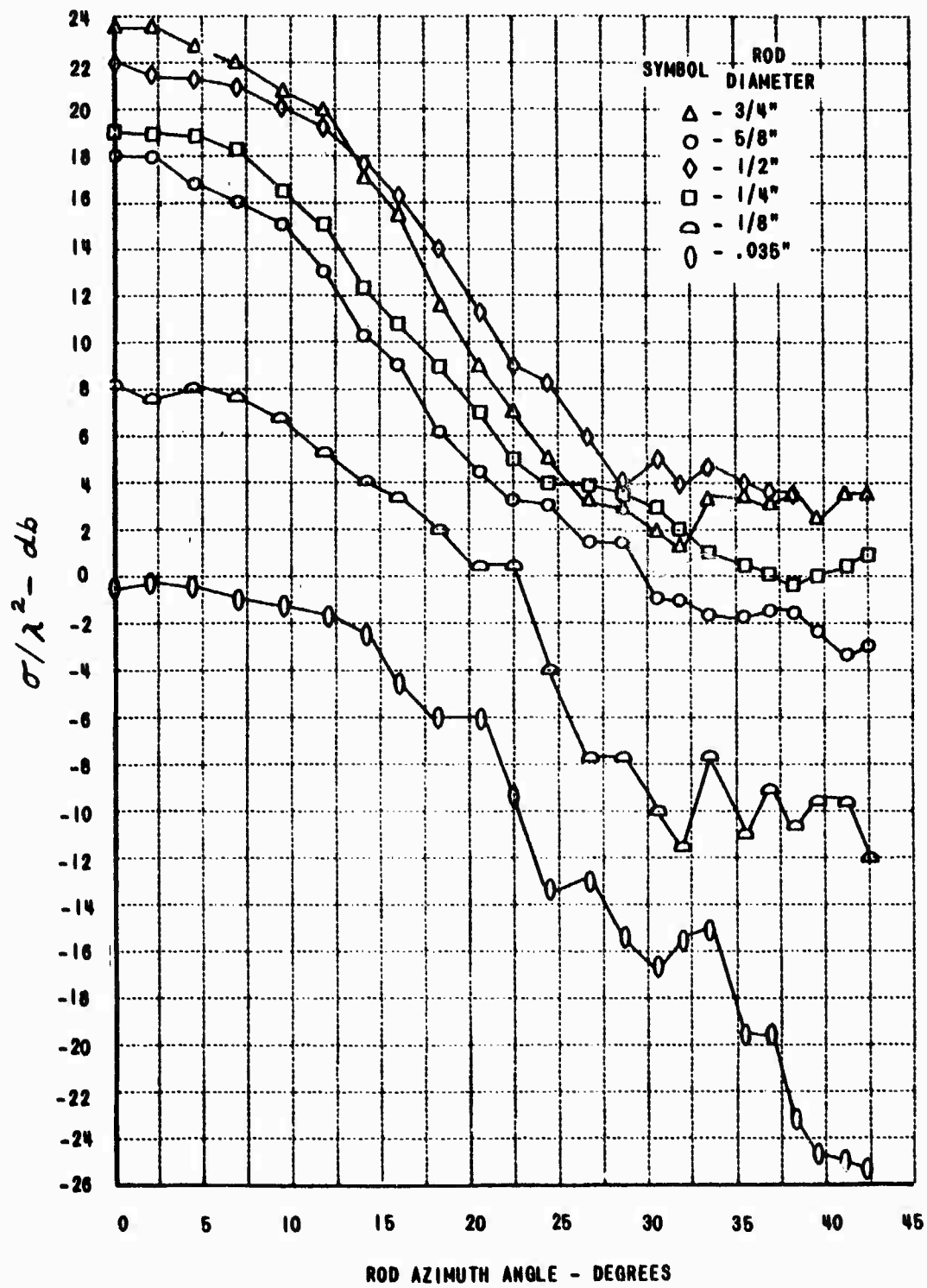   VERTICAL POLARIZATION

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Fig. 3-9 RADAR CROSS SECTION OF HORIZONTAL RODS, HORIZONTAL POLARIZATION

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Table 1 RADAR CROSS SECTION OF 1 INCH DIAMETER NYLON LINE

Horizontal Polarization

Frequency (Mc)	Cross Section, Sq. Meter
1,200	7.5×10^{-7}
4,500	1.1×10^{-6}
9,000	4.75×10^{-6}

Vertical Polarization

Frequency (Mc)	Cross Section, Sq. Meter
1,200	1.38×10^{-6}
4,500	6.95×10^{-7}
9,000	2.52×10^{-6}

Radar Cross Section of Main Suspension Line

In practice, the main suspension line does not remain horizontal, but sags in the V shaped manner shown in Figure 3-10. Two models of such "sagged" lines were measured in order to obtain a better simulation of full scale conditions, one, model R, with a 45 degree configuration, the other, model T, with a 22-1/2-degree configuration. Note that the load capability is given as
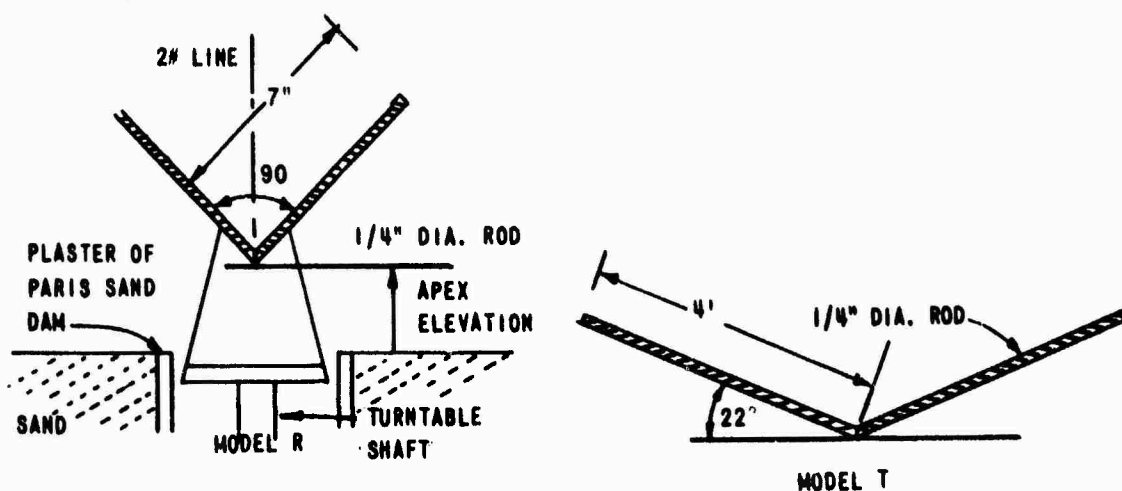
Fig. 3-10 MAIN SUSPENSION LINE MODELS

$$W = 2W_m \sin \theta_o \qquad \text{(16)}$$

where

W = load
W_m = line load
θ = sag angle

so that approximately a 2:1 load carrying capacity exists between the two.

Initial investigations were carried out with model R for apex elevations of 2-1/4, 3-1/2, 4-1/4, 5-1/4, 6-1/4, 7-1/4 and 9-1/4 inches above the ground plane, and for aspect angles from 0 to 45 degrees. The measurements were made with the following combinations of transmitter and receiver:

1. Vertical-vertical
2. Horizontal-horizontal
3. Vertical-horizontal
4. Horizontal-vertical
5. $\pi/4 - \pi/4$

For all polarization combinations, minima occur at the 45 degree aspect region, with additional minima at 4-1/4 and 9-1/4 inch apex elevation. At 4-1/4 inches (corresponding to RAT SCAT heights) and a 45 degree aspect, the return for all polarization combinations is at least 30 db below λ^2, for a cross section of 10^{-6} square meter at X band. With a full scale line diameter of 1 inch, load capacity is thus 33,600 pounds. Reducing line diameter to 1/2 inch full scale (load reduction to 9,000 pounds) reduces X band cross section to 1.6×10^{-7} square meter.

Of the polarizations examined, the most critical in terms of aspect dependence was the $\pi/4 - \pi/4$ combination. Here a one degree spread was the maximum aspect variation permissible to maintain the deep minima; in comparison, all other polarizations permitted at least a 2-degree deviation.

Since the critical polarization combination was revealed to be the $\pi/4 - \pi/4$ pair, tests on the model T configurations were restricted to this pair. Again the model apex was the elevation reference, and again cross section minima were noted at 4, 9 and 18 inch heights. However, angular minima were broadened, with such minima noted between 22 and 27 degrees and again between 37 and 45 degrees. Both these minima, at the 4 inch apex elevation were at least 39 db below λ^2, for an X band cross section of approximately 10^{-7} square meter. Load capacity is approximately 18,000 pounds.

Although these figures appear pessimistic, at the lower

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frequencies (below 1.2 Gc), the cross section of 1 inch nylon line will in all probability be somewhat smaller. Further, if reduction techniques on the line itself are allowed, then a figure of approximately 10^{-9} square meter at frequencies below 1.2 Gc seem possible.

Vertical Suspension Line Study

The direct return from the vertical support line is discussed here. Bistatic interaction occurs only if scattering from the vertical line illuminates the target below: such end fire scattering is not anticipated.

Reduction in the direct return from the vertical suspension line cannot be effected conventionally: range gating offers no reduction; aspect control is not available; and field minimums cannot be employed to produce a small cross section. Application of radar absorber and equipment nulling techniques are not expected to provide more than 20 db reduction in the return from the vertical line. These unfavorable conditions suggested a worst-case investigation limited to vertical polarization measurements since the vertical-line return will be diminished at other polarizations. Using the scale ground plane range at CAL, cross section measurement was made on nylon rods and lines having diameters of 0.0058, 0.0075, 0.0108, 0.0135, 0.017, 0.020, 0.031, 0.125, 0.250, 0.375, 0.5, 0.63 and 0.75 inches. (It was important to include small-diameter lines in this study to allow scaling to realistic line sizes, i.e., the 0.0058-inch-diameter line scales to about 1-inch-diameter line at a full scale frequency of 200 Mc.)

It has already been determined that an apex elevation between 4 and 5 inches above the scale ground plane allows minimization of the direct return from the main suspension line. Target elevation of 2-1/4 inches above the ground plane results in a vertical line length of about 2-1/2 inches (the corresponding full scale length at 200 Mc is 37 feet). Before measurements on realistic rod lengths were made, the cross sections on long rods were obtained. Their length was such that all rods, when placed vertically inside the turntable well, extended above the ground-plane field pattern. Results of the vertical polarization measurements are shown in Figure 3-11. Cross section data has been normalized by the square of the operating wavelength to facilitate eventual scaling of the data. It is seen that the smallest diameter line (0.0058 inches) provides a cross section less than 10^{-8} square meter at 35 Gc. A factor of 100 increase in line diameter results in about 70 db enhancement of vertical line cross section.
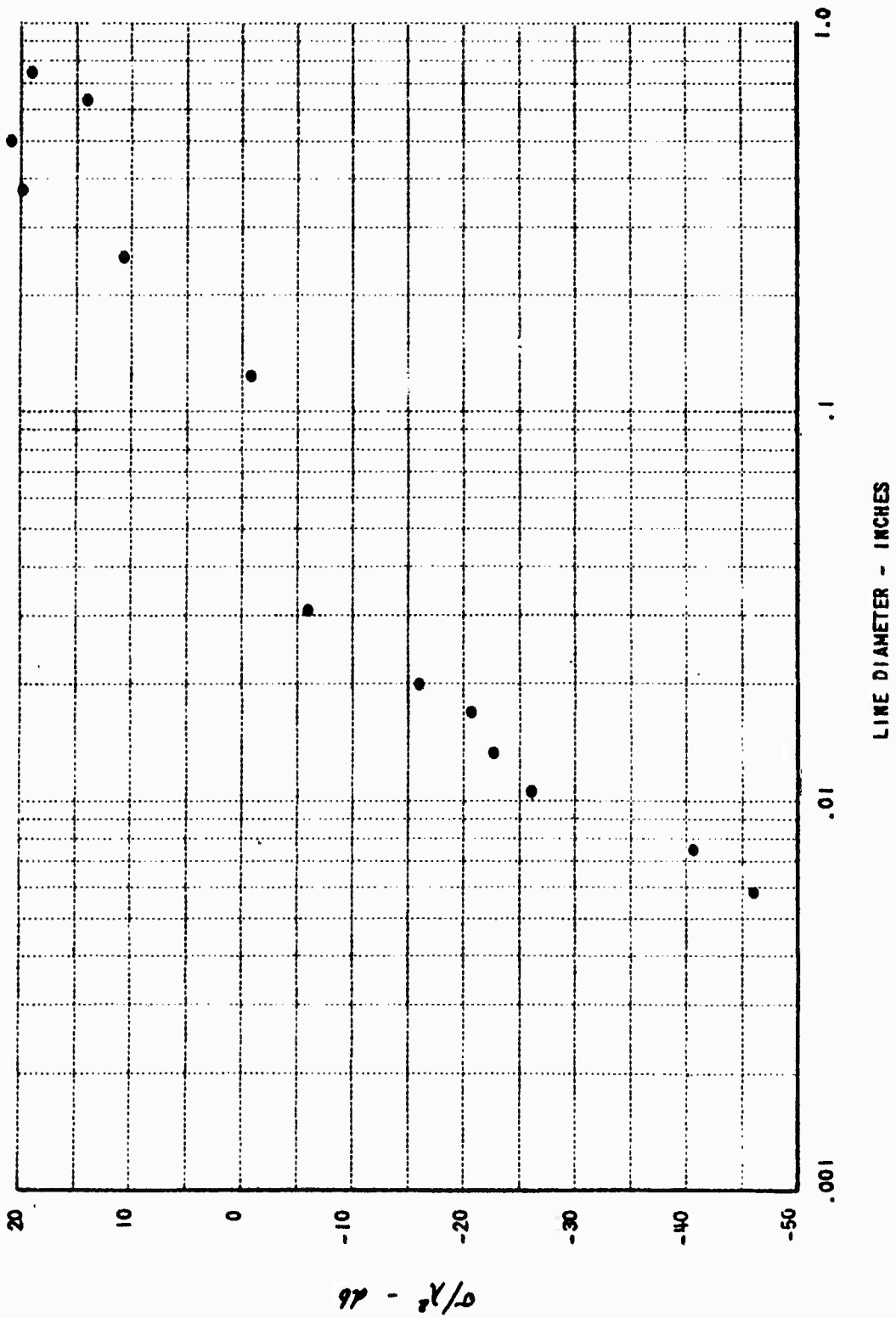
36

Fig. 3-11 VERTICAL SUPPORT LINE STUDY - LONG LINES VERTICAL POLARIZATION DATA

Next measurements were made on rods 2-1/2 inches long, a realistic scale length based upon main-line height studies and the optimum target measurement height. The lower end of the short rods were placed 2-1/4 inches above the ground plane, the upper end extending into the region of the null above the first lobe. Normalized data are shown in Figure 3-12. Comparison with Figure 3-11 indicates little dependence of cross section on rod length for small-diameter lines. The larger diameter rods exhibit a maximum cross section reduction of 15 db due to shortening. Again, only the smaller diameter lines have cross section less than 10^{-8} square meter at the measurement frequency.

Figure 3-13 interprets the data on short rods in terms of target support. Contours of constant vertical line radar cross section are plotted as a function of line breaking strength and radar operating frequency. The solid curves join data points obtained from the measurement program. (Data on the two largest diameter rods are not included in this figure; they pertain to support capabilities beyond those of present interest.) The dotted curves indicate vertical line performance based upon previous studies performed at CAL.

Allowing a 20-db reduction in vertical line radar cross section through application of radar absorber and equipment nulling technique, it is seen that lines having a breaking strength of $\geq$ 2000 pounds have a cross section less than 10^{-7} square meter at frequencies up to 1 Gc. Use of a non-conventional line composed of bundled glass fibres would result in equivalent radar performance with an attendant increase in line breaking strength up to 16,000 pounds. The above vertical lines provide target cross sections accurate to 3 db at a level of 10^{-6} square meter.

It is concluded that conventional vertical lines are marginally acceptable for target supports primarily at the low end of the frequency spectrum considered. This situation is not appreciably sensitive to substitution of alternative configurations for the vertical line component, i.e., use of an inverted v-shaped line to join the target sling to the main suspension line. While this approach offers a chance to match the v-shaped line cross section to that of the target as a function of aspect angle, the simple equipment nulling procedure is defeated. Investigation of non-conventional line materials is recommended to ease the present difficulty.

Target Sling Study

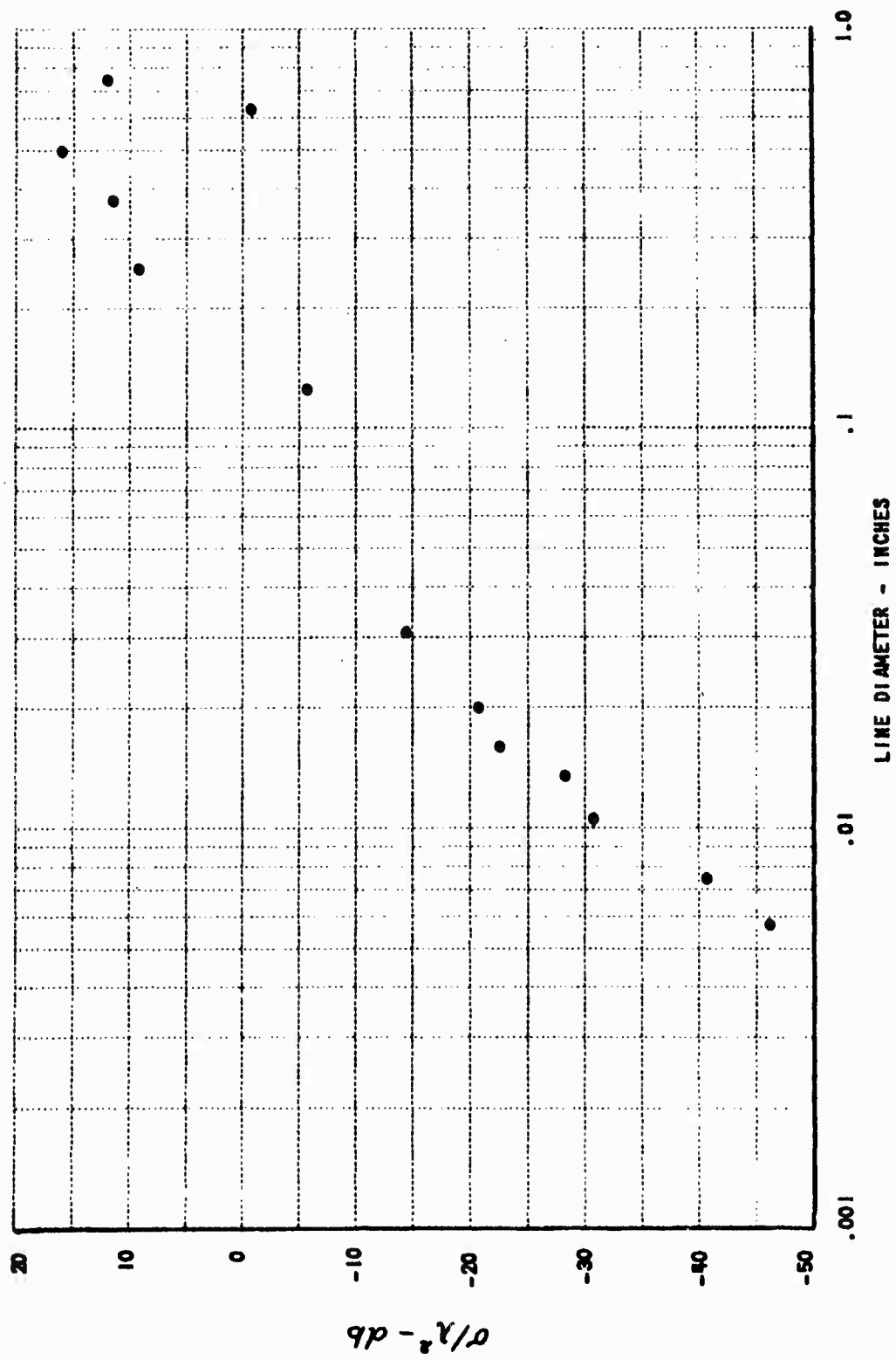Probably the most critical component of the suspension support

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Fig. 3-12   VERTICAL SUPPORT LINE STUDY - 2½ INCH LINE LENGTH
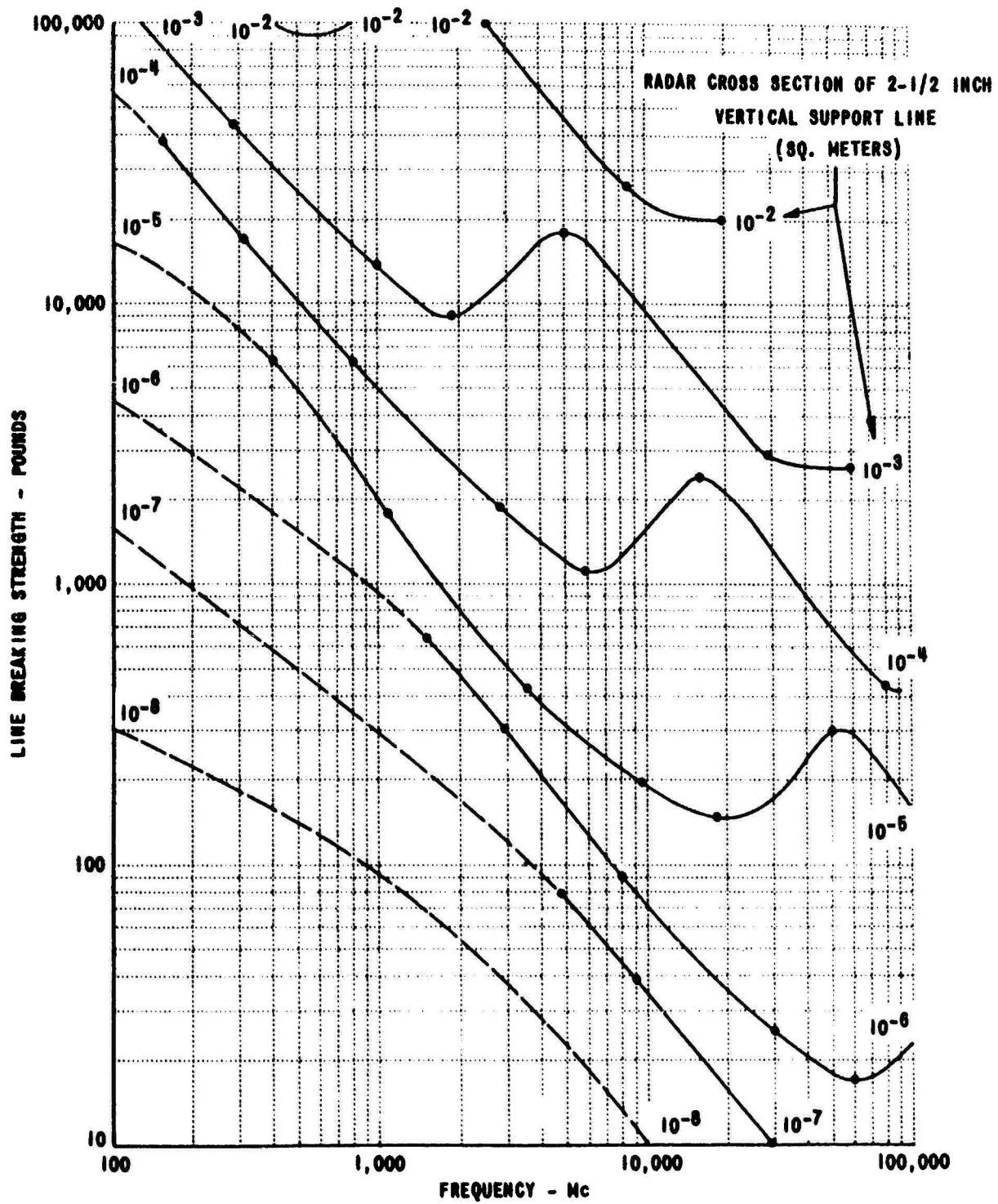VERTICAL POLARIZATION DATA

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Fig. 3-13   VERTICAL LINE STUDY (Contours of Constant Radar
             Cross Section)

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is the target sling. The presence of sling lines in the form of loops, harness, etc., about a target modifies the surface currents on the target, and, in some cases, produces sufficient perturbation in current distribution to cause a gross error in measured cross section. Furthermore, the proximity of the sling downlines introduces some bistatic effects, and, more seriously, introduces an aspect sensitive direct return which can be unacceptable in terms of the target return at the same aspect. Since cross section inaccuracies caused by downline direct return and bistatic interaction are impossible to separate, they are treated as a single entity in this report.

Because sling presence will be most apparent when target return is minimal, a low cross-section body was fabricated especially for the target sling study. An additional design consideration was precise alignment of the target: estimation of cross section inaccuracies as a function of sling diameter required alignment repeatability in pitch to within one degree. Figure 3-14 depicts the cone-cylinder-cone model employed during the sling investigation. Model length **is scaled to about 28 feet at** 200 Mc. Such size, along with pointed extremities, was necessary in easing the alignment procedure. The conventional sling configuration is illustrated in the same figure. A single loop of nylon line supported the model in the manner shown above. The measurement program involved slings of nylon line 0.0058, 0.0075, 0.0108 and 0.017 inches in diameter. Cross section measurements on the cone-cylinder-cone model supported by a 0.003 inch diameter nylon sling serve as a reference cross section.
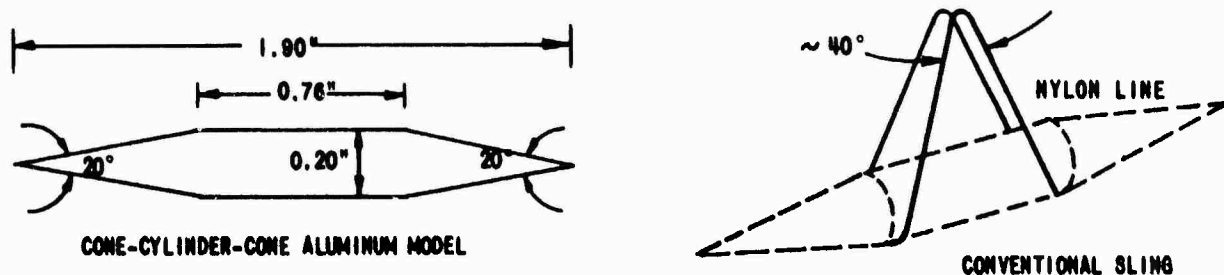

Fig. 3-14 MODELS USED IN TARGET SLING STUDY

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A typical reference run is shown in Figure 3-15. The vertical polarization cross section lies below the room null ($\sim 2 \times 10^{-9}$ square meter at Ka band) in the aspect regions near nose-on. At broadside the cross section compares to that of the reference sphere (6×10^{-5} square meter).

Target cross sections at vertical, horizontal, $\pi/4$, crossed-vertical and crossed-$\pi/4$ linear polarizations were obtained with slings of various line diameters providing support. These data were compared to the reference runs and whenever a 3 db variation in the two cross sections was observed, the aspect angle and cross section level was noted. Results are given in Figure 3-16.

The maximum variation in cross section for crossed vertical, and crossed-$\pi/4$ polarization, occurred in the aspect interval between 25 and 30 degrees. This contribution to measurement error was probably caused by the direct return from the target sling. In contrast horizontal and $\pi/4$ polarization cross sections produced a maximum error near nose-on. In this case the contribution to measurement error probably was associated with the bistatic interaction between the sling and the target.

Figure 3-16 indicates the cross section level at which 3 db measurement errors occur as a function of actual sling line diameter. Of all the polarization combinations investigated, the principal polarization measurements appear most sensitive to sling effects. Results show that a 3 db measurement accuracy is achieved at cross section levels 30 db below λ^2 for sling lines 0.0058 inches or less in diameter or an equivalent one inch diameter line at 200 Mc.

The resultant sling support capability can be approximated as follows. Sling lines with a breaking strength of x pounds will support a target weighing 4x pounds because the conventional sling loops the target twice. This weight capability is reduced by the factor sin θ, where θ is the sag angle of the sling line, about 50 degrees in this study. Thus, the sling breaking strength is approximately three times the line breaking strength.

Figure 3-17 relates full-scale sling breaking strength to radar operating frequency in terms of cross section levels at which a 3 db measurement error occurs. Data were obtained experimentally on the scale range, then converted to full scale. Worst case sling data were used (vertical polarization cross section results for the 0.0058, 0.0075, and 0.017 inch diameter lines, horizontal polarization cross section results for the 0.0108 inch diameter line), along with the approximate derivation of sling
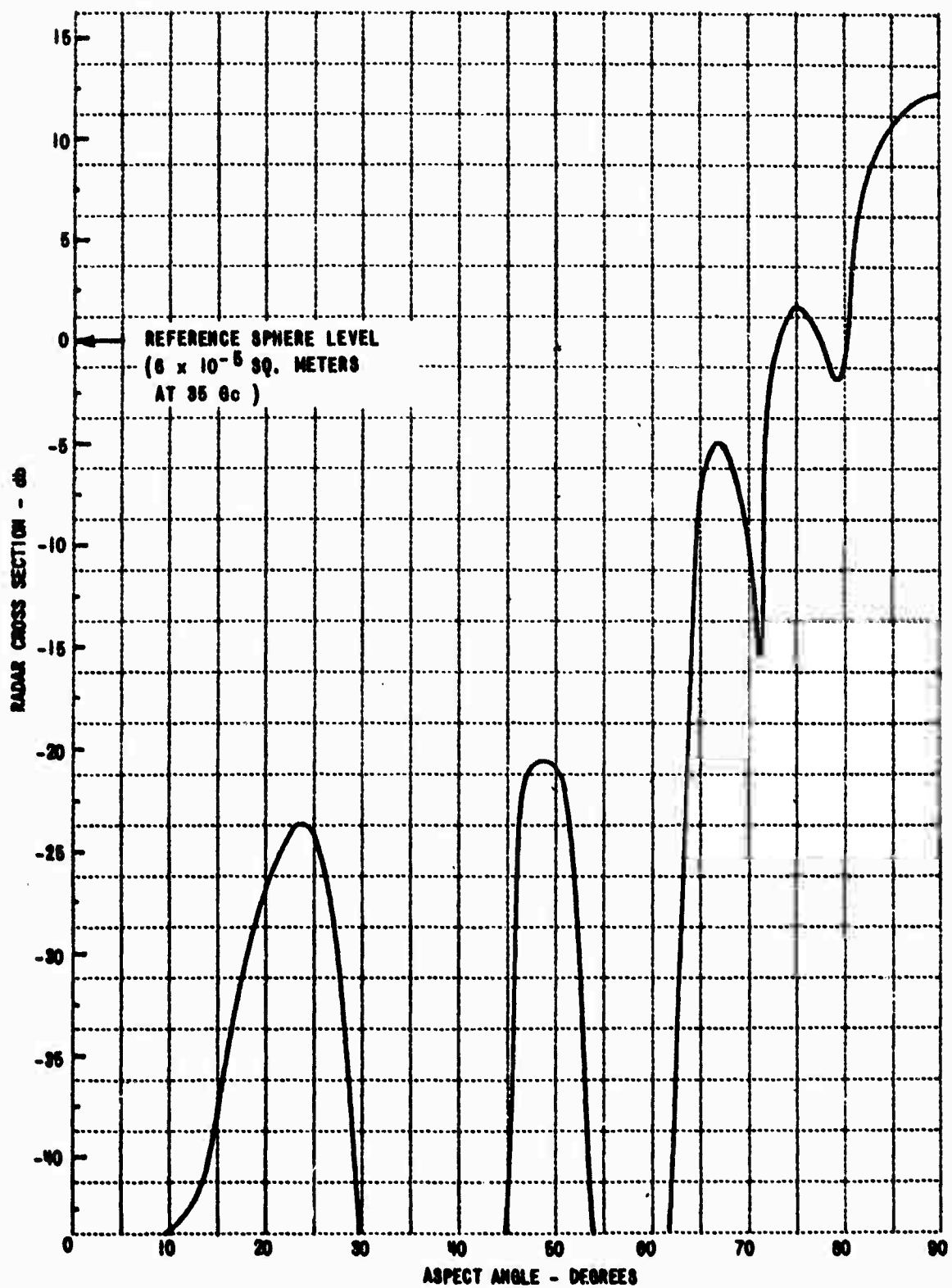
Fig. 3-15 RADAR CROSS SECTION OF CONE-CYLINDER - CONE MODEL
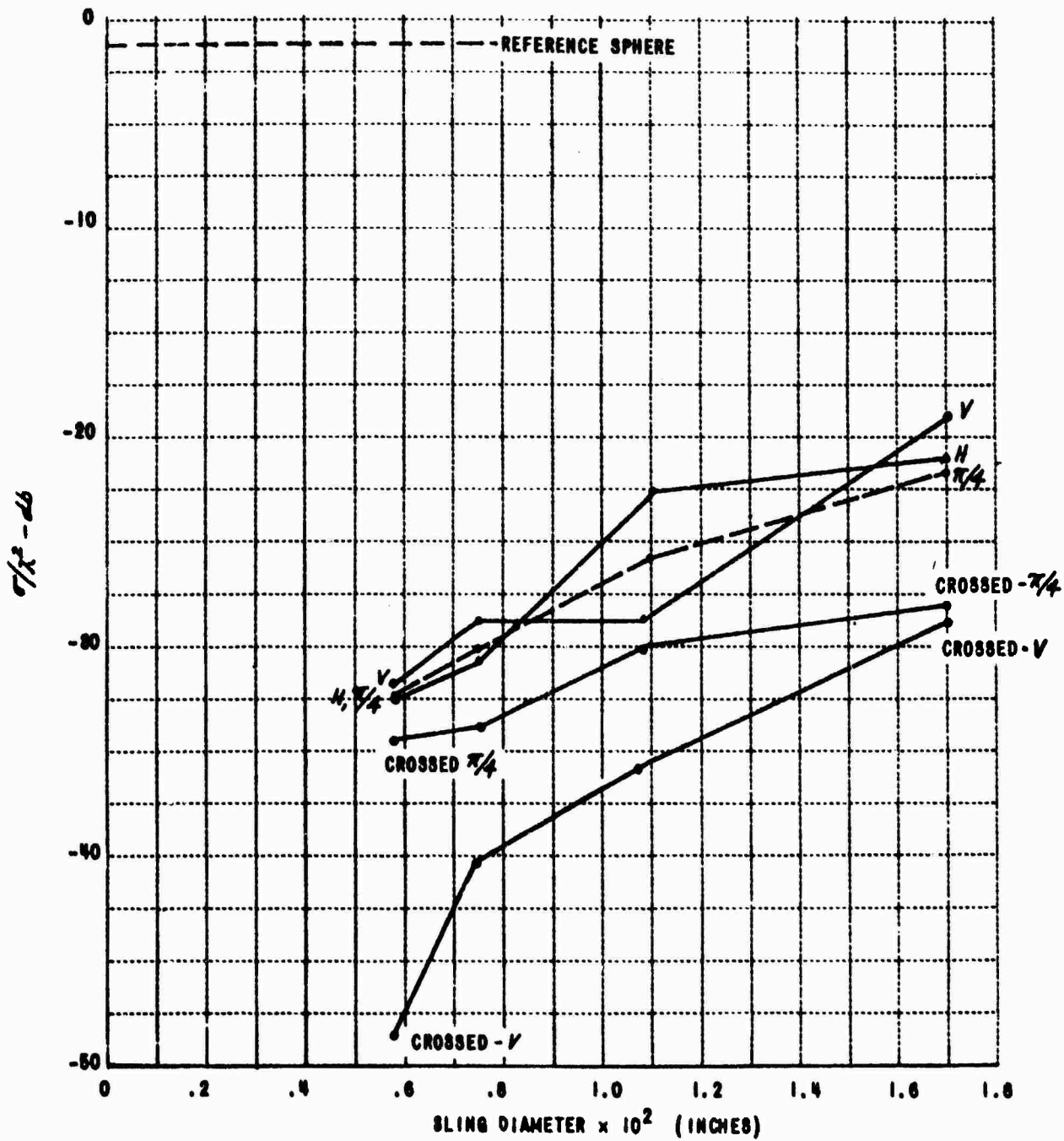VERTICAL POLARIZATION
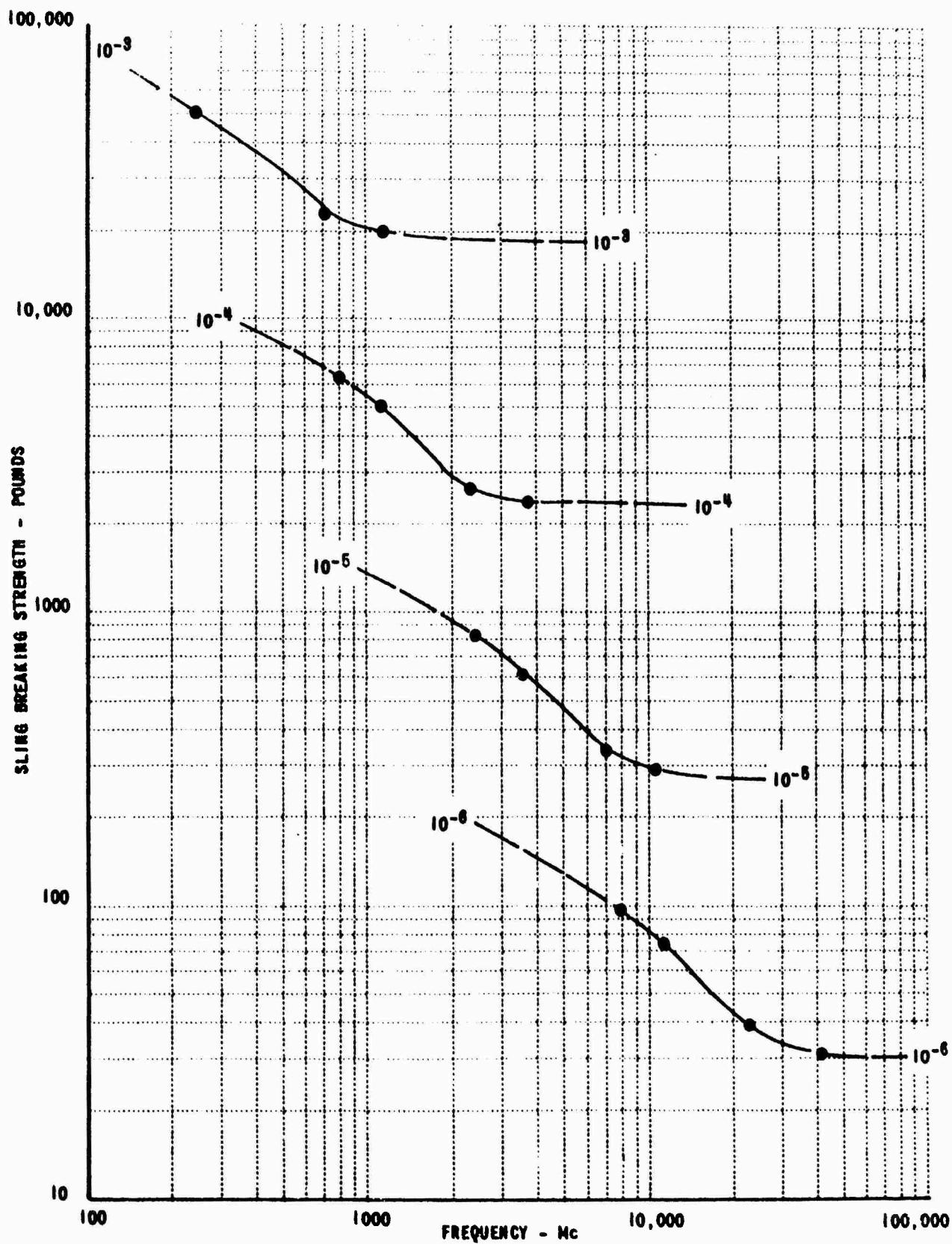
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Fig. 3-16   TARGET SLING STUDY

Fig. 3-17 TARGET SLING STUDY

strength. Conventional slings having a breaking strength of at least 1000 pounds allow cross section measurements accurate to within 3 db at levels as low as 10^{-5} square meter for radar operating frequencies less than 2 Gc. Greater accuracy is anticipated at lower frequencies.

A study of non-conventional techniques applied to the specific task of target support by slings is recommended. Such an investigation would entail more than a search for lines of greater tensile strength (i.e., use of bundled glass fibres increases sling strength from 1000 to 8000 pounds in the foregoing example). Efforts to obtain a better match between the electrical constants of the sling material and those of free space should prove rewarding; in this manner the effects of bistatic interactions can be reduced. Assuming this to be the case, direct returns from the sling can be minimized by distributing the target load over many small-diameter loops instead of two large-diameter loops.

<div align="center">Target Control Line Study</div>

Small diameter lines are used to transfer turntable motion to the target. It is usual to employ a scheme similar to that shown in Figure 3-18.
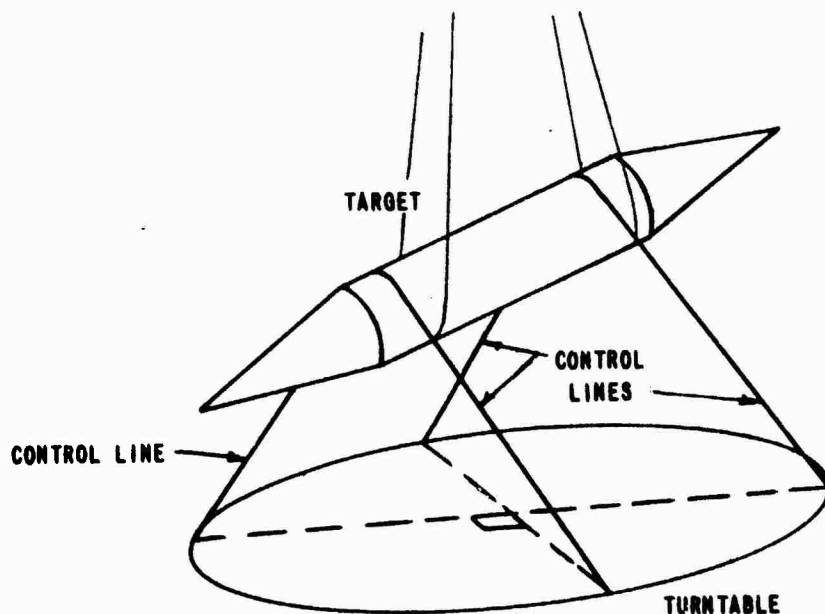

Fig. 3-18 CONTROL LINE CONFIGURATION

Control line strength is determined by the required tracking accuracy between turntable and target rotation. Although tracking oscillations must be minimized, a constant lag between target and turntable motions is acceptable. The required tracking accuracy is related to the variation in target cross section with azimuth rotation angle. Scattering patterns of elongated targets are typified by an average of $2 L/\lambda$ peaks per 90 degrees rotation where L is the length of the target. Because cross-section peaks are not uniformly spaced, two peaks may be less than $45 L/\lambda$ degrees apart. The previous considerations indicate that a nominal 10 foot target measured at L-band will produce about a 2-degree aspect separation between peaks and nulls in dense peak-null regions. This situation calls for target control to 0.5 degree.

The tendencies of nylon lines to stretch under tensile loads may be a critical factor in the accurate transfer of turntable rotation to a full-scale target weighing several tons. This problem becomes especially serious when the target is exposed to winds; aerodynamic forces tend to align the target with the wind direction causing target oscillations. It is necessary to provide sufficient strength to limit undesirable motion if wind gusts occur. Control lines fabricated of some stretch-resistant material, i.e., bundled glass fibers, would rectify this situation.

CONCLUSIONS

Both analytic and experimental data contained in this report support the following conclusions.

1. The towers required for a conventional suspension support can be located so as to introduce negligible effect in radar cross section measurement accuracy (less than 10^{-8} square meter cross section). A tentative design indicates a tower height of 150 feet with a separation of 270 feet is satisfactory with no application of absorber required. The design is based on a 100 nanosecond radar range gate and 15 db antenna side lobes.

2. The main line suspension between towers, using a dielectric material, can be so located that its cross section will meet RAT SCAT specifications on the low frequency complex.

3. The vertical support line, made of nylon or other conventional synthetic fiber (dacron or polypropylene) cannot meet RAT SCAT specifications. Allowing a 20 db reduction in vertical line radar cross section through application of radar absorber and equipment nulling techniques, conventional lines having a breaking strength of 2000 pounds provide cross sections accurate to 3 db at a level of 10^{-6} square meter at frequencies up to 1 Gc.

4. The limiting feature of the suspension support is the target sling. Conventional slings of nylon, dacron, or polypropylene have effective cross sections of 10^{-5} square meter and breaking strength of 1000 pounds in the frequency regime below 2 Gc.

5. The limiting feature of the overall ground plane range is the target control pit area for frequencies in the region of 200 Mc. At this frequency effective cross section of the pit is 10^{-5} square meter.

6. The suspension support using conventional materials can be used at 200 Mc to measure targets as low as 5 by 10^{-4} square meter with 1 db accuracy.

7. The suspension support, using a line material such as bundled glass fibers, will permit measurement (at 2 Gc or less) of cross sections as low as 2 by 10^{-5} square meter with 1 db accuracy, assuming a 1000 pound target

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and negligible pit cross section. For a 10,000 pound target, minimum cross section rises to 5 by 10^{-4} square meter.

RECOMMENDATIONS

It is recommended that the following areas be investigated to enable RAT SCAT to meet design goals.

1. Methods for reducing pit return. Regardless of what target support technique is used, the basic limitation of the current low frequency range is the return arising from the target control area. The basic problem is control of the surface wave associated with ground plane operation.

   Several orders of magnitude reduction are required.

2. Methods for reducing line cross section. Although a comparison between pedestal supports and suspension supports is beyond the scope of the present investigation, it is felt that the line technique offers the most promising way of achieving the low radar cross section levels required of target supports. This view follows directly from the mechanical properties of modern dielectric materials, which are generally stronger in tension than compression.

   Sufficient evidence exists to support the view that approximately a 20-db reduction in line cross section should be achievable through a combination of line material (such as glass fiber) and periodic loading of the line.

3. Methods of sling cross section reduction.

APPENDIX

THE SCALE GROUND PLANE RANGE

General

In order to provide experimental verification of theoretical results, and to provide data that is best obtained by direct measurement, a scale ground plane range was implemented to simulate the RAT SCAT low frequency complex. Utilizing the CAL Ka CW radar (35 Gc), the range was designed to scale operations at 200 Mc, since at these frequencies ground plane effects (inhomogeneities, surface curves, etc.) are much more pronounced.

Because a complete simulation is impossible (the scale ground plane must be finite in extent), the ground plane was limited to an area of 8 by 4 feet in front of the radar. Subsequent experimental results have verified the view that such limitation should not play a serious role in ground plane performance, since the ground plane area was much greater than a Fresnel zone.

Actual ground plane material was extremely fine grain bonding sand, held in a 8 by 4 by 1/2 foot water-proof container lined with radar absorber. Although it is not known whether a complete electrical match was obtained between RAT SCAT soil and the sand (200 Mc data on RAT SCAT soil was not available), excellent agreement in field strengths were obtained between full scale and scale model measurements.

Figure A-1 depicts the scale ground plane range in the smooth sand condition with the target (a 1-inch square flat plate) placed 34 inches from the antennas (full scale separation is 500 feet). Rectangular transmitting and receiving horns, approximately 1 inch square, scale to 15 foot horns, about the size of the RAT SCAT low frequency dishes. These linear polarization horns were employed to obtain cross sections having the following transmitting-receiving antenna polarization combination: vertical-vertical, horizontal-horizontal, $\pi/4$-$\pi/4$ and vertical-horizontal. A variable-tilt turntable was provided to allow target rotation about an axis perpendicular to the first lobe of the ground plane field pattern. Sand was dammed away from this turntable by means of a plaster of paris cylinder placed flush with the sand surface and extending through the bottom of the table.
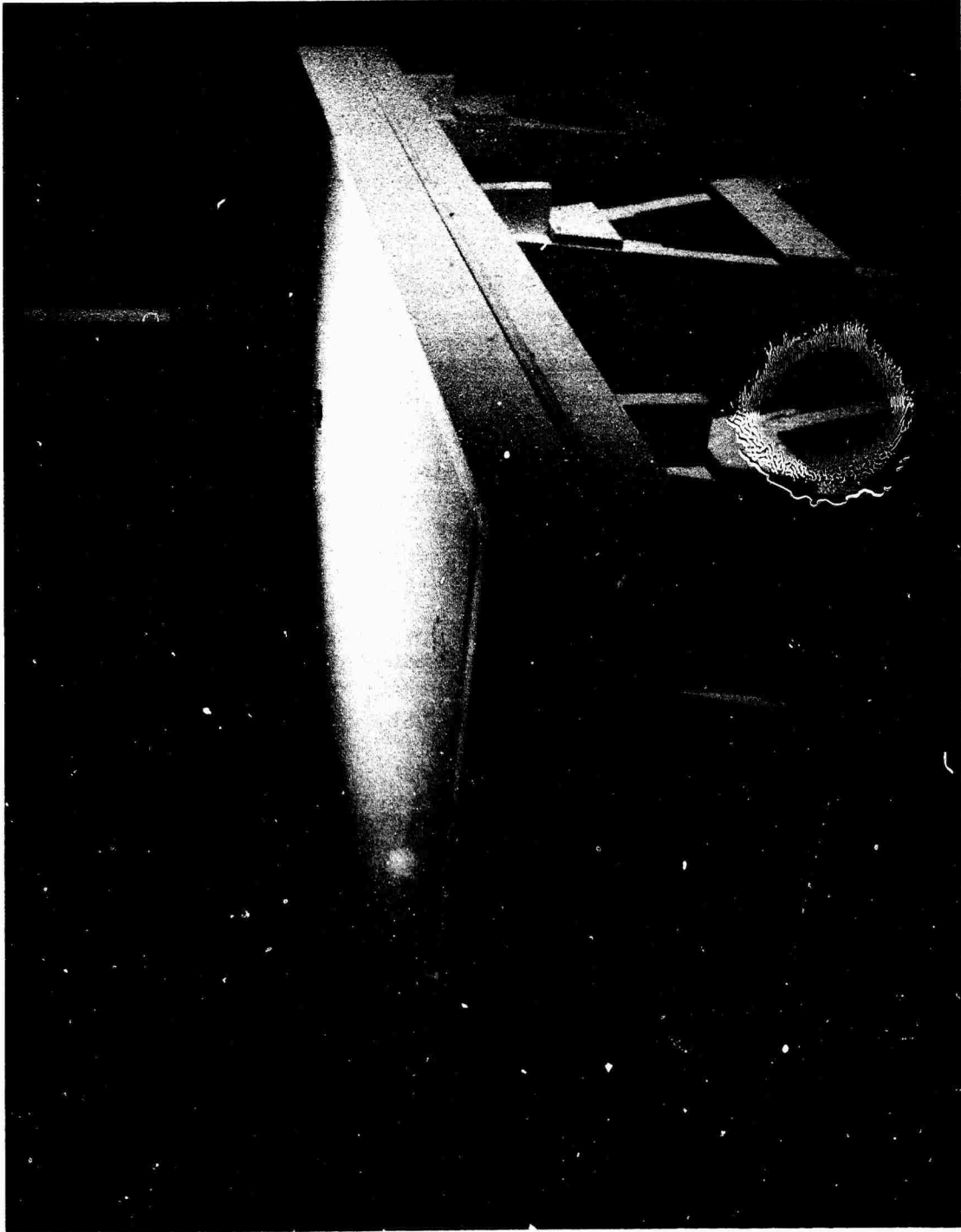
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Fig. A-1 SCALE GROUND PLANE RANGE

A program was carried out to provide field strength data above the scale ground plane range. A sphere was used to probe field magnitude across the target area in azimuth and elevation; the phase of the field was not obtained. (This technique is identical to that employed on the full scale RAT SCAT range.) Figure A-2 illustrates field strength measurement data in elevation at the control pit azimuth angle, using dry sand. The magnitudes of the first lobe peaks match to within 1 db for the two principal polarizations, the horizontal polarization peak being larger as expected. Field distributions predicted by theory are observed at the surface of the ground plane; for vertical polarization the surface wave contribution lies about 20 db below the first lobe maximum. This is the surface component which illuminates the control pit area on the full scale RAT SCAT range. The elevation of the first lobe maximums corresponds to a full scale height of 33 feet at 200 Mc.

A similar vertical coverage diagram with dry sand was obtained for the cross-polarization antenna combination: the transmission antenna orientation was vertical, the receiving antenna horizontal (see Figure A-3). It is seen that the undesired cross-polarization component is down 25 db from the principal polarization components at the chosen elevation of the target.

Figure A-4 provides gross characteristics of the field above the ground plane, again using dry sand. While contours of constant field strength vary irregularly in the second lobe above the ground plane, the first lobe characteristics are regular for both vertical and horizontal polarizations. An anomaly common to the field strength patterns for both polarizations is a deep null, symmetrically distributed in azimuth off to the sides of the target area, at the same elevation as the upper null of the first lobe directly above the target location.

Reference measurements on the scale ground plane range were based upon flat plate cross section. Free space (anechoic chamber) measurements of a reference one-inch-square flat plate were compared to ground plane range measurements for the principal polarization antenna combinations. (It should be noted that the tilt of the resultant ground plane field requires a target rotation axis slightly inclined towards the antenna position. The proper rotation-axis inclination for the scale ground plane range was about 2 degrees.) Results for vertical and horizontal polarization are shown in Figures A-5 and A-6, for dry sand. Agreement is excellent. Differences between free space and ground plane cross sections, existing only at the lower cross section levels, are considered acceptable.
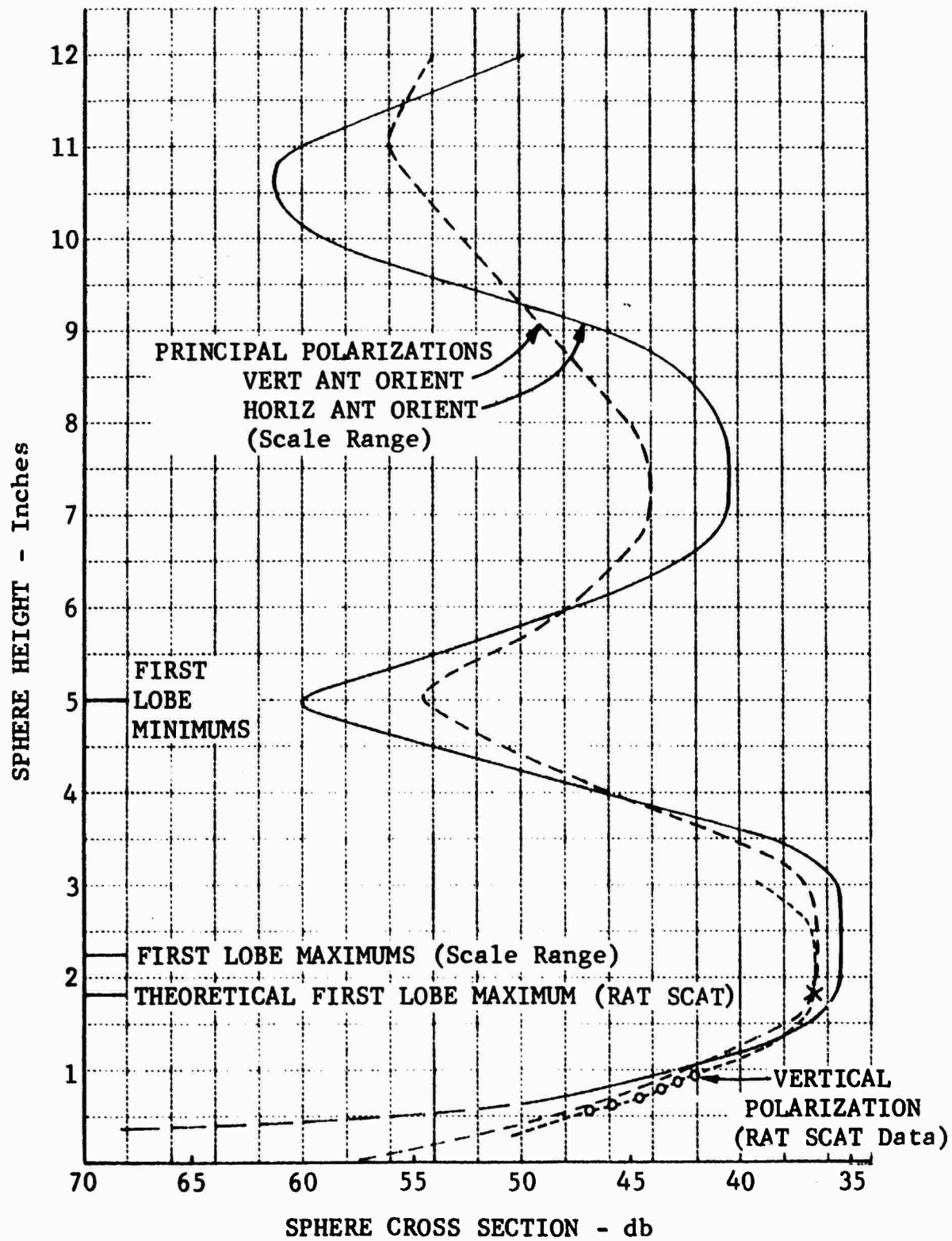
53

Fig. A-2 FIELD STENGTH MEASUREMENTS ABOVE TARGET
CONTROL PIT

54
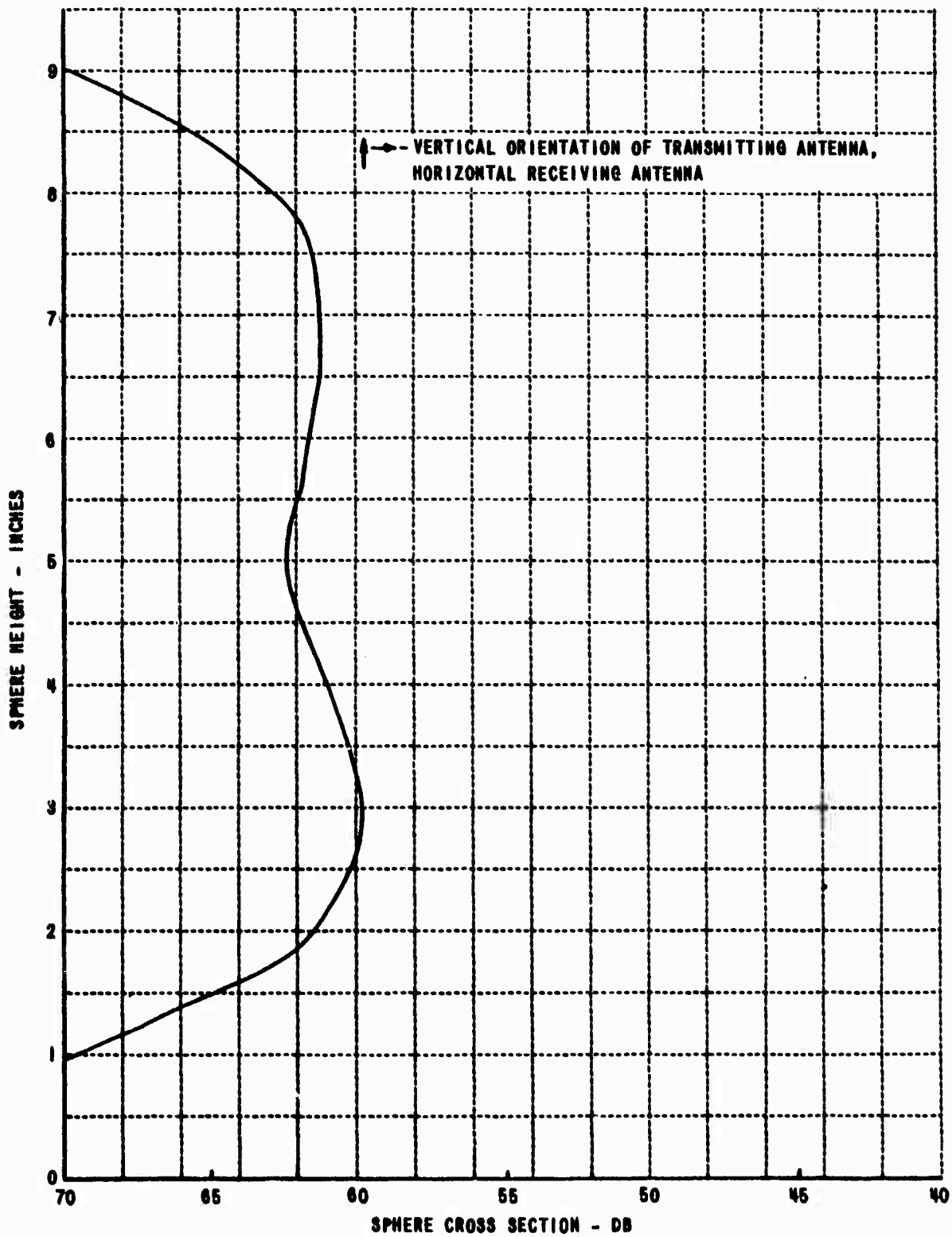
Fig. A-3 FIELD STRENGTH MEASUREMENT ABOVE TARGET CONTROL
PIT - LINEAR CROSS POLARIZATION
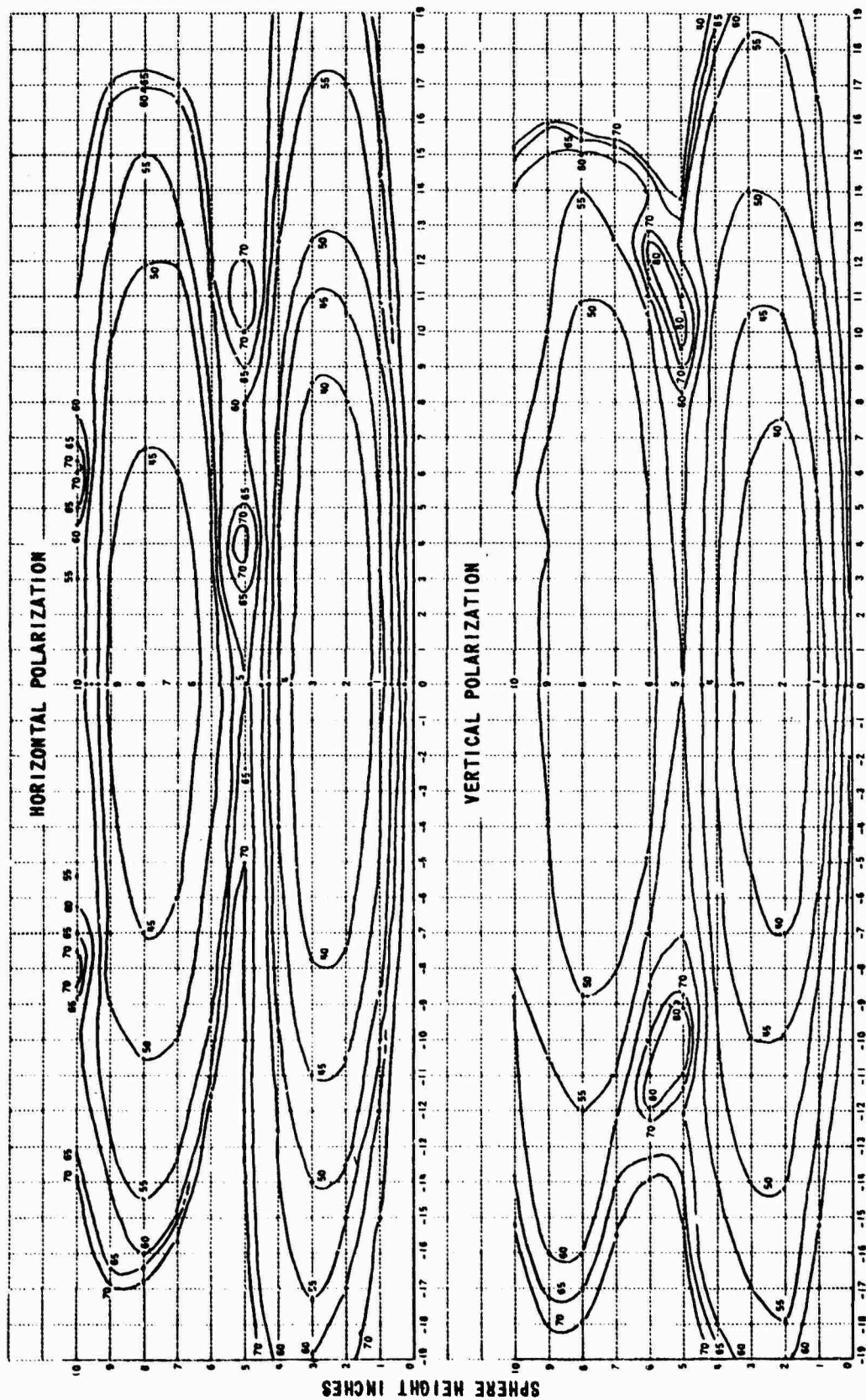
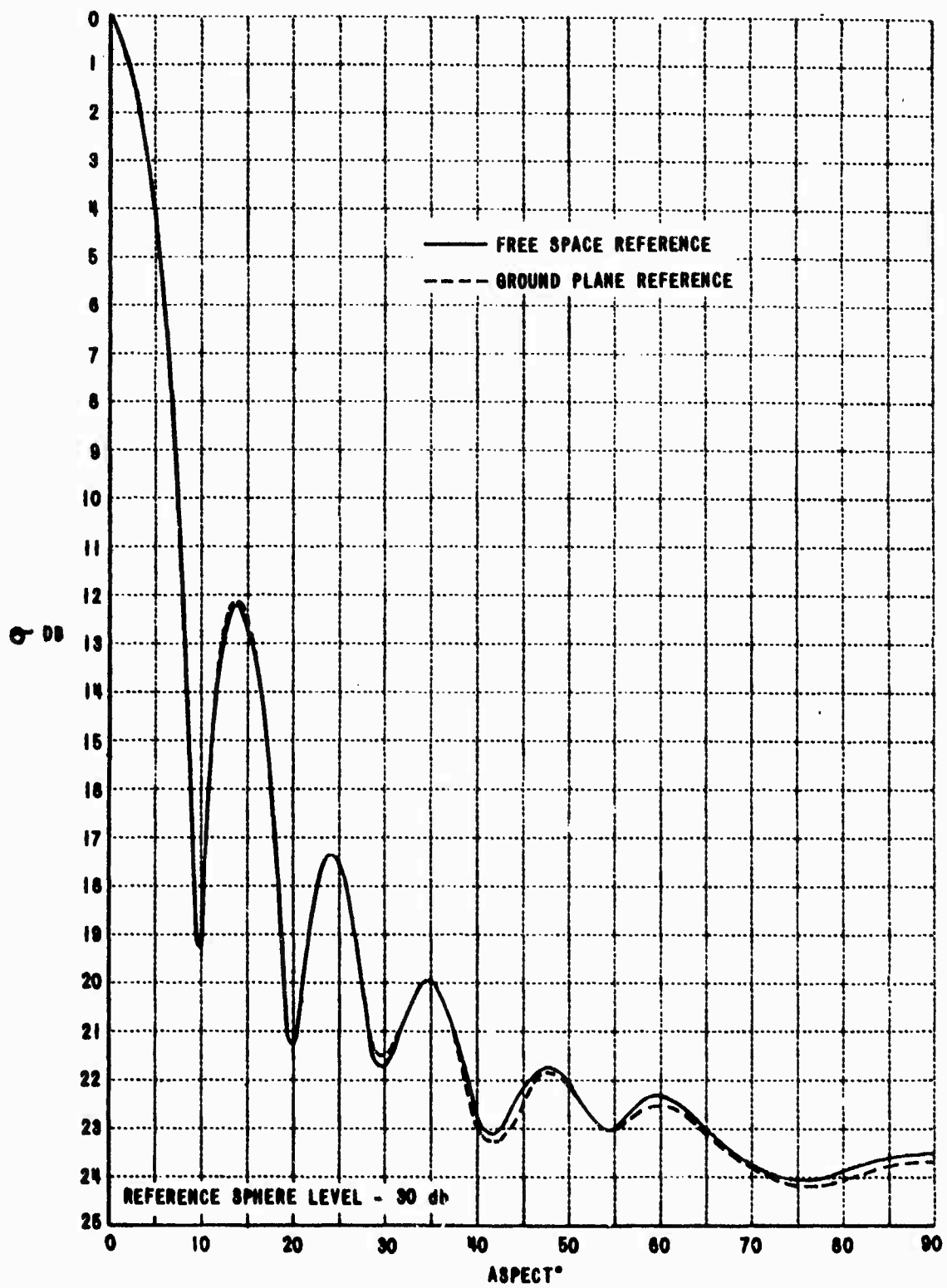Fig. A-4 FIELD STRENGTH MEASUREMENTS ABOVE THE GROUND PLANE

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Fig. A-5   PLANE REFERENCE RUNS, NEW ANTENNAS, 34-INCH
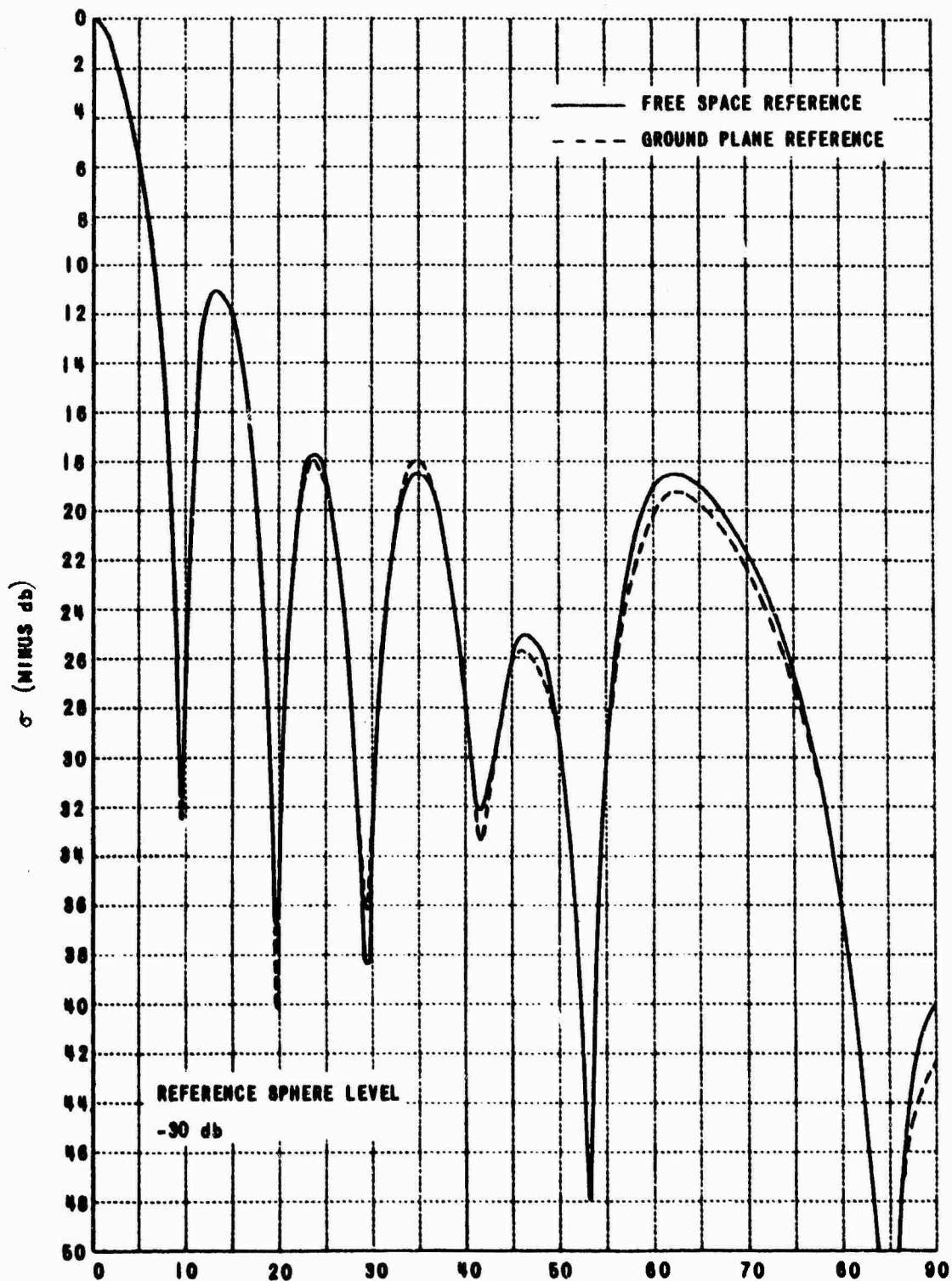A-T STATION 40, VERTICAL POLARIZATION

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Fig. A-6 PLANE REFERENCE RUNS, NEW ANTENNAS, 34-INCH
ͺ T STATION 40, HORIZONTAL POLARIZATION

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Comparison of the power levels secured from a reference sphere indicates a 9 db enhancement when using the ground plane range, instead of the 12 db predicated for ideal conditions. The loss in array gain at vertical polarization was directly attributable to reflection coefficient, since the minima at ground plane surface corresponded to the level computed from gain loss (a reflection coefficient of 0.68).

Circular Polarization Investigation

The standard configuration of the scale ground plane range has been outlined. A temporary configuration employed previously involved large three-inch horns capable of circular polarization operations. Same-sense and opposite-sense circular polarization cross sections of a three inch diameter sphere were measured. The results stated below reflect on the polarization dependence of the ground plane.

The three-inch horns were aligned such that the antenna center line was 1-1/2 inches above the sand parallel with the sand surface. Transmission of a right-sense circularly polarized wave produced a first lobe maximum 2-1/2 inches above the sand at a location 70 inches from the antennas. The resultant grazing angle was 3.5 degrees. The measurement program allowed evaluation of the polarization dependence of the scale ground plane for this grazing angle.

The ratio same-sense to opposite-sense circular polarization cross sections of a sphere, σ_S/σ_O sphere, is theoretically zero. Free space (anechoic chamber) measurements on the three inch diameter sphere gave σ_S/σ_O sphere = 32 db. This variance between theoretical and experimental values was largely due to the inability to achieve zero ellipticity in a practical antenna.

Corresponding measurements performed over the scale ground plane produced σ_S/σ_O sphere q.p. = 13.5 db. The 18.5 db variation in experimental results can be attributed to the polarization dependence of the ground plane. A formulation of this dependence allows expression of the ratio of circular polarization cross sections for a sphere in terms of ground reflection factors.

$$\frac{\sigma_S}{\sigma_O} \text{ sphere g.p.} = \left| \frac{\left[\Gamma_H e^{j\rho_H} \right]^2 - \left[\Gamma_V e^{j\rho_V} \right]^2}{\left[\Gamma_H e^{j\rho_H} \right]^2 + \left[\Gamma_V e^{j\rho_V} \right]^2} \right|^2 \tag{A-1}$$

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In the present analysis, the righthand side is equated to -18.5 db. Additional linear polarization cross section measurements of the sphere were performed on the scale ground plane range. Principal polarization measurements provided the ratio σ_V/σ_H sphere g.p. $= -1$ db or $\left[\Gamma_V/\Gamma_H\right]^4 = -1$ db. Substitution of this data in equation gives $\rho_V - \rho_H = \pm 8$ degrees. Consideration of the reflection process shows that the minus sign is correct here and that ρ_V and ρ_H are opposite in sign. It is not possible to interpret the above results directly in terms of the primary reflection coefficients $R_H e^{j\psi_H}$ and $R_V e^{j\psi_V}$. However, results of previous measurements at linear polarization gave $R_V = 0.68$, hence $R_H = 0.8$.

Investigation of the Disturbed Ground Plane Range

Operation of the scale ground-plane in an anechoic chamber insured measurements on the well behaved ground-plane range defined in Section IV. The following measurement programs were directed toward evaluation of certain disturbances associated with full-scale ground plane range operation:

1. The effects of surface irregularities

2. Variable-moisture-content effects

3. Problems associated with surface-wave illumination of the control pit and submerged turntable.

(It is possible to simulate a variety of ground conditions with the scale range; it is suggested that disturbances peculiar to the RAT SCAT range be investigated with this valuable tool.)

The Effects of Surface Irregularities

The ground plane acts as if it were perfectly smooth if Rayleigh's criterion is satisfied, that is, if the height of surface irregularities times the grazing angle ψ (in radians) is less than $\lambda/16$. Typical results are plotted in Figure A-7. For the scale ground plane range, $\psi \approx 2°$ and $\lambda \approx 1/3$ inch. The calculated allowable height irregularity was thus less than one inch. The smooth sand was deliberately disturbed to provide waves more or less perpendicular to the antenna line of sight in the region between the antenna and target locations. Troughs parallel to the antenna line of sight were made off to the sides. The approximate height of the sand waves was one inch. Principal polarization measurements on the reference flat plate (1 inch square) produced cross sections identical to the smooth-sand
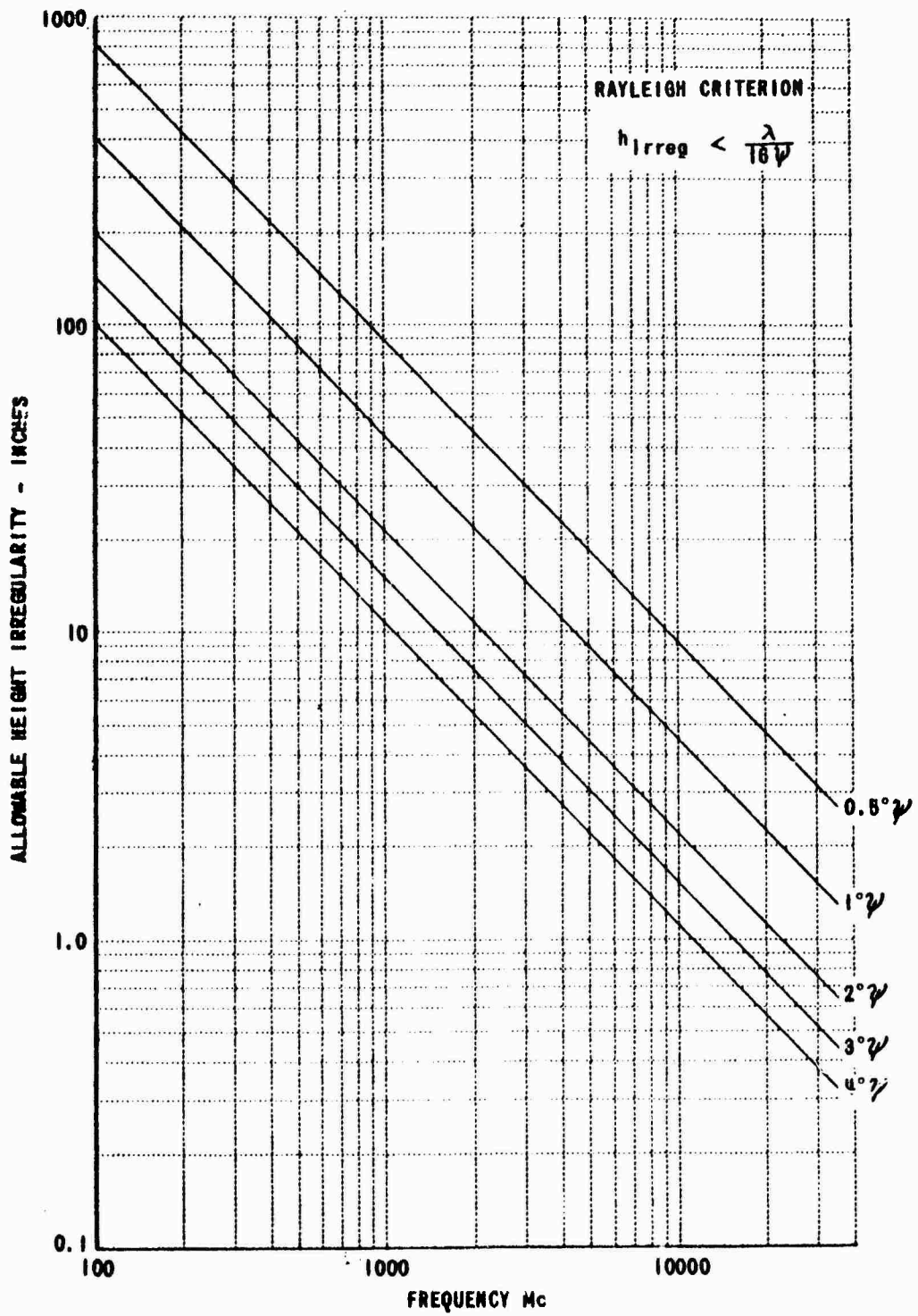
Fig. A-7 ALLOWABLE HEIGHT IRREGULARITY

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reference runs. Next a 6-inch mound was shaped in the sand behind the target area across the container. No effect on plate cross section was observable.

Compacting an 8 x 12-inch area of sand 3/8 inch in the location of the first Fresnel zone did not perturb measurements. Ground-plane height effects were first noticed when a 2-1/2-inch hill was run through the reflection area perpendicular to the line of sight. The specular peaks of the flat-plate cross sections were reduced 7 db, although the data retained symmetry. Angling of this hill with respect to the radar line of sight destroyed the symmetry. The program indicated validity of the Rayleigh criterion for surface irregularities in the region between the antenna and the target. Even larger irregularities may exist beyond the target without disturbing measured cross sections.

Operation of 10 Gc with a grazing angle of one degree allows height irregularities of about 4-1/2 inches by the Rayleigh criterion, hence, it is felt that irregularities in surface height will produce negligible errors in cross section measurements.

Variable-Moisture-Content Effects

Soil formations at the RAT SCAT Site result in a natural water basin. The presence of varying depths of water beneath the measurement site could complicate the basic ground plane concept, since the ground plane will exhibit the characteristics of a layered dielectric.

A layered dielectric was simulated on the scale ground plane range by placing a flat base of wet sand beneath a surface of dry sand. Seepage between the wet sand (16 per cent water by weight) and the dry sand (a fraction of one per cent) interface was not observed. Dry-sand surface thicknesses of 3, 2, 1 and 0 inches were examined. Using the 3-wavelength-square flat plate as a target for both vertical and horizontal polarizations, layered-dielectric effects became noticeable when the dry surface thickness was reduced to one inch. Results are given in Figures A-8 and A-9. Even for the all-wet-sand case, the measured cross sections are within 0.5 db of their free space counterparts.

The all-wet-sand configuration approximates an appreciably conducting ground plane. Investigation of the surface wave for vertical polarization involved raising a sphere through the field to provide a vertical coverage diagram. No increase over the small surface wave component existing in the dry ground plane case (refer to Figure A-2) is observed in Figure A-10.
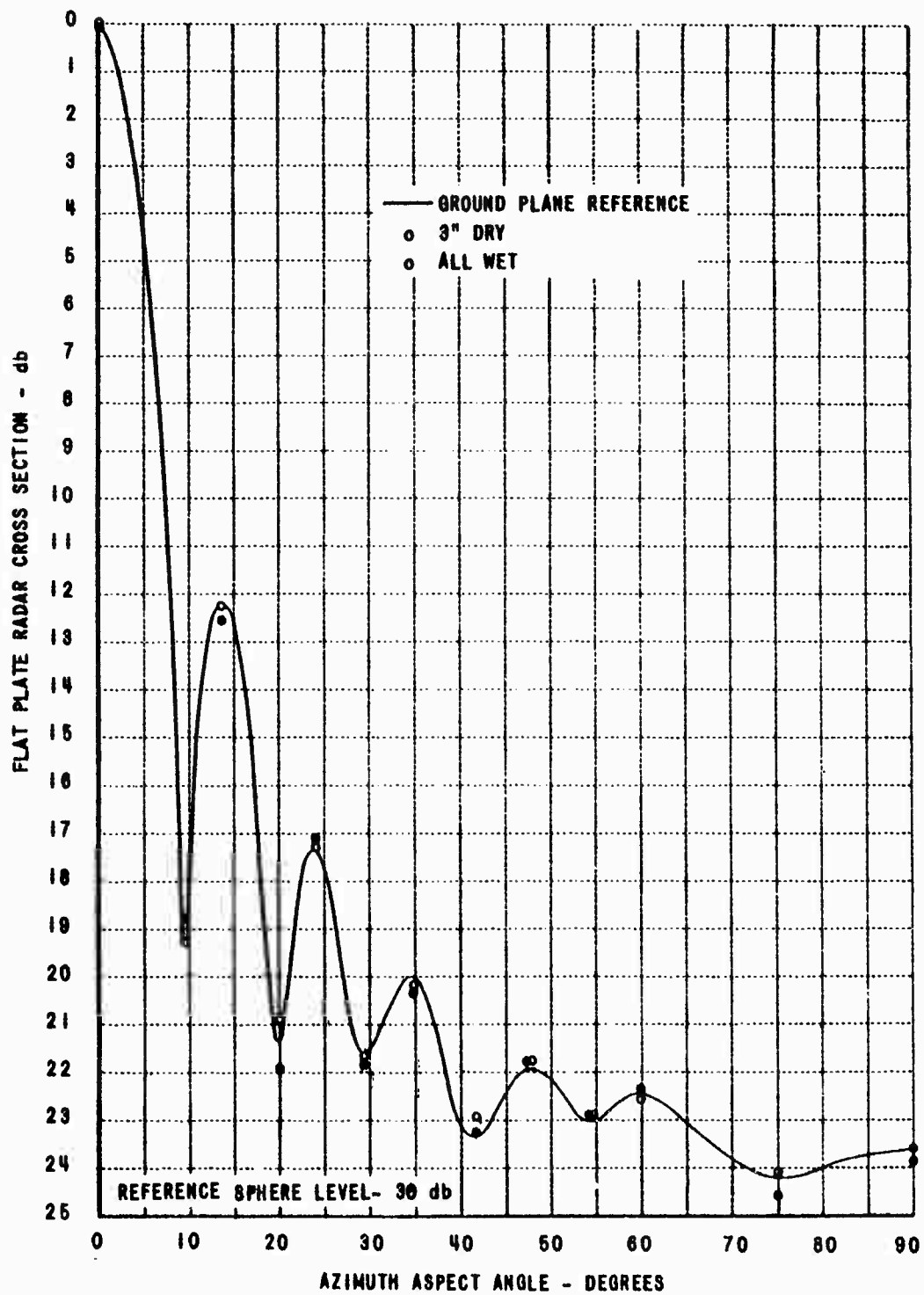
62

Fig. A-8   COMPARISON OF WET AND DRY SUBSURFACE, VERTICAL
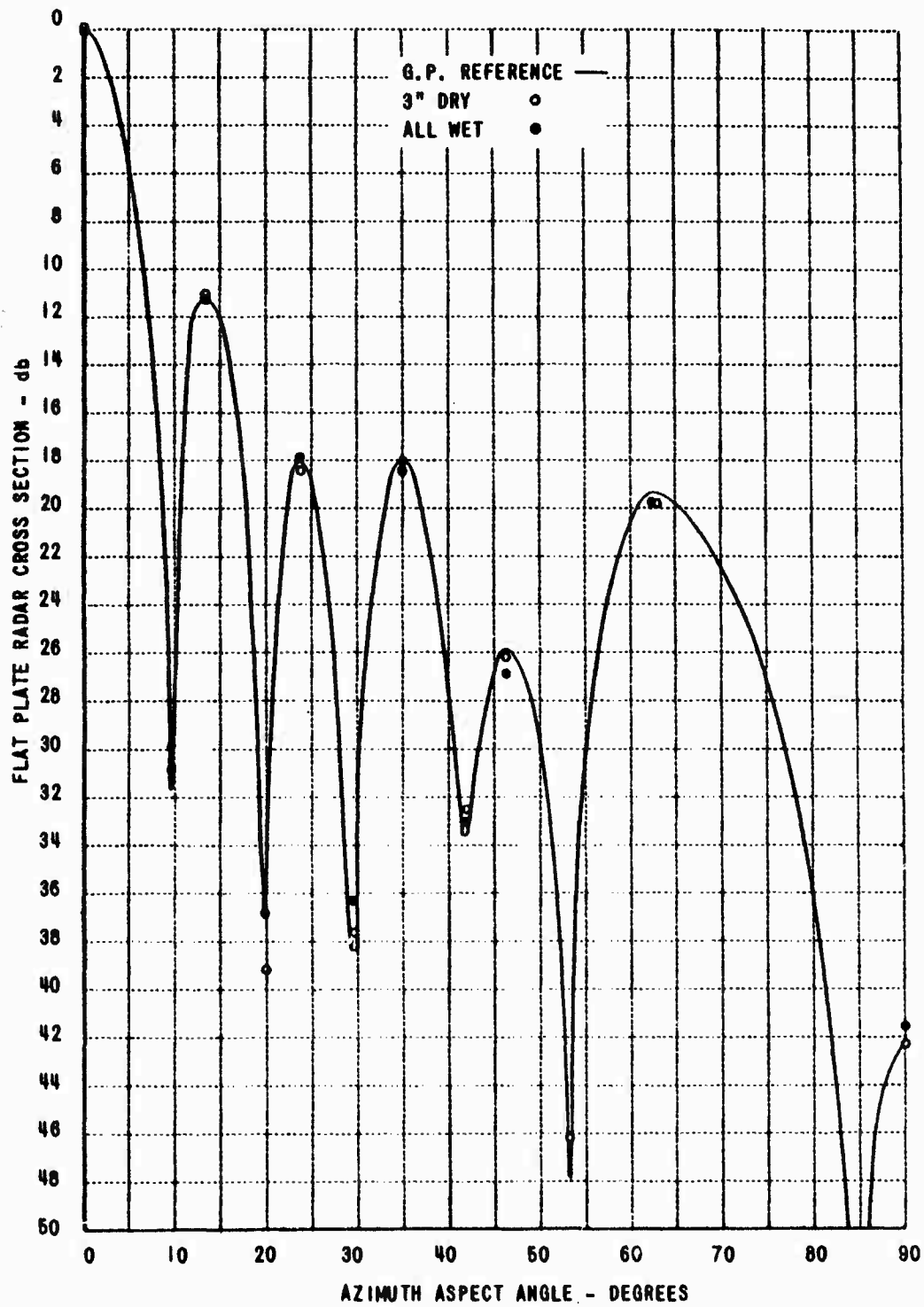POLARIZATION

Fig. A-9   COMPARISON OF WET AND DRY SUBSURFACE,
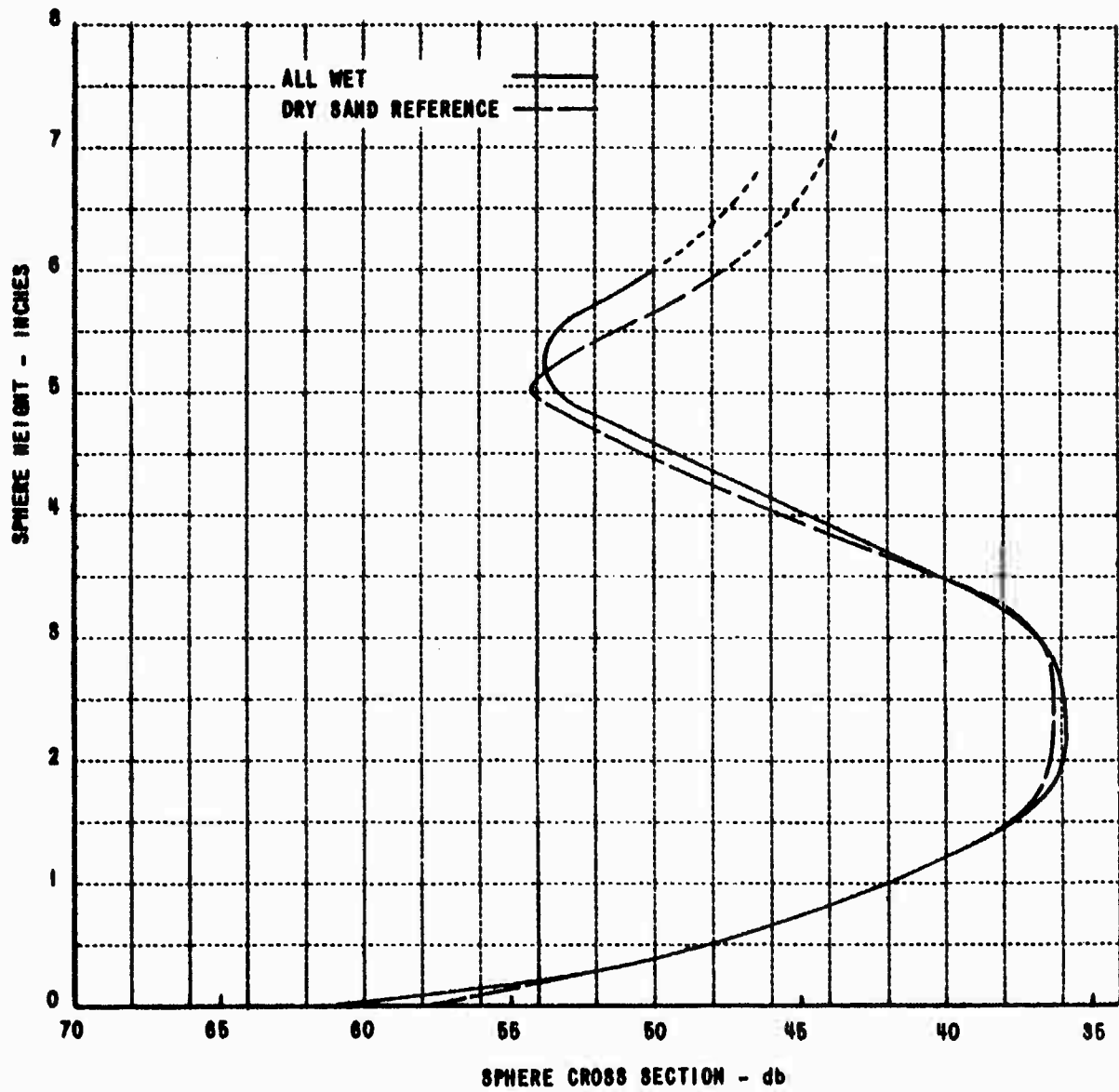   HORIZONTAL POLARIZATION

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Fig. A-10   FIELD STRENGTH DIAGRAM, WET AND DRY SUBSURFACE,
VERTICAL POLARIZATION

Control Pit and Submerged Turntable

The conventional solution to the problem of target control involves use of a rotating turntable. Full-scale ranges usually provide a control pit in which the turntable is submerged. However, vertical polarization transmission over a ground plane results in an appreciable surface-wave component which illuminates the control pit. The direct return from the pit can be nulled out with the background. Nonetheless, sensitivity is lost due to the variation of pit return with turntable rotation. In addition, nulling procedures do not reduce the possible bistatic contribution attendant with pit illumination. The application of absorber material over the turntable will effectively reduce target illumination due to control-pit scattering. However, little reduction of the direct return is observed through this procedure. Of significance to RAT SCAT is the following history of the direct return from the control pit and turntable employed on the scale ground-plane range. Worst-case results are associated with cross-section measurements using the vertical-vertical antenna polarization combination.

In the scale-range configuration, a sand dam corresponded to the control pit. Figure A-11 shows a 3-inch-diameter copper tube extending from the ground-plane surface through to the sand box. A 2-inch-diameter plexiglass turntable was located inside the sand dam 1 inch below the surface. Four small screws set in the plexiglass disc provided attachments for target control lines. The disc was cemented to a pipe flange attached to a 3/4-inch-diameter steel shaft. Provision for variable shaft tilt allowed final inclination of the turntable rotation axis three degrees from vertical in the direction of the radar.

The measurements involve pit and turntable returns only. In each case the return from the stationary configuration was nulled. The vertical polarization peak return was 12-db below the reference sphere level as the turntable rotated, i.e., undesired returns were as high as 10^{-5} square meter at Ka band. A 2-inch-diameter disc of CV 6* 3/4 inches thick was then placed on the turntable, without appreciable effect. The turntable was next lowered to a new height, 1-1/2 inches below the surface and a ring of CV 6 3/4 inches high and 1/2 inch thick installed in the inner surface of the copper sand dam flush with the top. The range was nulled again and resultant peaks as high as 10^{-6} square

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*A radar absorber product of the Emerson and Cummings firm.

meter were measured. However, most of the return as a function of aspect remained in the null, below 10^{-8} square meter. Application of two more rings beneath the first showed no improvement, nor did insertion of a turntable cover of CV 6. Finally, a 5-inch-square piece of CV 6 was placed over the sand-dam opening. The rotating turntable still exhibited at 10^{-6} square meter cross section at several rotation angles.

At this point the copper tube was replaced by a plaster of Paris form. The pipe flange was removed and the plexiglass disc was joined to the rotating shaft by means of a centrally located screw. Resultant cross-section measurements of this pit configuration indicated undesirable returns below the room null, about 10^{-9} square meter. No dependence of the return with turntable orientation was observed.

It must be emphasized that reduction of pit cross section was beyond the scope of effort; the achievement of accurate simulation of full scale conditions was the basic goal.
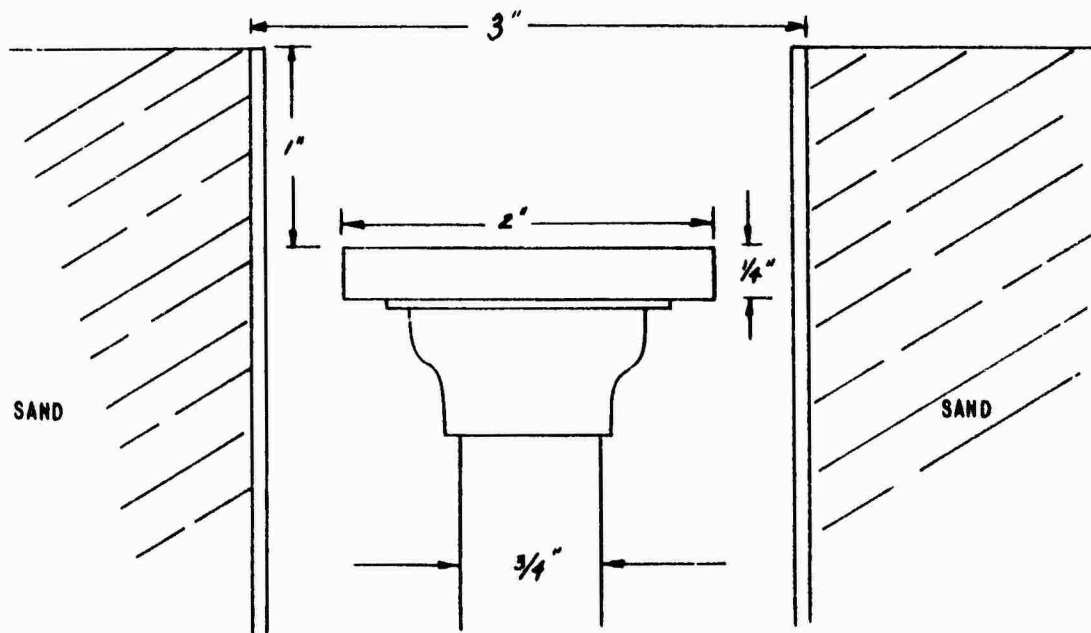

Fig. A-11 TURN TABLE CONFIGURATION

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13. ABSTRACT

The shielded metal column program was devoted specifically to the investigation of errors in cross section measurement resulting from the use of a large, hydraulically actuated metal target support at the RAT SCAT Site. The analytical model used and the factors taken into consideration in arriving at a test program for use in evaluating shielding techniques for the metal target support are described in this report. The suspension target support program was an experimental program carried out by Cornell Aeronautical Laboratory. A scale ground plane range was used to simulate low-frequency operation on the RAT SCAT range. Most of the measurements made were for the purpose of determining the cross section return of such conventional suspension target supports as nylon. The parameters of primary concern were size and the polarization of the transmitter and receiver. This report is No. 5 in a series of 8 RAT SCAT Research and Development Program reports.

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