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ELEVATED TARGET PROGRAM

P. N. James

DECEMBER 1969

Prepared for

DIRECTORATE OF PLANNING AND TECHNOLOGY
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

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Project 7160
Prepared by
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FOREWORD

This document was prepared in support of Project 7160, Over-the-Horizon Backscatter Systems and Technology, by The MITRE Corporation, Bedford, Massachusetts, under Contract No. AF 19(628)-68-C-0365.

REVIEW AND APPROVAL

This technical report has been reviewed and is approved.

JOSEPH N. ALLRED, Capt, USAF
Technical Project Officer
Development Engineering Division
Directorate of Planning & Technology

ABSTRACT

The program "High Frequency Prediction Using Parabolic Layer Theories ... ITSA ... 1966" has been modified for two-way radar propagation and for application to elevated targets. In addition to a listing, results can be displayed as scatter plots, histograms, and distributions. The maximum set of sky-wave paths considered is 1F±, 2F±, 3F-, 1E±, 2E±. Antenna gain patterns are defined by tabular values of gains versus frequency and elevation angle.

In this version of the program, arbitrary frequencies are considered but the target must not be in an ionized layer.

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SECTION I

INTRODUCTION

This program which is entitled ELTAR4 is a modification of the program "High Frequency Prediction Using Parabolic Layer Theories... ITSA...1966". It is written in Fortran IV for the IBM-7030 Data Processing System. Approximately 35,000 words of 7030 memory are required by this program, which has now been in use for the past few months. The program in its original form applies ionospheric data to the problems of high frequency communications via the ionosphere; however, only one-way propagation is considered over a ground to ground path.

The inputs to both the original and revised programs are those quantities from which ionospheric and noise environment can be predicted along the ray path and at the receiver--hour, month, sunspot number, geographic locations. In addition, of course, the gain patterns of the antennas involved, operating frequency, and power transmitted must be specified.

The primary outputs of the original program are three distributions which are functions of the above input parameters. The first is the probability of support versus frequency for a number of path structures, computed primarily from an empirical model. The second

and third are the (split normal) probability density functions of signal and noise in db. The signal to noise ratio is given by the familiar equation

$$S/N = \frac{P_t G_t G_r \lambda^2 L}{(4\pi)^2 R^2 N} .$$

The loss factor L, which accounts for such effects as ground reflection loss, ionospheric absorption, fading and polarization factors; and the noise power per cps, N, which accounts for man made, atmospheric, and galactic noise at the receiver site, are represented by split normal distributions in db. The split normal distribution are normal on either side of the median but with generally different standard deviations. The range, R, is the equivalent (group) path distance. The signal to noise ratio refers to those times when the mode is supported and must be considered in relation to the probability of support.

As modified for two way, radar analysis the signal-to-noise is now based upon

$$S/N = \frac{P_t G_t G_r \lambda^2 L T \sigma}{(4\pi)^3 R^4 N}$$

where the quantities have the same meaning as before; σ is the

backscattering cross section of the assumed target and T is the coherent integration time. The outputs of the present modified program refer to median values; no indication is given as to the spread of either signal or noise which may be large. Thus, the MUF and related data refer to a frequency which is supported 50% of the time.

The main modification is an addition which allows computations to be performed for targets situated above the surface of the earth. The target must, however, not be in an ionized layer for accurate results. Operating frequency may be taken as the MUF, a fraction of this frequency or arbitrary frequencies. The main addition to the program involves an iterative procedure which determines an "equivalent receiver site" on the earth's surface in the original ITSA program (or target site as the program is here modified for the radar case) which when used in the original computation leads to a ray path which comes within a predetermined distance of the target. Since the equivalent ground point is a function of time, certain quantities such as backward bearing and reflection area coordinates must now be recomputed as a function of time.

The space loss computation is modified so that the group path (equivalent) distance to the target is computed as the distance to the intersection of the equivalent path with a line determined by

the center of the earth and target location. The equivalent path is based upon the elevation angle of the ray at the transmitter site, and thus is exact only for targets below the E layer. The absorption losses in the lower regions are arbitrarily assumed to occur at 100 km. For example, for a 1F- mode, the absorption is assumed to occur twice for a target elevation above 100 km and 4 times if less than 100 km.

The "excess system loss" of the original (communications) ITSA program has been omitted for lack of information as to the proper modification for the radar case. Other users have generally used this loss without change. This loss can be easily added if desired.

Additional modifications are of the following types: (1) the specification of antenna power gain patterns from a table of gain values versus frequency and elevation angle; (2) the location of targets by range and bearing from transmitter site as well as by specified latitude and longitude; (3) the elimination of all tabular outputs except one; (4) the elimination of statistical reliability information; (5) the addition of new data presentations in the form of histograms, cumulative distributions and scatter diagrams and the ability to consider a number of different antenna gain patterns in a single run. The type of output desired can be controlled by suitable coding on a control card. In general, no changes have been made in

any of the basic computational formulas of the original program that have been retained, except to make a few minor corrections that have been indicated from various sources.

A detailed appreciation of the meaning of the output data available from this program is best obtained by reading "ESSA Technical Report ITSA-1." This report contains in considerable detail information as to the mathematical models used to approximate such features as the electron density profile of an ionospheric layer, the method used to compute MUF (50) frequencies, ground reflection loss, etc. Justification for the methods used (which are often semi-empirical) may be found in the references listed in the above report.

This program considers a fixed sequence of modes: 1F-, 2F-, 3F-, 1E-, 2E-, 1F+, 2F+, 1E+, 2E+. It is, however, optionally possible to suppress the computation of higher order modes if a lower order mode is found to exist (and satisfy a minimum take-off angle constraint). Thus, 1F-, 1E-, 1F+, 1E+ modes are always computed; the other modes may be suppressed. For example, if the 1F- mode did not exist but 2F- did the computation of 3F- could be suppressed depending on an input code.

SECTION II

COMPUTATIONS

A method is presented here which determines the associated ray geometry for the case of an elevated target for a number of E and F2 modes. The procedure determines the coordinates of a ground point which when used as a receiver site in the original ITSA program (or the ground reflection point in the program as modified for radar use) leads to a ray path which comes arbitrarily close to the elevated target. In fact, one method of checking the program has been to use the coordinates of the "equivalent ground point" in the original ITSA program. The target must not be in an ionized layer, but operation is not restricted as to frequency.

The problem is complicated by the fact that in the ITSA program, although computations are performed on the basis of assumed concentric and uniform parabolic E and F2 layers, the three parameters which are used to specify an ionospheric layer are computed as averages (or possibly minimum values) obtained from points in the region of actual reflection. Therefore, the ionospheric parameters are functions of the ground reflection point. Furthermore, three different methods of averaging are used to obtain the ionospheric parameters depending on the magnitude of the ground range involved.

The result is that the ionospheric parameters may not be continuous functions of ground range in a particular region of interest. For F2 modes bending in the E-layer also affects ray geometry in a rather complicated manner. The result of the above is that it is not practical to obtain an analytic function which describes the closeness of a ray path to an elevated target as a function of an assumed ground reflection point. On the other hand, since the ionospheric data used in the program consists of smoothed averaged data, it is expected that errors introduced by ignoring ionospheric changes and changes in E layer bending resulting from a single iterative step in ground range will not be important.

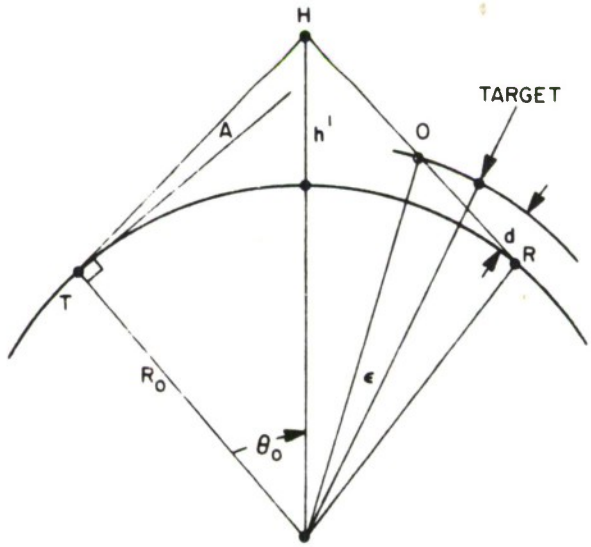
The basic plan of the program is then to compute a correction in ground range on the basis of the error found for the present ground range using its related ionospheric parameters and bending. If due to the approximations made, the error is found to increase at a particular step, this approach is abandoned at least temporarily in favor of a very simple grid search approach which insures a minimum error obtainable from the pre-selected grid size (the minimum error is a local minimum). For the test cases which have so far been run convergence has always been obtained without resorting to the grid approach.

The details of the procedure for finding a ground point such that the ray to this point also passes arbitrarily closely to the elevated target is now presented. During the previous iteration an angular ground range of 2 θ_o has been used (Figure 1). The ray path for the operating frequency has been obtained according to regular procedures of the ITSA program (with E-layer bending for F2 layer reflections). Thus, we have available the take-off angle A (Figure 1). Now assuming the target is below the E layer it is a matter of geometry to compute the error angle ϵ. We wish to find

$$\Delta\theta = f(\epsilon)$$

such that when $\Delta\theta$ is added to θ_o the new ray path will meet the target. To find $f(\epsilon)$ note that, as computed in the ITSA program, the virtual height is fortunately a slowly varying function of ground range. Therefore, the height h' is taken to remain constant in the computation of $\Delta\theta$ (actually h' is not the virtual height since E layer bending is included, but we ignore any changes in h' due to the dependence of bending on range). It can be shown (Appendix A) that $\Delta\theta$ can be found from the equation

$$\Delta\theta + \int_{\theta_o}^{\theta_o + \Delta\theta} \frac{R_o L' \sin A}{(R_o + d)\, L \sin A'}\, d\theta = \epsilon \qquad (1)$$



IA – 25,407

Figure 1.

where with reference to Figure 1

$$L = \overline{HR}; L' = \overline{HO}$$

and A, A' are the take off angles on the ground and at the target height, respectively. It would be possible to find an approximate solution to (1) by numerical integration by expressing L, L', A, A' as a function of θ or we might expand the integrand about θ_o and integrate a few terms. Use of only the constant term in the expansion appears to be adequate and convergencies obtained by iteration. Thus, the first approximation to $\Delta\theta$ is obtained from

$$\Delta\theta = \frac{\epsilon}{\left[1 + \frac{R_o L'_o \sin A_o}{(R_o + d) L_o \sin A'_o}\right]} \qquad (2)$$

and the process is iterated until the error ϵ is reduced to a given small quantity. Convergence characteristics are considered in Appendix A. Test cases have obtained convergences to a small fraction of a kilometer in 2 or 3 iterations.

When the target is above the E-layer the ray in the neighborhood of the target appears to have come from a transmitter site displaced from the actual site by an earth's angle of β (β = E-layer bending) however, with the same take-off angle as the actual ray.

Consequently, the only change introduced in this case is to compute the error, ϵ, on the basis of $\theta_o - \beta$ rather than θ_o.

Formula (2) gives the angular correction in terms of the error for the 1 hop minus case. The formula is easily generalized for the n hop, + or - case:

$$\Delta\theta = \frac{\epsilon}{\left[(2n \pm 1) \pm \frac{R_o L_o' \sin A_o}{(R_o + d) L_o \sin A_o'}\right]} \quad . \tag{3}$$

The upper sign is for the n hop - case and the lower sign is for the n hop + case. $2\,\Delta\theta$ is the correction in great circle ground range of each hop.

The next step of course is to use the new ground range as input to original ITSA program and check that the resultant ray path is satisfactory, iterating the above two phases if it is not. The majority of the time is consumed in the second (original ITSA) phase of the computation since ignoring bending and ionospheric parameter changes greatly simplify the mathematics.

Much of the time in the second phase is consumed in computing ionospheric parameters. Instead of recomputing these parameters directly an intermediate phase has been added which interpolates values of these parameters from values previously computed. The interpolation consists of fitting an interpolating polynomial in

ground range angle through the computed values. Only when convergence is obtained at this level of approximation do we revert to the full ITSA treatment. At this last stage a single pass through the ITSA computation is usually sufficient to confirm that the ray path passes within 1 or 2 kilometer of the target and no further iterations at this level are required.

The proper degree for the above interpolating polynomial has not really been determined. For short ranges, ionospheric parameters are computed at only one point in the normal run of the ITSA program. Therefore, an additional set of parameters must be computed at some other range point for even a linear fit. For longer ranges two sets of values are already available so that a linear fit is easily obtained. If a higher degree polynomial is desired, parameters must be computed at additional points. At present a fourth degree polynomial may be used for the interpolation. It is also optionally possible to use the polynomial approximations computed for one circuit to define the ionosphere for another (closely related) circuit through the initial iterations. Of course, once convergence is obtained for the approximate ionosphere further iterations employ the original ITSA computations. Presumably this shortcut could be used for circuits of the same parameters (month, sun spot number, bearing, etc.) but decreasing range. This approach

has been tested only with 4th degree polynomials. As stated before, 9 modes can be computed and the same polynomial approximations, once available, are of course used for all modes.

It is evident that the location of the equivalent ground reflector point will change not only with mode but with time for the same mode. Therefore, quantities such as control point geometry, must be recomputed for each time interval. The original ITSA program has been modified in this regard to use the forward bearing, which is not a function of time, rather than the backward bearing. After convergence the backward bearing is computed for print-out.

SECTION III

INPUTS

The input cards are patterned after those of the original ITSA program both in layout and sequence, however, there are rather significant differences as can be seen below. The input cards can be classified into five groups plus some control cards which are used to separate groups. The groups 1 through 5 will be termed a section of data cards. Any number of sections are possible within limits indicated below.

Considered in order of entry the first group (a single card-card 1.1 below) contains physical constants and input/output control information which will apply to all the computations of the section. This card must always be present. The second group of cards describe the gain patterns of the transmitting and receiving antennas. Gains patterns are described by a table of values giving gain values versus frequency and elevation angle. 728 gain values (for 28 frequencies and 26 angles) are allowed and the input order of the gain values must be ascending angle within ascending frequency. The minimum angle is 0° and the angular increment is 2 degrees. The minimum frequency is 3 MHz and the frequency increment is 1 MHz. A maximum

of 4 antennas may be considered in a section and an antenna title card must precede each set of gain cards. The cards of group 2 may be omitted in which case constant gain antennas are assumed with gain values obtained from columns 40, 41, and 51, 52 of card 4.2.

Cards of group 3 may or may not be present depending on whether it is desired to specify arbitrary frequencies for a section or not. A code indicating whether these cards are included is contained on card 1.1. If frequencies are to be specified two cards (type 3.1 below) each containing 12 frequencies are required. These 24 frequencies refer sequentially to the 24 hours of the day (GMT). The same frequency is used for all modes for a given hour if the mode exists. It is not possible to consider a complement of 13 frequencies as in the original program. If these two cards are omitted the MUF frequency or some specified multiple of the MUF will be used. The MUF here refers to the maximum usable frequency for the mode bring considered and is therefore generally different for each mode.

The cards of group 4 contain circuit data. This information is contained on 2 cards per circuit when the target location is to be specified by its latitude and longitude and on three cards when the target location is given by its range and bearing from the radar site. Any number of circuits may be specified by the cards of group 4 except for the overall job size limitations discussed below. Cards

of group 4 are separated from those of group 5 by a blank card followed by a "9's" cards just as in the original ITSA program.

The cards of group 5 are of only one type (card 5.1), namely the month, sunspot number cards of the original ITSA Program. The minimum ray elevation angle is also contained on this card, however, only fixed modes are computed by the elevated target program. No attenpt is made (as in the original ITSA Program) to satisfy the minimum angle by an arbitrary number of path hops. Any number of cards of this type may be contained in group 5 (again subject to overall job size limitation). The "-1" card which must follow group 5 cards separates one section from another or if the (-1) card is followed by a blank card the job is ended. The "month and sunspot number cards" are generally not required to be in any order but it is recommended that they be in order of increasing month to avoid tape rewind and search time. However, if a scatter diagram is required to differentiate (a maximum of 4) sunspot number by symbol, the cards must be in order of increasing sunspot number.

Because of the present size of arrays used to store results for scatter plots, etc. a restriction exists on the number of cases that can be computed in one section. If T is the number of time blocks in a day ($T = \frac{24}{IHR}$; IHR = hourly interval), then

(No. of circuits) (No. of month and sunspot number cards) $T \leq 1584$.

1.	Card 1.1	METH, SIG, IHR, JNOCIR, IHIST, IDIST, ICDIST, ISCAT, IDANT, IJEF, MDEL, PRMUF FORMAT (I2,F10.3, 2I2, 4I1, 3I2,F5.2)
METH		Code I to read circuit data from cards. Code 0 to read circuit data from tape.
SIG		Radar cross section of target in sq. meters (db).
IHR		Hourly interval of computation.
JNOCIR		The number of circuits or the number of sunspot numbers to be distinguished by print symbol in the scatter diagram. JNOCIR ≤ 4 and may be omitted if no scatter diagram is desired (see ISCAT).
IHIST		Code 1 if histograms of frequencies, angles, S/N are wanted; code 0 (or blank) otherwise.
IDIST		Code 1 if cumulative distributions of frequencies, angles, and S/N are wanted; code 0 (or blank) otherwise.
ICDIST		Code 1 if complement of cumulative distributions for frequencies, angles, and S/N are desired; code 0 (or blank) otherwise.
ISCAT		Code 1 for a scatter plot of frequencies vs. elevation angles. A maximum of 4 circuits may be distinguished by the symbols . , *, +, -. Code 2 the same as code 1 except that the symbols · , *, +, -, are used to distinguish plotted points for a maximum of 4 sunspot numbers. Use code 0 (or blank) if no scatter plot is wanted.

IDANT	Code 0 or blank for isotropic antennas with 2 gains read from cols. 40, 41, and 51, 52 of card 4.2. The code n ($1 \leq n \leq 4$) implies that data for n antennas are to be read from cards of group 2. The codes 11, 12, 13, 14 have the same affect as codes 1, 2, 3, 4, respectively except that gain values previously read in from another section are to be used again.
IJEF	Leave blank (not presently used).
MDEL	If left blank all nine modes will be computed (IF±, 2F±, 3F-, 1E±, 2E±). If MDEL = 1 only 1F±, 1E± modes will ordinarily be computed. Higher modes will be computed only if the corresponding lower mode fails to exist due to having an elevation angle less than "GMO" or, in the case of an F- mode, non penetration of the E- layer.
PRMUF	If PRMUF < 0.0 a frequency is specified for each hour of the day (GMT) on cards 3.1. If some multiple of MUF values are to be used PRMUF = multiplying constant. In particular when MUF values are to be used PRMUF = 1.00.

2.	Card 2.1	TANT1(I), TANT2(T)
		FORMAT (2A6)
TANT1(I)		The name of the transmitting (and receiving) antenna.
TANT2(I)		Continuation of name.
3.	Card 2.2	GAINS (I,J,K); I = 1,26; J = 1,28; K = 1,IDANT.
		FORMAT (13F5.1)
GAINS (I,J,K)		Power gains in db. 56 GAINS cards are required for each antenna.
<u>NOTE:</u>		Cards of type 2.1 and 2.2 are present only if IDANT = 1,2,3, or 4. The above sequence of 57 cards must then be repreated once for each antenna.
4.	Card 3.1	UF(I); I = 1,24
		FORMAT (12F5.1)
UF(I)		24 frequencies, one for each hour of the day (GMT). If the hourly interval (IHR) is greater than 1, frequencies for the unused hours may be left blank.
<u>NOTE:</u>		Cards of type 3.1 are present only when PRMUF ≥ 0.
5.	Card 4.1	DNOT(I), DNOR(I), PELTR, PIMINT, JSAVE: I = 1,2
		FORMAT (4A6, F10.1, F10.2, I2)
DNOT(I)		Name of transmitter site.
DNOR(I)		Name of target.

PELTR	Elevation of target in kilometers.
PIMINT	Coherent integration time in sec.
JSAVE	Ordinarily blank; when set to 1 the approximation to the ionospheric parameters used for the previous circuit will be used again for the initial iterations in order to (hopefully) reduce running time.
6. Card 4.2 (Option 1)	X1X, Y1Y, X2X, Y2Y, TWR, ITANT, IRANT, MANN, HAO FORMAT (2(F5.2, F6.2), 5X, F3.0, 9X, I2, 9X, I2, I3, 15X, A2)
X1X	Latitude of transmitter to hundredth of a degree; + for north, - for south.
Y1Y	Longitude of transmitter to hundredth of a degree; + for west, - for east.
X2X	Latitude of target to hundredth of a degree; + for north, - for south.
Y2Y	Longitude of target to hunredth of a degree; + for north, - for south.
TWR	Average transmitted power.
ITANT	Power gain of constant gain transmitting antenna (required when IDANT = 0).
IRANT	Power gain of constant gain receiving antenna (required when IDANT = 0).

MANN		Code for selecting man-made noise at receiver input in a 1 Hz bandwidth at 3 MHz (same codes as original ITSA program).
HAO		Customer identification code.
7.	Card 4.2 (Option 2)	X1X, Y1Y, X2X, Y2Y, TWR, ITANT, IRANT, MANN, HAO Format (2(F5.2, F6.2), 5X, F3.0, 9X, I2, 9X, I2, I3, 15X, A2). All variables are as defined for card 4.2 (option 1) except X2X, Y2Y:
X2X		99999
Y2Y		999999
8.	Card 4.3	BNC, AZP, IMP FORMAT (2F8.2, I2)
BNC		Range of target from transmitter.
AZP		Bearing of target from transmitter to hundredth of a degree east of north.
IMP		Code 1 if BNC in nautical miles, 0 if in kilometers.
<u>NOTE:</u>		Card 4.3 is used only with card 4.2 (option 2).
9.	Blank Card	The blank and 9's card must precede the first card 5.1.
10.	9's Card	9's in cols. 1-19.
11.	Card 5.1	MONS, SUNS, GMO FORMAT (22X, I2, F3.0, 39X, F2.0)

MONS	Month
SUNS	Sunspot number
GMO	Minimum acceptable elevation angle of take-off and arrival in degrees. If blank, zero is assumed.
<u>NOTE:</u>	Card 5.1 may be repeated for other months and sunspot numbers.
12. -1 Card	MONS
	FORMAT (22X, I2)
MONS	The last card 5.1 must be followed by "-1 card" with -1 punch in the month field (cols. 23, 24).
Blank Card	The last card of the input data deck must be a blank card.

SECTION IV

OUTPUTS

The outputs are a listing and (optionally) scatter plots, histograms, and cummulative distributions. All of the data which are presently available are contained in the listing, an example of which is shown in Appendix B. A description of each item in the listing is given below.

A. PAGE HEADINGS

First Line

1. a sequence number for circuits;
2. month;
3. sunspot number;
4. customer identification number--the first two characters come from Cols. 71, 72 of the input data card 4.2; the other numbers are derived from great circle distance and backward bearing.

Second Line

1. name and latitude and longitude of transmitter site;
2. great circle bearings from transmitter to target's sub-point on the earth in degrees east of north.

Third Line

1. azimuth deviation of target from antenna boresight, called "off-azimuth" (this quantity is not used in any computation in the program and is a vestige from the original ITSA program);
2. minimum angle (degrees) above the horizon below which a mode will not be considered as a candidate for "best mode" selection for graphical outputs. A mode with an elevation angle below this level (even negative) will, however, appear on the listing.

Fourth Line

1. average transmitted power;
2. measured or assumed man-made noise level at the receiving (and transmitting) antenna site (db < 1 watt at 3 MHz in a 1 Hz bandwidth);
3. required signal-to-noise ratio (not used at present and like "off-azimuth" will always show 0).

Fifth Line

1. backscattering cross section of target (db > 1 meter^2).

Sixth Line

1. target altitude in kilometers;
2. ground range from transmitter to target's sub-point on the earth.

Seventh Line

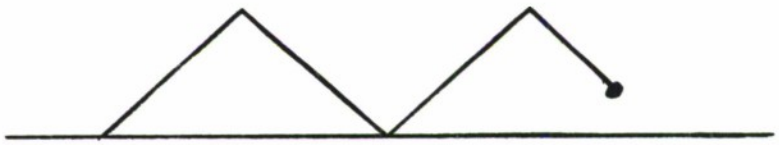
1. antenna name (transmitter and receiver must be the same);

2. coherent integration time.

B. BODY OF PRINT-OUT

The body of the print-out is grouped by hour (Greenwich mean time). The printed information is the same for each hour and is described below by column headings.

MODE: The first group of modes are of the minus type. The last group of modes, listed under "ASCENT CASES," are plus modes. For example, 2F in the first group refers to



and in the last group refers to

The mode always refers to the low ray, ordinary wave.

(fraction) MUF: Monthly median Maximum Usable Frequency in MHz. It is expected that for F2 modes the MUF will be less (or greater) than this value 50% of the time when "fraction" = 1.00. The probability of support for other modes and MUF fractions is listed under the heading P.S. (below). Prints when input code PRMUF > 0.

FREQ: This prints when the input code PRMUF < 0 and is a listing of the requested frequency for each hour.

ANGLE: The take-off and arrival angle to the nearest degree. If this angle is negative, the mode of course does not exist.

LOSS ... DB: The total computed loss in db made up of (1) space loss based on group (equivalent) path distance to target (2) ionospheric absorption loss (3) loss due to ground reflection (4) the transmitting and receiving antenna power gain in the direction of the selected ray path. This loss differs from the loss figure in the original ITSA program in that it does not contain the "expected excess system loss." This is 9 db in temperate regions and greater at higher geomagnetic latitudes. The excess system loss is also absent in "-DBW" and "S/N..DB".

-DBW: Integrated expected signal power at the receiving antenna terminals. DBW is the signal energy, S, in S/N. In terms of report titles we have, when PWR and INTGRTM TIME are expressed in db:

-DBW = -PWR + (LOS..DB) - (TARGET CROSS SECTION) -(INTGRTN TIME).

S/N..DB: Ratio of expected signal energy to expected noise power per Hz. These are expected values for those times when the mode is supported.

P.S.: The probability (percent of the days within the month) that the above mode exists at the above frequency.

PATH-KM: The one-way group path length to the target in kilometers.

GAINS: The transmitting and receiving antenna power gain.

BOUNCE POINT: This refers to the "equivlanet ground point" computed for use in the original ITSA computations. For minus modes it is the ground point visited by the ray immediately after passing the target and for plus modes it is the ground point visited by the ray immediately before striking the target.

AZIMUTH: The great circle bearing from the BOUNCE POINT to the transmitter site in degrees.

ERR-KM: The perpendicular distance by which the ray misses the target in kilometers.

If it is found that, in the cases of an F mode, the ray does not penetrate the E-layer, the comment "MODES DOES NOT EXIST" will appear in place of the above data. The same applies to E modes when the ray penetrates the E layer.

The optional outputs consist of scatter plots, histograms, and cumulative distributions; in every case the data that are displayed are taken from the listing discussed above. For every time interval one mode is selected for display from the (maximum of nine) modes

computed. The selection is made on the basis of maximum signal-to-noise ratio from among those modes which satisfy the "minimum angle requirement." When no minimum angle is specified, any mode with a non-negative elevation angle becomes a candidate for selection.

Data for a number of different combinations of circuits, months, and sunspot numbers can be combined in one graphical display; however, a limit of 1584 data values of one type (such as frequency) exists. The nature of the data presentation is probably made fairly clear simply by examining the examples in Appendix B; however, a brief description may be in order.

Scatter Plot

A point is plotted for every data pair (MUF, ANGLE) that is selected from the listings. Due to the fact that data is quantized for plotting it is obvious that a number of points might overprint at a given location. If this happens a digit equal to the number of points (mod 10) is printed at the location. If only one point is to appear at a given location one of four symbols (., *, +, -) may be selected to distinguish one of four possible circuits, or optionally one of four possible sunspot numbers. Adjustment of range and increment values for the two variables can be handled at present only by data changes internal to the program. A scatter plot of (FREQ, ANGLE) may also be obtained when arbitrary frequencies are requested; however, the overprint problem will presumably be aggravated.

Histogram

Histograms may be obtained showing the distributions of (fraction) of MUF, ANGLE, and S/N values. Data for a single antenna type but any combination of circuits, months, and sunspot numbers may be combined in a single plot (as long as the number of values does not exceed 1584). No attempt is made to classify the points by any parameter, but each histogram is on a separate sheet.

Cumulative Distribution

Cumulative distributions can be plotted for the above histograms. These are simply integrals of the above histograms when the histogram areas are normalized to unity. Plots of one minus the integrals can also be obtained.

APPENDIX A

The problem is to find the change $\Delta\theta$, in θ_o such that the ray path HR will pass through the target, given that the virtual height h' does not change and that specular reflection occurs. If the points H and R (Figure 2) are both rotated through an angle $\Delta\theta$ the angular error is changed to $\epsilon - \Delta\theta$. When R is moved again by $\Delta\theta$ (H fixed) the angle ϵ changes by

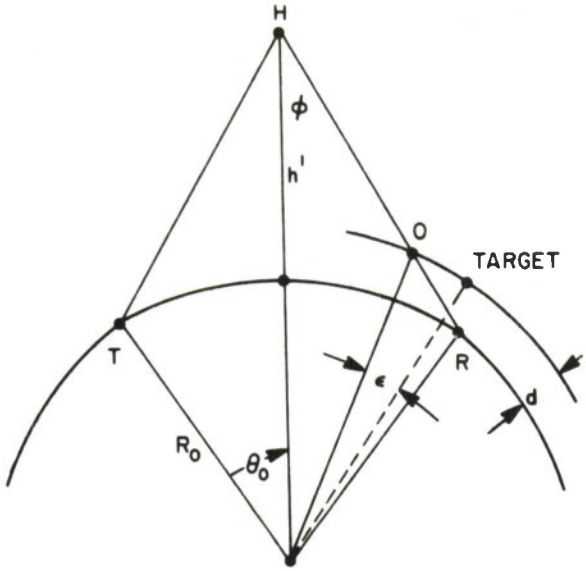
$$\Delta\epsilon = \frac{R_o}{R_o + d} \int_{\theta_o}^{\theta_o + \Delta\theta} \frac{\overline{HO} \sin A}{\overline{HR} \sin A'} \, d\theta$$

where A is the elevation angle at R, and A' the elevation angle at O. This follows since

$$R_o \sin A \, d\theta = \overline{HR} \, d\phi$$

$$\frac{\overline{HO} \, d\phi}{\sin A'} = (R_o + d) \, d\epsilon \quad .$$

where $\overline{HR}$, $\overline{HO}$ are the distances from H to R and H to O respectively.



IA-25,408

Figure 2.

Therefore, $\Delta\theta$ is determined by

$$\Delta\theta + \frac{R_o}{R_o + d} \int_{\theta_o}^{\theta_o + \Delta\theta} \frac{\overline{HO} \sin A}{\overline{HR} \sin A'} \, d\theta = \varepsilon \quad .$$

When $\overline{HO}$, A, $\overline{HR}$, A' are expressed in terms of θ, the integral is found to be difficult to evaluate, so that a gradient method is used, based on

$$\left.\frac{d\varepsilon}{d\theta}\right|_{\theta=\theta_o} = 1 + \frac{R_o}{R_o + d} \left.\left(\frac{\overline{HO} \sin A}{\overline{HR} \sin A'}\right)\right|_{\theta=\theta_o} = 1 + X_o \quad .$$

It can be seen from Figure 3 that

$$\left| \frac{R_o \, \overline{HO} \sin A}{(R_o + d) \, \overline{HR} \sin A'} \right| < 1$$ so that $\Delta\theta$ as computed from the gradient

will always have the correct sign. Moreover, a numerical investigation of the integrand shows it to have (at least for parameter values which are possible in the present application) the general shape shown in Figure 4. From this it is evident that if θ_o is such that X_o is greater than the mean value of the integrand over the integration range then

$$\Delta\theta = \frac{\varepsilon}{1 + X_o}$$

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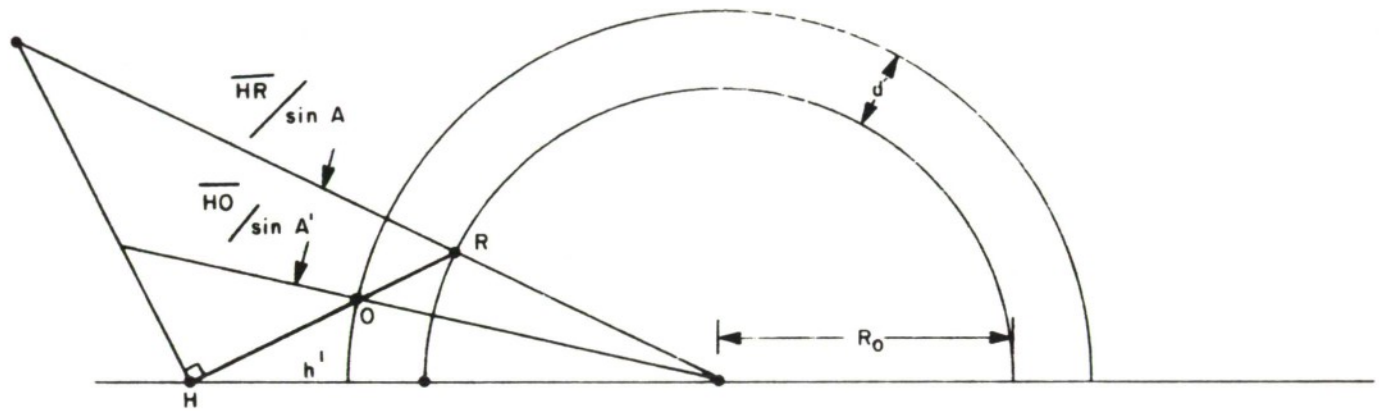


Figure 3.

is too small in absolute value and the new value of θ_o, is closer to and on the same side of the desired value. On the other hand, if the approximation, θ_o, happens to yield a value of X_o, which is less than the mean value of the integrand over the integration range, the new value of θ_o will lie on the opposite side of the desired value with a monotonically decreasing integrand in the integration region. We can conclude that if the elevated target is at a distance from the transmitter such that it can be intersected by the ray in a 1 hop minus mode (with the full hop covering the great circle distance of 180° or less), then the gradient method will converge for any initial value of $0^o \leq \theta_o \leq 180^o$. In the iteration process any value of $\theta_o > 180^o$ should be replaced by 180° and any value $\theta_o < 0^o$ should be replaced by 0°.

IA-25,406

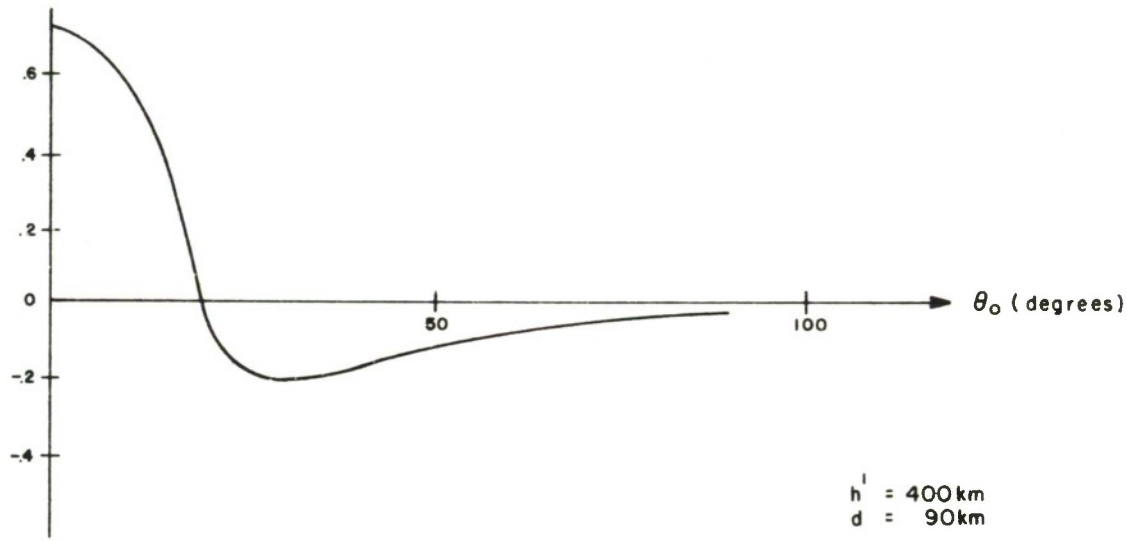


Figure 4

APPENDIX B

LISTING OF SAMPLE INPUT DECK FOLLOWED BY RESULTING OUTPUT

INPUT CARDS

CARD COLUMNS

10 20 30 40 50 60 70 80

```
[illegible] 20.000 4 11112 [illegible] 1.00
WASH.D.C.   KENNEDY          [illegible]
 3892  7704 2839  7926      200          25          25 -3                NS
WASH.D.C.   KENNEDY          75.5        [illegible]
 3892  7704 2769  7858      200          25          25 -3                YS
WASH.D.C.   KENNEDY          107.9       [illegible]
 3892  7704 2765  7777      200          25          25 -3                YS
WASH.D.C.   KENNEDY          142.7       [illegible]
 3892  7704 2738  7687      200          25          25 -3                NS
WASH.D.C.   KENNEDY          187.5       [illegible]
 3892  7704 2706  7578      200          25          25 -3                YS
BLANK CARD
999999999999999999999
                        3100
                        6100
                       -1
BLANK CARD
```

OUTPUT

(ONLY THE LISTING FOR TARGET HEIGHT = 58.1KM IS SHOWN, THE SCATTER PLOT AND HISTOGRAMS SHOW ALL CASES)

OFF AZIMUTH 0 DEG. MIN.ANGLE= 0 DEG.
PWR=[illegible].0KW 3MC/S MAN.[illegible] ERR. S/N= 0DB
TARGET CROSS SECTION=20.00 D2
TARGET ALTITUDE= 50.1KM TARGET GROUND RANGE 1120.7KM
ANTENNA TYPE=CONST.GAIN TRACKING TIME= 1.0000SEC.

GMT= 4 HOURS

MODE	1.00MUF	ANGLE	LOSS..DB	-DBW	S/N..DB	P.S.	PATH-KM	GAINS TRANS	GAINS REC	BOUNCE POINT RANGE	BOUNCE POINT LAT	BOUNCE POINT LONG	AZIMUTH	ERR-KM
1F	10.0	26	202	128	30	50.0	1442.0	25.0	25.0	1335.9	(27.07N	79.44W)	9.0	-.451E-00
2F	6.7	48	221	147	3	50.0	1931.6	25.0	25.0	1272.7	(27.63N	79.34W)	9.1	.135E-00
3F	5.9	60	243	169	-21	50.0	2558.6	25.0	25.0	1254.5	(27.79N	79.31W)	9.1	.128E-00
1E	3.0	6	210	136	3	99.0	1255.3	25.0	25.0	1636.5	(24.39N	79.91W)	8.8	-.103E+01
2E	1.7	20	228	154	-21	99.0	1332.8	25.0	25.0	1370.6	(26.76N	79.50W)	9.0	.492E-01
ASCENT CASES														
1F	8.9	31	216	142	13	50.0	1499.5	25.0	25.0	1125.5	(28.94N	79.11W)	9.2	.968E-01
2F	6.5	50	237	163	-13	50.0	2021.5	25.0	25.0	1173.2	(28.51N	79.18W)	9.1	.135E-00
1E	2.2	13	213	139	-3	99.0	1278.0	25.0	25.0	994.9	(30.10N	78.89W)	9.3	.213E-00
2E	1.4	25	231	157	-26	99.0	1379.3	25.0	25.0	1098.7	(29.17N	79.06W)	9.2	-.157E+01

GMT= 8 HOURS

MODE	1.00MUF	ANGLE	LOSS..DB	-DBW	S/N..DB	P.S.	PATH-KM	GAINS TRANS	GAINS REC	BOUNCE POINT RANGE	BOUNCE POINT LAT	BOUNCE POINT LONG	AZIMUTH	ERR-KM
1F	9.1	26	201	127	30	50.0	1440.4	25.0	25.0	1335.9	(27.07N	79.44W)	9.0	-.666E+00
2F	6.1	48	221	147	1	50.0	1927.1	25.0	25.0	1272.9	(27.63N	79.34W)	9.1	.140E-00
3F	5.3	59	242	168	-21	50.0	2551.2	25.0	25.0	1254.7	(27.79N	79.31W)	9.1	.130E-00
1E	3.0	6	210	136	4	99.0	1255.3	25.0	25.0	1636.5	(24.39N	79.91W)	8.8	-.103E+01
2E	1.7	20	228	154	-20	99.0	1332.8	25.0	25.0	1370.6	(26.76N	79.50W)	9.0	.492E-01
ASCENT CASES														
1F	8.1	31	215	141	13	50.0	1497.9	25.0	25.0	1125.5	(28.94N	79.11W)	9.2	.276E-00
2F	5.9	50	236	162	-13	50.0	2017.1	25.0	25.0	1173.2	(28.51N	79.18W)	9.1	.266E-00
1E	2.2	13	213	139	-2	99.0	1278.0	25.0	25.0	994.9	(30.10N	78.89W)	9.3	.213E-00
2E	1.4	25	231	157	-25	99.0	1379.3	25.0	25.0	1098.7	(29.17N	79.06W)	9.2	-.157E+01

GMT=12 HOURS

MODE	1.00MUF	ANGLE	LOSS..DB	-DBW	S/N..DB	P.S.	PATH-KM	GAINS TRANS	GAINS REC	BOUNCE POINT RANGE	BOUNCE POINT LAT	BOUNCE POINT LONG	AZIMUTH	ERR-KM
1F	13.4	21	205	131	34	50.0	1571.0	25.0	25.0	1369.2	(26.77N	79.50W)	9.0	.686E-01
2F	8.4	42	226	152	7	50.0	1718.[illegible]	25.0	25.0	1285.1	(27.52N	79.36W)	9.1	.982E-01
3F	7.1	54	251	177	-19	50.0	[illegible]	25.0	25.0	1262.4	(27.72N	79.33W)	9.1	.117E-00
1E	8.7	6	211	137	22	99.0	1255.3	25.0	25.0	1636.5	(24.39N	79.91W)	8.8	-.103E+01
2E	4.8	20	239	165	-12	99.0	1332.8	25.0	25.0	1370.6	(26.76N	79.50W)	9.0	.492E-01
ASCENT CASES														
1F	11.5	26	218	144	19	50.0	1418.7	25.0	25.0	1105.4	(29.12N	79.07W)	9.2	.624E-01
2F	8.0	45	245	169	-10	50.0	1747.3	25.0	25.0	116[illegible]	(28.60N	79.17W)	9.1	.973E-01
1E	6.4	13	219	145	11	99.0	1276.	25.0	25.0	994.[illegible]	(30.10N	78.89W)	9.3	.213E-00
2E	4.1	25	251	177	-26	99.0	1379.3	25.0	25.0	1098.7	(29.17N	79.06W)	9.2	-.157E+01

5 MAR SSN= 100. FE 19.006
TRANSMITTER SITE WASH. D.C. (38.92N - 77.04W) AZIMUTH 190.3
OFF AZIMUTH 0 DEG. MIN.ANGLE= 0 DEG.
PWR=200.00KW 3MC/S MAN.NOISE=-148 DBW REQ.S/N= 0DB
TARGET CROSS SECTION=20.00 DB
TARGET ALTITUDE= 58.1KM TARGET GROUND RANGE=1220.79KM
ANTENNA TYPE=CONST.GAIN INTGRTN TIME= 1.000SEC.

GMT=16 HOURS

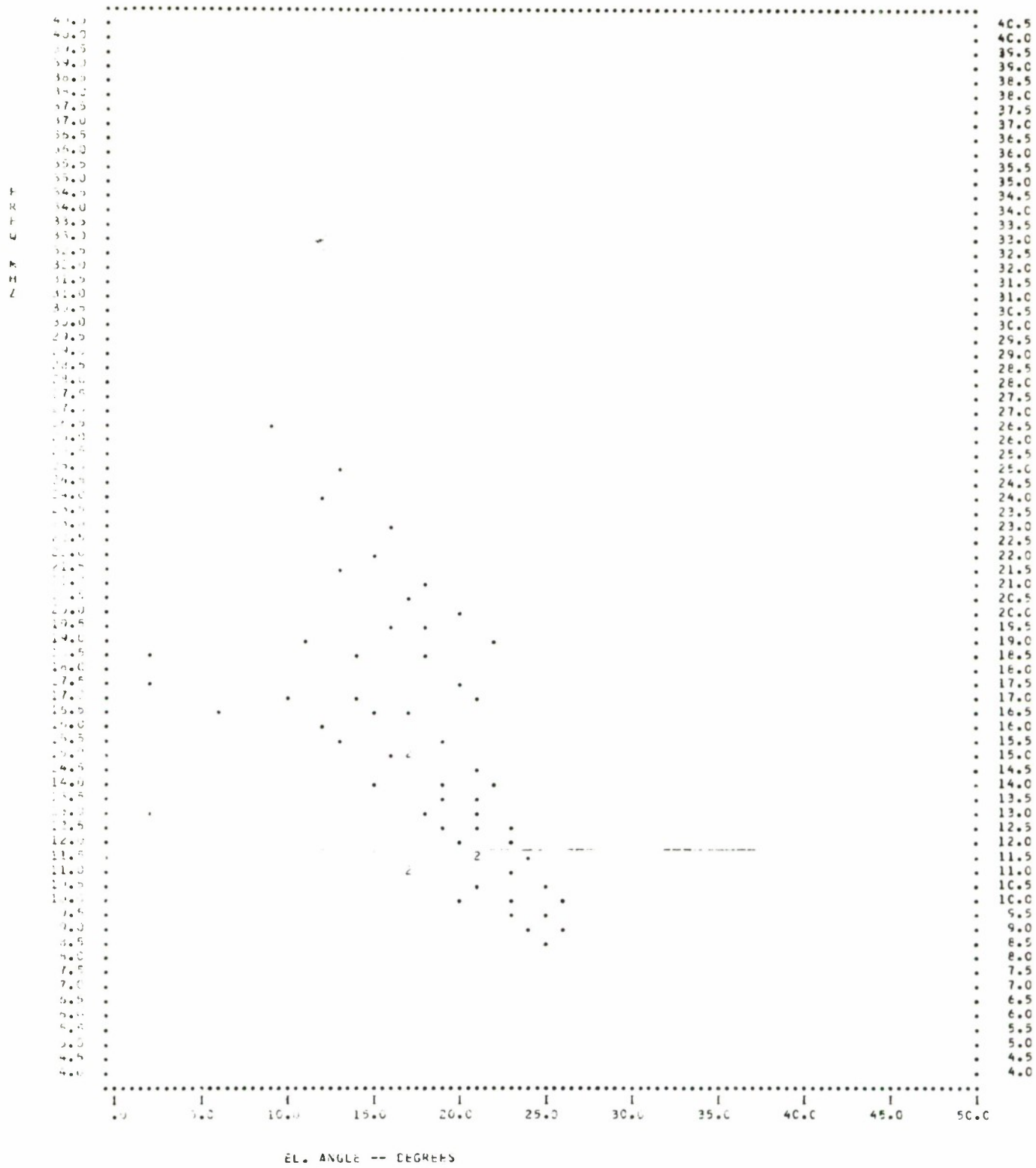
MODE	1.00MUF	ANGLE	LOSS..DB	-DBW	S/N..DB	P.S.	PATH-KM	GAINS TRANS	GAINS REC	BOUNCE POINT RANGE	BOUNCE POINT LAT	BOUNCE POINT LONG	AZIMUTH	ERR-KM
1F	19.4	18	213	139	30	50.0	1345.7	25.0	25.0	1387.8	(26.61N	79.53W)	9.0	.248E-01
2F	11.7	39	243	169	-5	50.0	1638.4	25.0	25.0	1292.0	(27.46N	79.37W)	9.0	.171E-00
3F	9.7	51	279	205	-43	50.0	2046.3	25.0	25.0	1266.6	(27.68N	79.33W)	9.1	.131E-00
1E	15.3	6	225	151	15	99.0	1255.3	25.0	25.0	1636.5	(24.39N	79.91W)	8.8	-.103E+01
2E	8.4	20	277	203	-43	99.0	1332.8	25.0	25.0	1370.6	(26.76N	79.50W)	9.0	.492E-01
ASCENT CASES														
1F	16.2	24	227	153	14	50.0	1391.0	25.0	25.0	1095.3	(29.20N	79.06W)	9.2	.476E-01
2F	11.1	42	261	187	-24	50.0	1716.8	25.0	25.0	1162.9	(28.60N	79.17W)	9.1	.391E+01
1E	11.1	13	236	162	0	99.0	1278.0	25.0	25.0	994.9	(30.10N	78.89W)	9.3	.213E-00
2E	7.1	25	295	221	-63	99.0	1379.3	25.0	25.0	1098.7	(29.17N	79.06W)	9.2	-.157E+01

GMT=20 HOURS

MODE	1.00MUF	ANGLE	LOSS..DB	-DBW	S/N..DB	P.S.	PATH-KM	GAINS TRANS	GAINS REC	BOUNCE POINT RANGE	BOUNCE POINT LAT	BOUNCE POINT LONG	AZIMUTH	ERR-KM
1F	19.1	22	211	137	32	50.0	1381.8	25.0	25.0	1362.7	(26.83N	79.49W)	9.0	.528E-01
2F	12.1	43	238	164	0	50.0	1750.8	25.0	25.0	1282.7	(27.54N	79.36W)	9.1	.129E-00
3F	10.3	55	269	195	-33	50.0	2246.2	25.0	25.0	1260.8	(27.73N	79.32W)	9.1	.125E-00
1E	14.0	6	223	149	16	99.0	1255.3	25.0	25.0	1636.5	(24.39N	79.91W)	8.8	-.103E+01
2E	7.7	20	269	195	-36	99.0	1332.8	25.0	25.0	1370.6	(26.76N	79.50W)	9.0	.492E-01
ASCENT CASES														
1F	16.5	27	225	151	16	50.0	1431.8	25.0	25.0	1109.5	(29.08N	79.08W)	9.2	.778E-01
2F	11.5	46	256	182	-18	50.0	1833.9	25.0	25.0	1162.9	(28.60N	79.17W)	9.1	-.147E+01
1E	10.1	13	233	159	2	99.0	1278.0	25.0	25.0	994.9	(30.10N	78.89W)	9.3	.213E-00
2E	6.5	25	285	211	-54	99.0	1379.3	25.0	25.0	1098.7	(29.17N	79.06W)	9.2	-.157E+01

GMT=24 HOURS

MODE	1.00MUF	ANGLE	LOSS..DB	-DBW	S/N..DB	P.S.	PATH-KM	GAINS TRANS	GAINS REC	BOUNCE POINT RANGE	BOUNCE POINT LAT	BOUNCE POINT LONG	AZIMUTH	ERR-KM
1F	16.9	21	204	130	38	50.0	1379.7	25.0	25.0	1362.7	(26.83N	79.49W)	9.0	-.349E-00
2F	10.7	43	222	148	13	50.0	1744.6	25.0	25.0	1283.1	(27.54N	79.36W)	9.1	.144E-00
3F	9.0	55	244	170	-10	50.0	2235.5	25.0	25.0	1261.1	(27.73N	79.32W)	9.1	.128E-00
1E	3.0	6	210	136	11	99.0	1255.3	25.0	25.0	1636.5	(24.39N	79.91W)	8.8	-.103E+01
2E	1.7	20	228	154	-14	99.0	1332.8	25.0	25.0	1370.6	(26.76N	79.50W)	9.0	.492E-01
ASCENT CASES														
1F	14.5	27	218	144	22	50.0	1429.7	25.0	25.0	1109.5	(29.08N	79.08W)	9.2	.391E-00
2F	10.1	46	240	166	-5	50.0	1828.0	25.0	25.0	1162.9	(28.60N	79.17W)	9.1	-.122E+01
1E	2.2	13	213	139	4	99.0	1278.0	25.0	25.0	994.9	(30.10N	78.89W)	9.3	.213E-00
2E	1.4	25	231	157	-19	99.0	1379.3	25.0	25.0	1098.7	(29.17N	79.06W)	9.2	-.157E+01



THIS GRAPH PLOTS RESULTS FROM COMBINATIONS OF SECTION 1 AND SECTION 2
FOR INTERVALS OF 4 HOURS

SECTION 1		SECTION 2	
TRANSMITTER	TARGET	MONTH	SUNSPOT NUMBER
WASH. D.C.	KENNEDY	MAR	100.
WASH. D.C.	KENNEDY	JUN	100.
WASH. D.C.	KENNEDY		
WASH. D.C.	KENNEDY		
WASH. D.C.	KENNEDY		

FREQUENCY DISTRIBUTION

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11.00   .XXX                                                                     .
11.50   .XX                                                                      .
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13.50   .XXXX                                                                    .
14.00   .XXXX                                                                    .
14.50   .X                                                                       .
15.00   .XX                                                                      .
15.50   .XX                                                                      .
16.00   .XXXX                                                                    .
16.50   .X                                                                       .
17.00   .                                                                        .
17.50   .XXXXX                                                                   .
18.00   .XX                                                                      .
18.50   .X                                                                       .
19.00   .XXX                                                                     .
19.50   .                                                                        .
20.00   .XXX                                                                     .
20.50   .XX                                                                      .
21.00   .X                                                                       .
21.50   .                                                                        .
22.00   .XX                                                                      .
22.50   .X                                                                       .
23.00   .                                                                        .
23.50   .X                                                                       .
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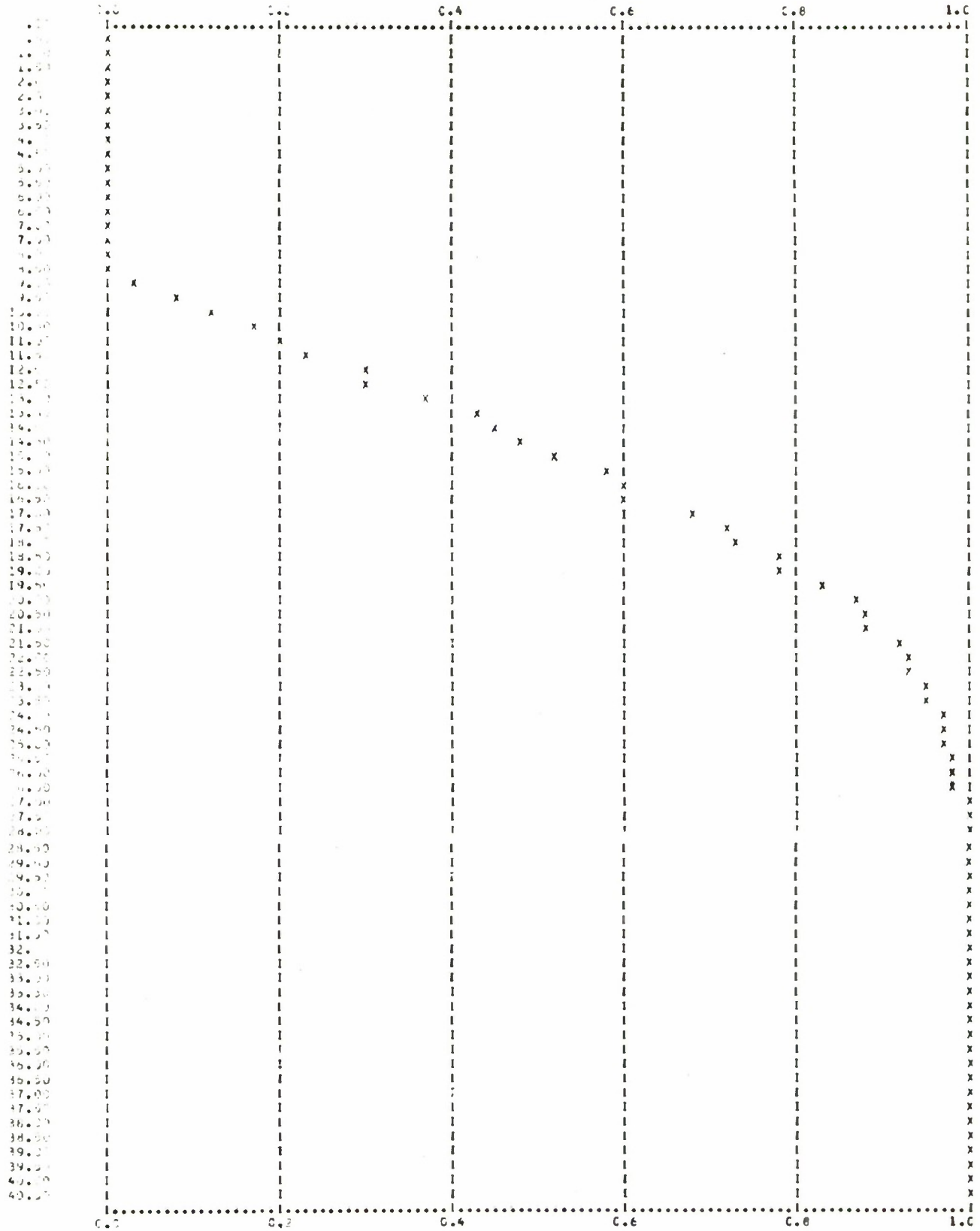
0.0
0.2
0.4
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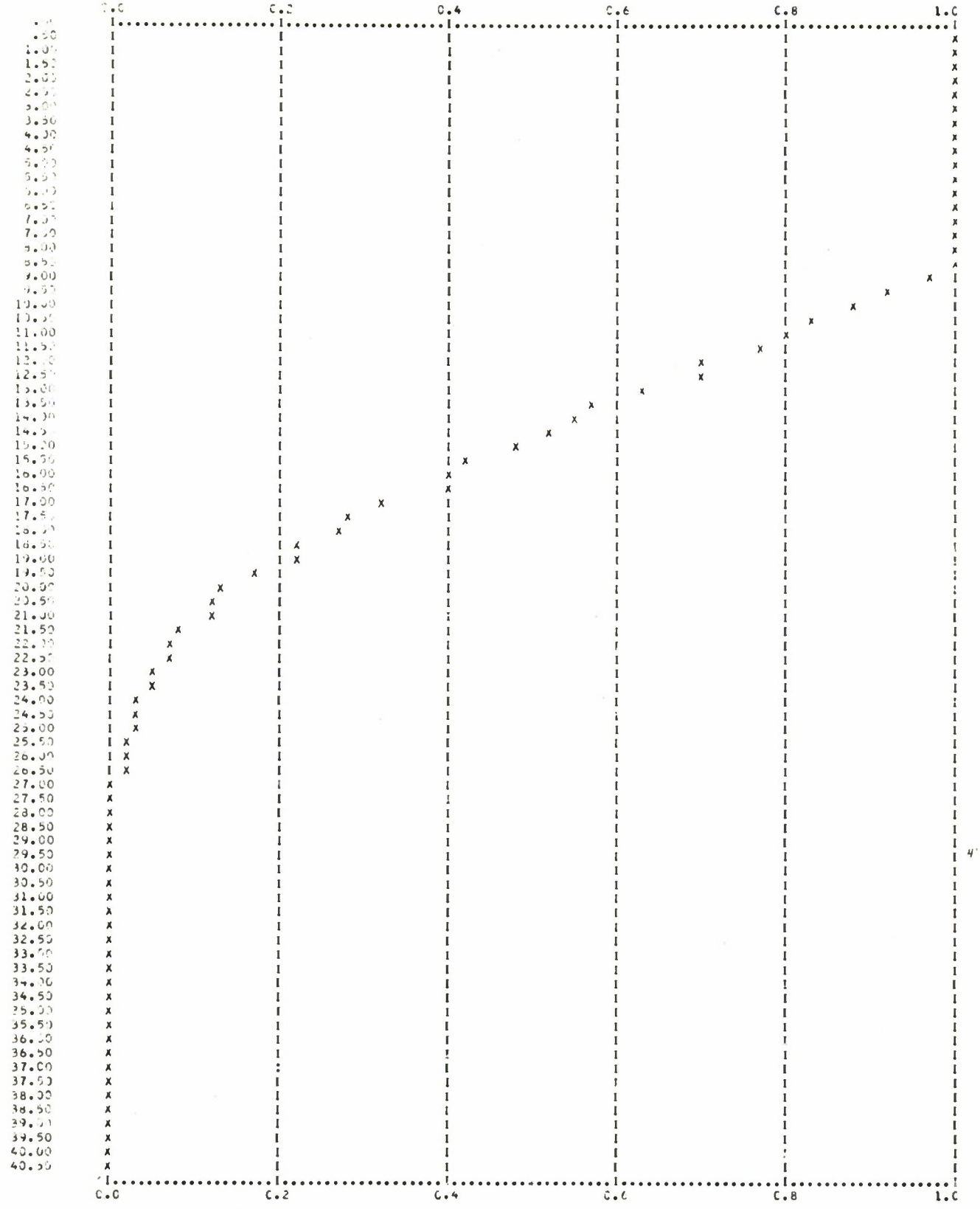
1.0

FREQUENCY DISTRIBUTION



ANGLE DISTRIBUTION

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 .00   ..........................................................................................
1.00   .                                                                                        .
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7.00   .x                                                                                       .
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9.00   .                                                                                        .
10.00  .x                                                                                       .
11.00  .x                                                                                       .
12.00  .x                                                                                       .
13.00  .xx                                                                                      .
14.00  .xxx                                                                                     .
15.00  .xx                                                                                      .
16.00  .xxx                                                                                     .
17.00  .xxx                                                                                     .
18.00  .xxxxxx                                                                                  .
19.00  .xxxx                                                                                    .
20.00  .xxxx                                                                                    .
21.00  .xxxx                                                                                    .
22.00  .xxxxxxxx                                                                                .
23.00  .xx                                                                                      .
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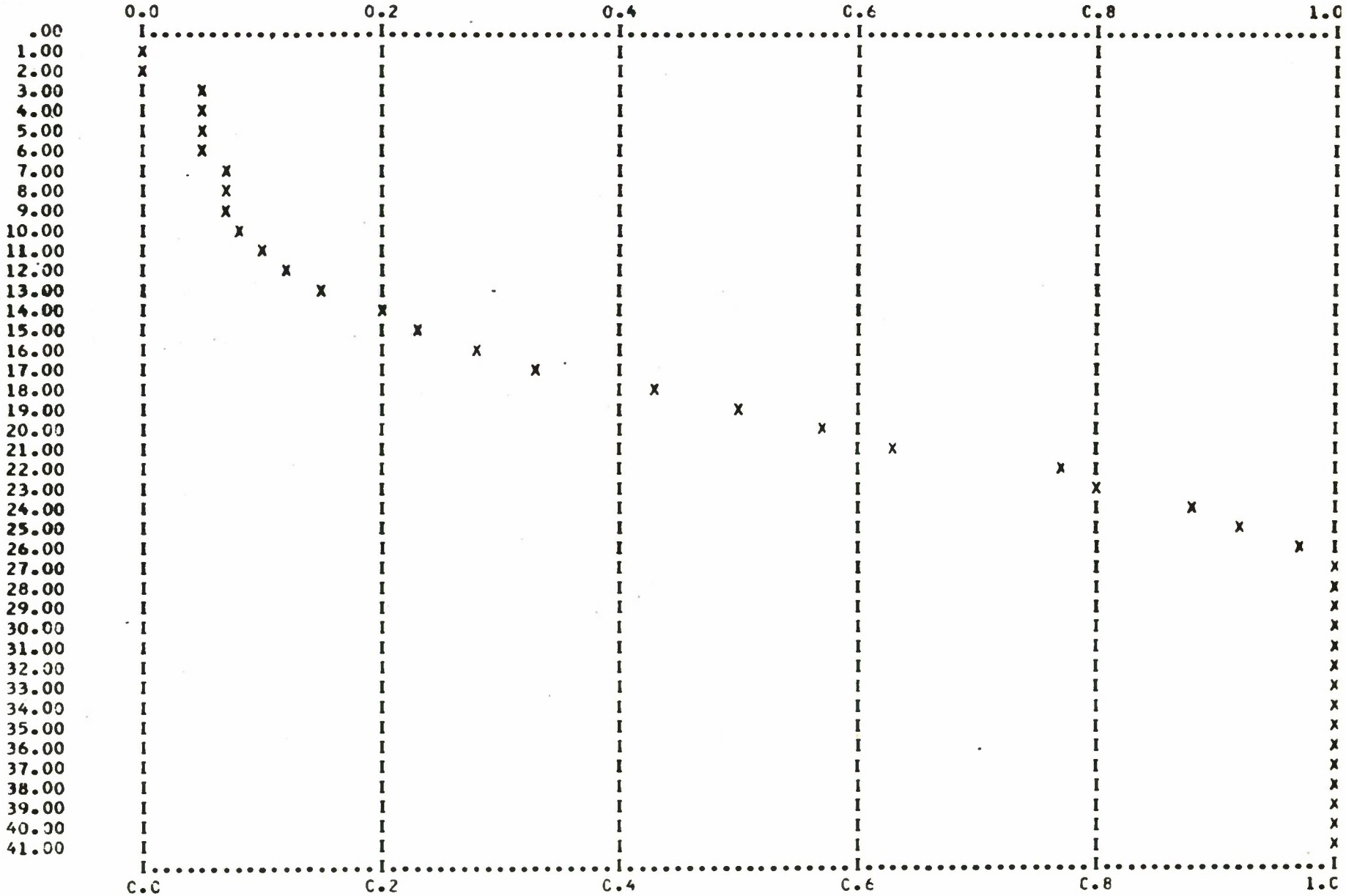

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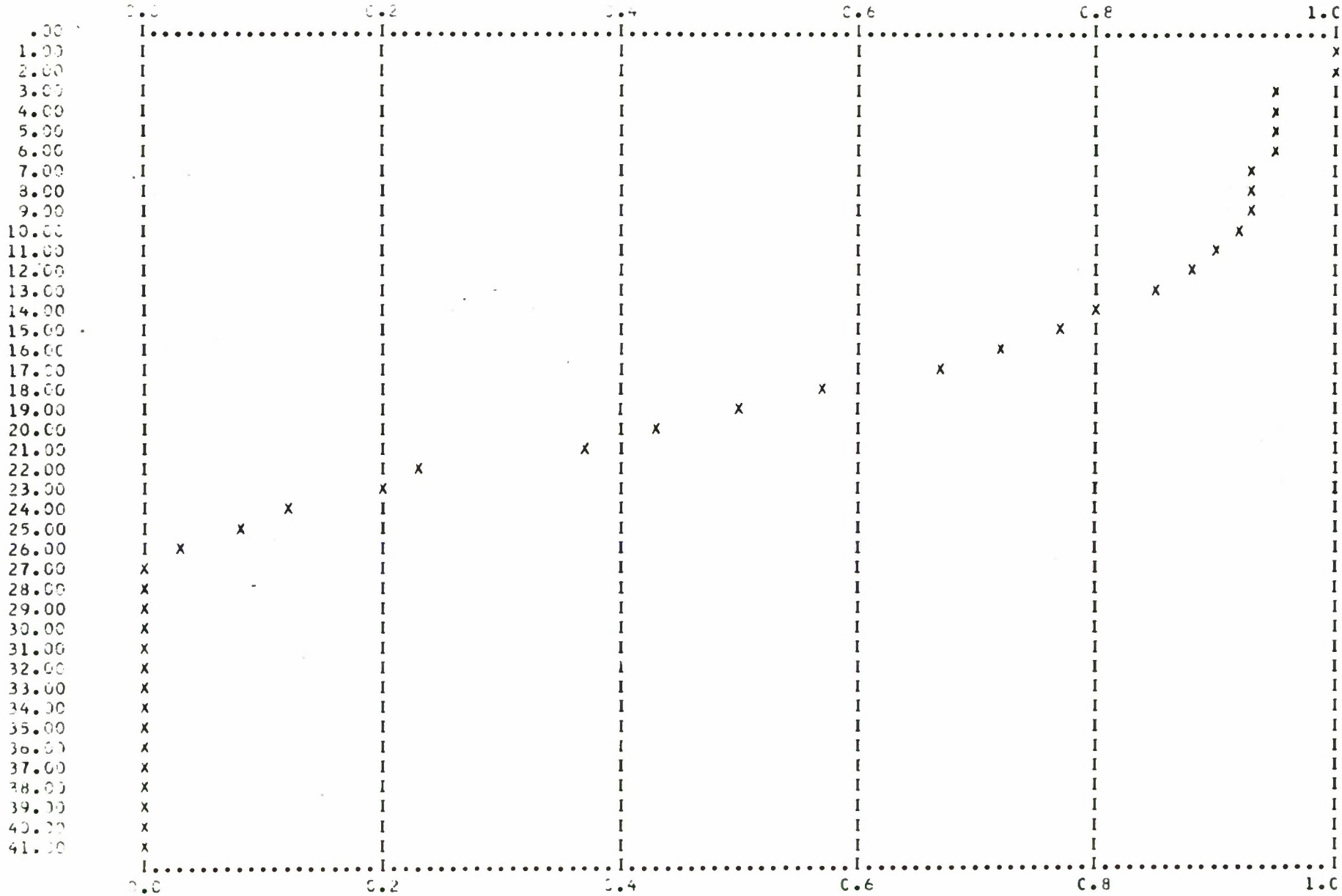

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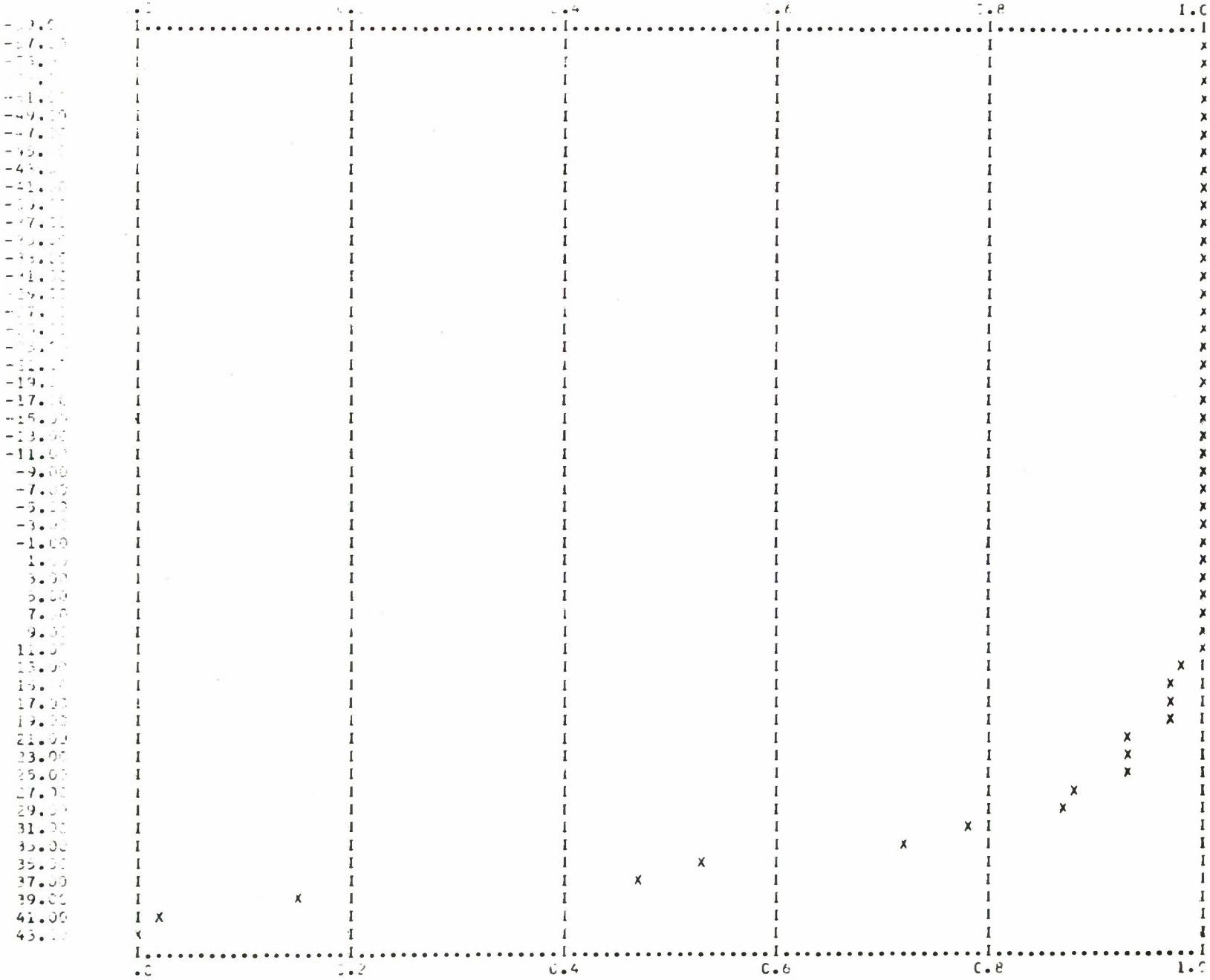

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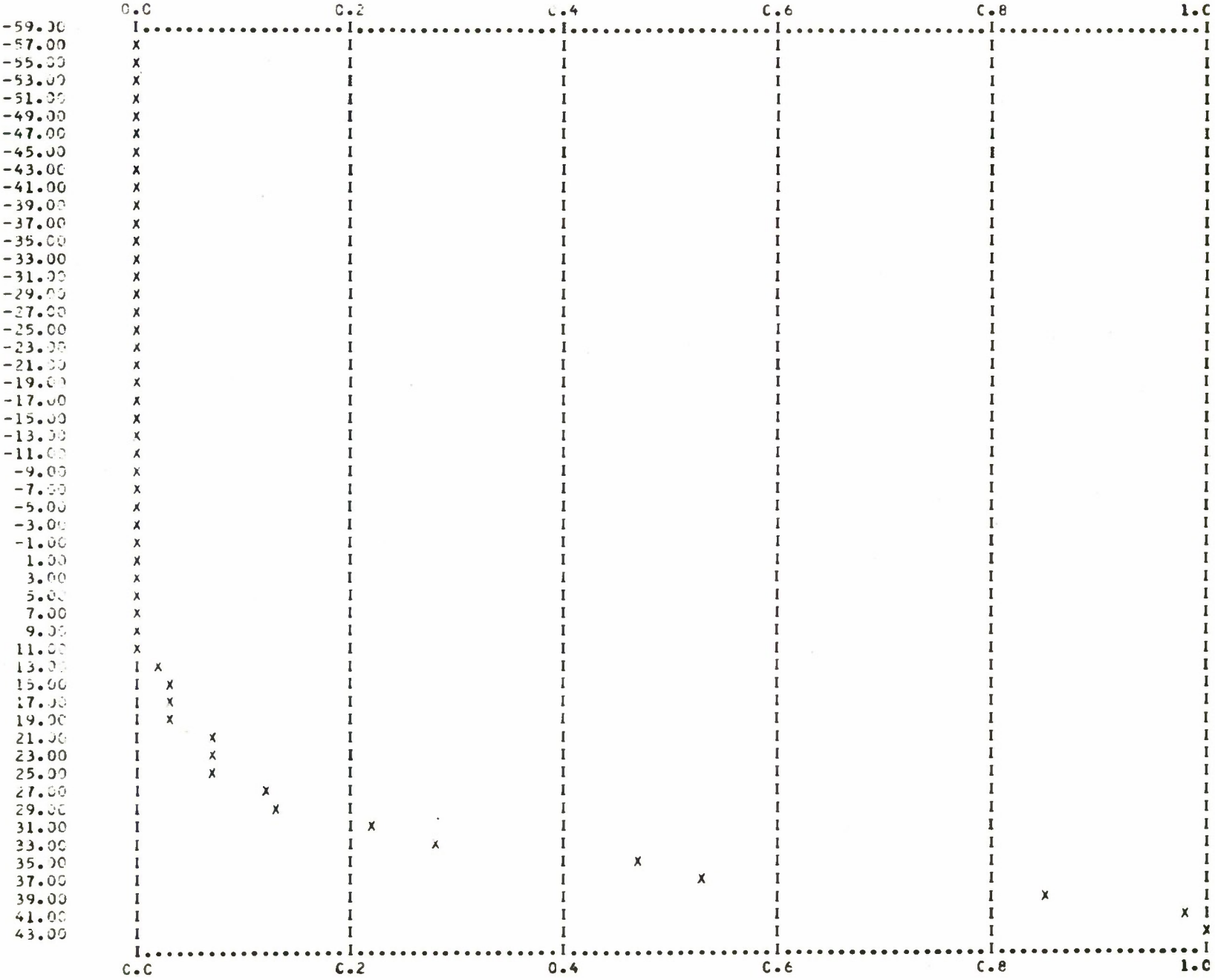

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13. ABSTRACT

The program "High Frequency Prediction Using Parabolic Layer Theories ... ITSA ... 1966" has been modified for two-way radar propagation and for application to elevated targets. In addition to a listing, results can be displayed as scatter plots, histograms, and distributions. The maximum set of sky-wave paths considered is 1F±, 2F±, 3F-, 1E±, 2E±. Antenna gain patterns are defined by tabular values of gains versus frequency and elevation angle.

In this version of the program, arbitrary frequencies are considered but the target must not be in an ionized layer.

DD FORM 1 NOV 65 1473

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
OTH Backscatter						
Ionosphere Prediction Program						
A Signal-to-Noise Ratio						
Mode-Support Probability						
Prediction Program						