ORDER

6310.6

REPRINTED TO
INCLUDE CHANGE 1
DATED 5/13/82

PRIMARY/SECONDARY
TERMINAL RADAR SITING HANDBOOK

JULY 20, 1976

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

Distribution: A-W(AF/AT/FO/RD)-3; A-X(AF/AT/FS)-3 Initiated By: AAF-350

RECORD OF CHANGES

DIRECTIVE NO. 6310.6

CHANGE TO BASIC	SUPPLEMENTS			OPTIONAL USE	CHANGE TO BASIC	SUPPLEMENTS			OPTIONAL USE
1									

FAA Form 1320-5 (5-68) SUPERSEDES PREVIOUS EDITION

GPO : 1968 OF—308-383

CHANGE

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION

6310.6
CHG 1

5/13/82

SUBJ: PRIMARY/SECONDARY TERMINAL RADAR SITING HANDBOOK

1. PURPOSE. This change transmits revised pages to Order 6310.6 to incorporate the ASR-8 antenna used with the ASR-4/5/6/7 radar systems.

2. DISPOSITION OF TRANSMITTAL. This transmittal may be retained.

PAGE CONTROL CHART

Remove Page	Dated	Insert Page	Dated
vii and viii	7/20/76	vii	5/13/82
		viii	5/13/82
ix and x	7/20/76	ix	5/13/82
		x	5/13/82
xi and xii	7/20/76	xi	5/13/82
		xii	5/13/82
xiii and xiv	7/20/76	xiii	5/13/82
		xiv	7/20/76
3(and 4)	7/20/76	3(and 4)	5/13/82
11 and 12	7/20/76	11	7/20/76
		12	5/13/82
		12A and 12B	5/13/82
13 and 14	7/20/76	13	7/20/76
		14	5/13/82
15 and 16	7/20/76	15	5/13/82
		16	7/20/76
27 and 28	7/20/76	27	5/13/82
		28	5/13/82
29 and 30	7/20/76	29	5/13/82
		30	7/20/76
		34A and 34B	5/13/82
35 and 36	7/20/76	35	5/13/82
		36	7/20/76
37 and 38	7/20/76	37	5/13/82
		38	7/20/76
39 and 40	7/20/76	39	7/20/76
		40	7/20/76
55(and 56)	7/20/76	55(and 56)	5/13/82

Distribution: A-W(AF/AT/FO/RD)-3;
A-X(AF/AT/FS)-3

Initiated By: AAF-350

PAGE CONTROL CHART-Continued

Remove Page	Dated	Insert Page	Dated
63 and 64	7/20/76	63	7/20/76
		64	5/13/82
65 and 66	7/20/76	65	7/20/76
		66	5/13/82
67 and 68	7/20/76	67	7/20/76
		68	5/13/82
69 and 70	7/20/76	69	5/13/82
		69A	5/13/82
		69B	5/13/82
		70	5/13/82
71 and 72	7/20/76	71	5/13/82
		71A	5/13/82
		71B	5/13/82
		72	5/13/82
73 and 74	7/20/76	73	5/13/82
		74	5/13/82
		76A (and 76B)	5/13/82
87 and 88	7/20/76	87	5/13/82
		88	7/20/76
93 and 94	7/20/76	93	5/13/82
		94	7/20/76
95 and 96	7/20/76	95	5/13/82
		96	7/20/76
101 and 102	7/20/76	101	7/20/76
		102	5/13/82
103 and 104	7/20/76	103	5/13/82
		104	7/20/76
119 and 120	7/20/76	119	5/13/82
		120	7/20/76
131 and 132	7/20/76	131	5/13/82
		132	5/13/82
133 and 134	7/20/76	133	7/20/76
		134	5/13/82
137 and 138	7/20/76	137	5/13/82
		138	7/20/76
149 and 150	7/20/76	149	7/20/76
		150	5/13/82
165 and 166	7/20/76	165	7/20/76
		166	5/13/82
189 and 190	7/20/76	189	7/20/76
		190	5/13/82
227 and 228	7/20/76	227	5/13/82
		228	7/20/76
		230A	5/13/82
		230B	5/13/82

PAGE CONTROL CHART - Continued

Remove Page	Dated	Insert Page	Dated
		230C	5/13/82
		230D	5/13/82
		230E	5/13/82
		230F	5/13/82
231 and 232	7/20/76	231	5/13/82
		232	5/13/82
233 and 234	7/20/76	233	5/13/82
		234	5/13/82
235 and 236	7/20/76	235	5/13/82
		236	7/20/76
237 and 238	7/20/76	237	7/20/76
		238	5/13/82
		238A (and 238B)	5/13/82
241 and 242	7/20/76	241	5/13/82
		242	7/20/76
243 and 244	7/20/76	243	5/13/82
		244	5/13/82
		244A (and 244B)	5/13/82
245 and 246	7/20/76	245	5/13/82
		246	5/13/82
247 and 248	7/20/76	247	5/13/82
		248	5/13/82
APPENDIX 7			
		1	5/13/82
		2	5/13/82
		3	5/13/82
		4	5/13/82
TRANSPARENCIES			
3-18 thru 3-21	7/20/76	3-18 thru 3-21	5/13/82

GERALD L. THOMPSON
Director, Airway Facilities Service

FOREWORD

1. PURPOSE. This handbook is to provide a complete and useful presentation of all information necessary for selection of terminal ASR/ATCBI radar sites to meet FAA operational requirements.

2. DISTRIBUTION: This directive is distributed to branch level in the Airway Facilities, Air Traffic, and Systems Research and Development Services and the Office of Flight Operations in Washington headquarters; and to branch level in the regional Airway Facilities, Air Traffic, and Flight Standards divisions.

3. CANCELLATIONS. FAA Order AF P 6310.10, "Site Selection of Airport Surveillance Radar," is canceled.

4. BACKGROUND.

   a. As a result of continued growth in air travel, ever more severe demands are being placed upon FAA facilities and personnel. These demands have resulted in general upgrading and expansion of all FAA radar and signal/data processing capabilities. Inasmuch as the site selected for installation of radar and beacon equipment has great impact on the operational capability of the equipment installed, it is important that all possible care be taken to optimize the site selection process. Optimum site selection must give appropriate consideration to all of the specific operational equipment and economic factors involved. These include radar coverage, compatibility with locational restrictions imposed by existing FAA facilities and equipment, interference, ground clutter, vertical lobing, false targets, reflections, propagation effects, environmental effects, land acquisition, site establishment, and maintenance costs.

   b. Preparation of this handbook was undertaken in response to a clear need for establishing uniform and technically appropriate practices for ASR/ATCBI site selection. Utilization of such practices will allow superior future site selection at a lower net long-term cost to FAA. The handbook itself was prepared as part of a 6-month study of FAA regional site selection practices, and incorporates the best of such practices into a single document for general use.

5. RELATED DOCUMENTS. The information contained in this handbook was obtained from previous FAA siting documents, FAA headquarters and regional engineering personnel, FAA technical specifications and instruction manuals, and other more general sources. Specific document references are made in the text, with a complete reference index at the end of the handbook.

6. APPLICATION. The information and criteria set forth in this handbook are applicable to the siting of new and/or relocated facilities, and to the correction of siting problems.

7. SCOPE.

a. This handbook covers site selection and report preparation for ASR-4B, 5, 6, 7, and 8, and ATCBI-3, 4, 5. System data and siting procedures presented represent current practices and may require periodic updating. Charts and graphs incorporated herein were prepared with this in mind, however, so as to allow for extended utility even in the event of minor handbook modifications.

b. Because of the assumptions made in order to reduce the equations contained in this handbook to a usable form, the user should be aware that coverage predicted by the techniques described herein will necessarily be only a close approximation to the actual coverage obtainable from a given installation. The principal value of the selection techniques and equations presented is as a realistic yardstick for the comparison of various sites under consideration.

8. HANDBOOK ORGANIZATION. The handbook is organized into three chapters, each covering a major aspect of the siting problem. Chapter 1 provides a description of the radar and beacon systems with emphasis on those aspects that are most relevant to the siting engineer. Chapter 2 contains a description of several special problem areas of concern in radar siting, and provides detailed technical data to aid engineers in optimizing their site selection. Chapter 3 deals with the actual conduct of a siting operation. It contains procedures for preliminary studies and selection, site surveys, data analysis, and siting report preparation. Special additional material is presented in appendixes at the end of the handbook.

9. REVISION OF HANDBOOK. Revision of the material in this handbook will be made periodically as required. Such revisions will be initiated and controlled by Airway Facilities Service. Any errors noted or changes recommended should be addressed to Airway Facilities Service, Attention: Chief, AAF-300.

Warren C. Sharp
WARREN C. SHARP
Director, Airway Facilities Service

TABLE OF CONTENTS

Page No.

Page No.

--- -

--- LIST OF FIGURES

Figures		Page No.

Figures | Page No.

Figures		Page No.

Figures | Page No.

CHAPTER 1. EQUIPMENT CONSIDERATIONS

SECTION 1. INTRODUCTION

1. INTRODUCTION. This chapter of the ASR/ATCBI siting handbook constitutes a short review of the operation of air traffic control equipment commonly installed at terminal radar sites. Topics to be covered include a brief description of system functions together with a discussion of those system characteristics and parameters which are important to site selection or siting data analysis. It should be noted, however, that this chapter is not intended as a comprehensive general treatment of radar and beacon system operation, but rather as a brief highlighting of those ASR and ATCBI features important to site selection. For more detailed textbook treatment the reader is referred to references 1 and 2.

SECTION 2. AIRPORT SURVEILLANCE RADAR

2. FUNCTION.

a. A surveillance radar consists basically of an antenna, a transmitter, a receiver, and an indicator. The transmitter generates short pulses of radio energy that are radiated into space by the antenna. A small portion of this energy is returned to the radar after striking reflecting objects. Echo energy picked up by the antenna is sent to the radar receiver for amplification and detection, and is then displayed on an indicator for operational purposes. Since radar energy travels at the speed of light, distance to the reflecting object can be determined on the basis of time required for the radar pulse to travel to and from the object. The bearing of the target is determined by the direction in which the antenna beam is pointed when the reflected pulse is received.

b. The Airport Surveillance Radar (ASR), as its name implies, is a surveillance radar system designed to detect the presence and location of aircraft in the vicinity of an airport terminal facility and allow its control from the airport control tower TRACON (terminal radar approach control) facility. (The term TRACON, as used in this handbook, may be considered as interchangeable with the designations for other types of traffic control facilities (i.e., TRACAB, IFR room).) Use of ASR equipment is extremely important to the expeditious movement of air traffic, especially during inclement weather conditions. As such, the ASR has been designated as the PRIMARY RADAR to distinguish its functions from other terminal radar equipment. While this latter designation may be subject to alteration as more sophisticated beacon radars assume a larger role in terminal operations, the nature of ASR equipment is such that it will probably always be required. A surveillance radar is the only type of system capable of providing information on the presence and location of non-beacon equipped aircraft in the controlled airspace.

3. EQUIPMENT PARAMETERS. The important parameters and features of all ASR equipments commonly employed at FAA terminals are tabulated in table 1-1.

4. AREA COVERAGE. The ASR is capable of detecting aircraft that are within its line-of-sight as the antenna rotates azimuthally through 360°. The precise region of area coverage provided by an ASR is dependent upon (a) the parameters of the particular radar, (b) the target being detected, and (c) the nature of the radar site. Currently, the FAA utilizes Airport Surveillance Radars designated as ASR-4B, 5, 6, 7, or 8. (ASR-3 radars are not covered in this discussion since all of this equipment is expected to be replaced in the near future.) The pertinent parameters of these systems are presented in table 1-1, and typical vertical coverage charts are given in figures 1-1 through 1-3. (More detailed coverage charts are presented in chapter 2.) It should be noted that ASR equipment is used both for detection of relatively distant aircraft and for positional monitoring of traffic very near the airport. Air traffic controllers are desirous of maintaining continuous ASR coverage of aircraft virtually until runway touchdown.

5. CHARACTERISTICS PERTINENT TO SITE SELECTION.

a. Antenna Coverage. The function of the ASR antenna system is to radiate the transmitter output energy in a directional beam, and receive the returning echo energy, passing it on to the receiver with a minimum of loss. An electronic switching technique is used to switch the antenna from transmitter to receiver, thereby facilitating operation and providing protection against receiver overload during the time of pulse transmission. This occurs during (nominally) 0.1% of the prf cycle.

(1) Antenna Pattern. Probably the most important aspect of an antenna's performance is its directive radiation pattern wherein the transmitted energy is concentrated in some particular direction(s). ASR antennas employ $\csc^2\theta$ fan beam patterns as illustrated in figures 1-4 and 1-5. The actual radiation patterns of "as installed" ASR antennas will differ from the free-space patterns shown because of the effects of the ground and other nearby objects.

(2) Antenna Gain. The gain of an antenna is a quantitative measure of the power transmitted in a given direction as compared to some reference standard. Normally an isotropic radiator is used as a reference, and antenna gain is given in decibels above the isotropic level (dBir). Although antenna gain is actually angle dependent, a single number, the maximum value of the antenna's gain, is frequently used to describe antenna performance. Maximum gain for ASR antennas is approximately 34 dBir, as tabulated above.

TABLE 1-1 ASR PARAMETERS AND FEATURES

RADAR PARAMETERS/FEATURES		ASR-4B	ASR-5 and 6	ASR-5E and 6E	ASR-7	ASR-7E	ASR-8
PARAMETERS							
Nominal PPI Range		60 nmi	60 nmi	60 nmi	60 nmi	60 nmi	60 nmi
Accuracy							
Azimuth		±1% displ.dia.	±1% displ.dia.	±1% displ.dia.	±1% displ.dia.	±1% displ.dia.	±1% displ.dia.
Range		±0.02R	±0.02R	±0.02R	±0.02R	±0.02R	±0.02R
Resolution							
Azimuth		2.25°	2.25°	2.25°	2.25°	2.25°	2.25°
Range		1.5 τc/2	1.5 τc/2	1.5 τc/2	1.5 τc/2 or 1%	1.5 τc/2 or 1%	1.5 τc/2 or 1%
Antenna							
Main							
Pattern Shape		$csc^2\theta$	$csc^2\theta$	$csc^2\theta$	$csc^2\theta$	$csc^2\theta$	$csc^2\theta$
Beamwidth							
Azimuth		1.5°	1.5° ± 0.15°	~1.45°	~1.5°	~1.45°	~1.45°
Elevation		~5°	~5°	6.2°	5°	6.2°	6.2°
Max Gain	dBir	+34	+34	+33.85	+35	+33.85	+33.85
Scan Rate	rpm	12.68 or 15	15	12.5	13	12.5	12.5
Polarization		Vert/Circular	Vert/Circular	Vert/Circular	Vert/Circular	Vert/Circular	Vert/Circular
Passive							
Pattern Shape				$csc^2\theta$		$csc^2\theta$	$csc^2\theta$
Beamwidth							
Azimuth				~1.45°		~1.45°	~1.45°
Elevation				6.75°		6.75°	6.75°
Max Gain	dBir			+33.75		+33.75	+33.75
Polarization				Vert/Circular		Vert./Circular	Vert/Circular
RF Frequency	MHz	2700-2900	2700-2900	2700-2900	2700-2900	2700-2900	2700-2900
PRF	pps	710-1200	710-1200	710-1200	710-1200	710-1200	710-1200
Peak Power Output		400 kW	400 kW	400 kW	425 kW	425 kW	1 MW
Pulse Duration, τ	(μs)	0.833	0.833	0.833	0.833	0.833	0.6 ± 0.05 μs
Receiver Noise Figure	(dB)	4.0	4.0	5.0	4.75	5.1	4.0
Sensitivity							
Normal	(dBm)	-109	-109	-108	-108	-108	-110
MTI	(dBm)	-107	-107	-106	-106	-106	-108
Normal Log	(dBm)	-	-	-	-106	-106	-109 to -110
MTI Log	(dBm)	-	-	-	-104	-104	-106 to -108
MTI Improvement Factor	(dB)						34
Subclutter Visibility	(dB)	25	25	25	25	25	28
Cancellation Ratio	(dB)	30	30	30	30	30	
Antenna Tilt Capability (Nose of Beam)		-2° to +7°	-2° to +7°	1/-2.5° to +2.5°	-2° to +7°	1/-2.5° to +2.5°	1/-2.5° to +2.5°
IF Bandwidth							
Normal Receiver	(MHz)	2.1 - 2.7	2.1 - 2.7	2.1 - 2.7	2.1 - 2.7	2.1 - 2.7	2.0 - 2.33
MTI Receiver	(MHz)	4 - 5	4 - 5	4 - 5	4 - 5	4 - 5	4 - 5
Maximum Remoting Cable Length (Feet)		12000	12000	12000	12000	12000	20000
RG-11A/U Armored (for direct burial)							
RG-216U (for burial in ducts or conduit)							
FEATURES							
• Overall Functions							
IACC							
STC-1					x	x	x
-2					x	x	x
-3					x	x	x
-4					x		
• Normal Receiver							
IACC		x	x	x			
FTC-1		x	x	x			
-2		x	x	x			
STC-1		x	x	x			
-2		(adj at site)	(adj at site)	(adj at site)			
-3							
-4							
Integr. (Enhanced) Video		x	x	x	x	x	x
R.C. Integr. Video		x	x	x			
• Log FTC Normal Receiver							
Integr. (Enhanced) Video					x	x	x
R.C. Integr. Video							
• MTI Receiver							
Single Canceler A		x	x	x	x	x	x
B		x	x	x	x	x	x
Double Canceler		x	x	x	x	x	x
Double Canceler w Veloc. Shape		x	x	x	x	x	x
FTC-1		x	x	x			
-2		x	x	x			
STC-1		x	x	x			
-2		(adj at site)	(adj at site)	(adj at site)			
-3							
-4							
PRF Stagger		x	x	x	x	x	x
Integr. (Enhanced) Video					x	x	x
R.C. Integr. Video		x	x	x			
• Log FTC, MTK Receiver							
Integr. (Enhanced) Video					x	x	x
R.C. Integr. Video							

1/Reference to lower 3 dB point.

τ = duration of transmitted pulse
c = velocity of light
dBir = dB with respect to an isotropic radiator

FIGURE I-1. FREE-SPACE ASR-4B, 5, AND 6 COVERAGE OF T-33 AIRCRAFT

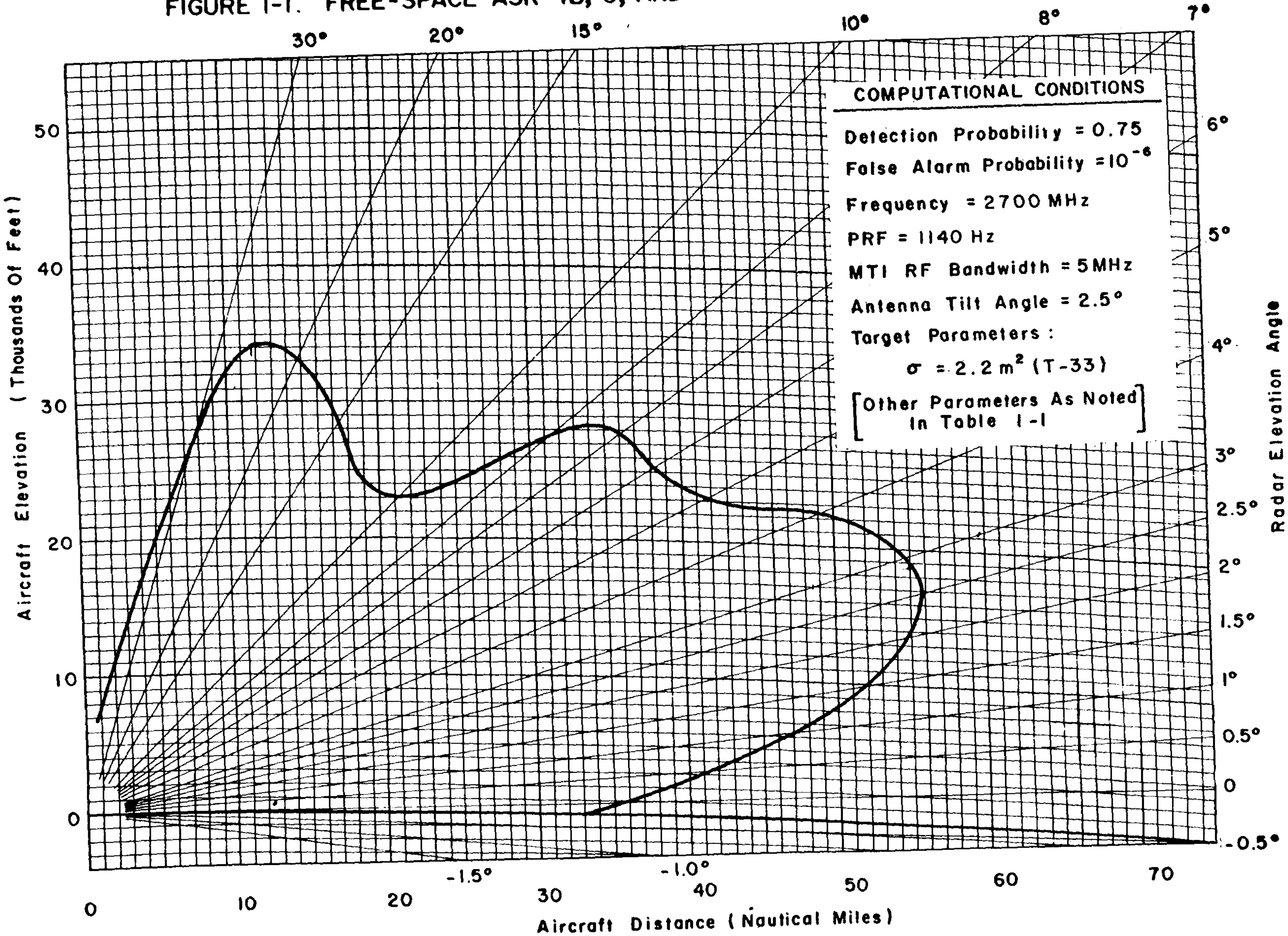


FIGURE I-3. FREE-SPACE ASR-8 COVERAGE OF T-33 AIRCRAFT

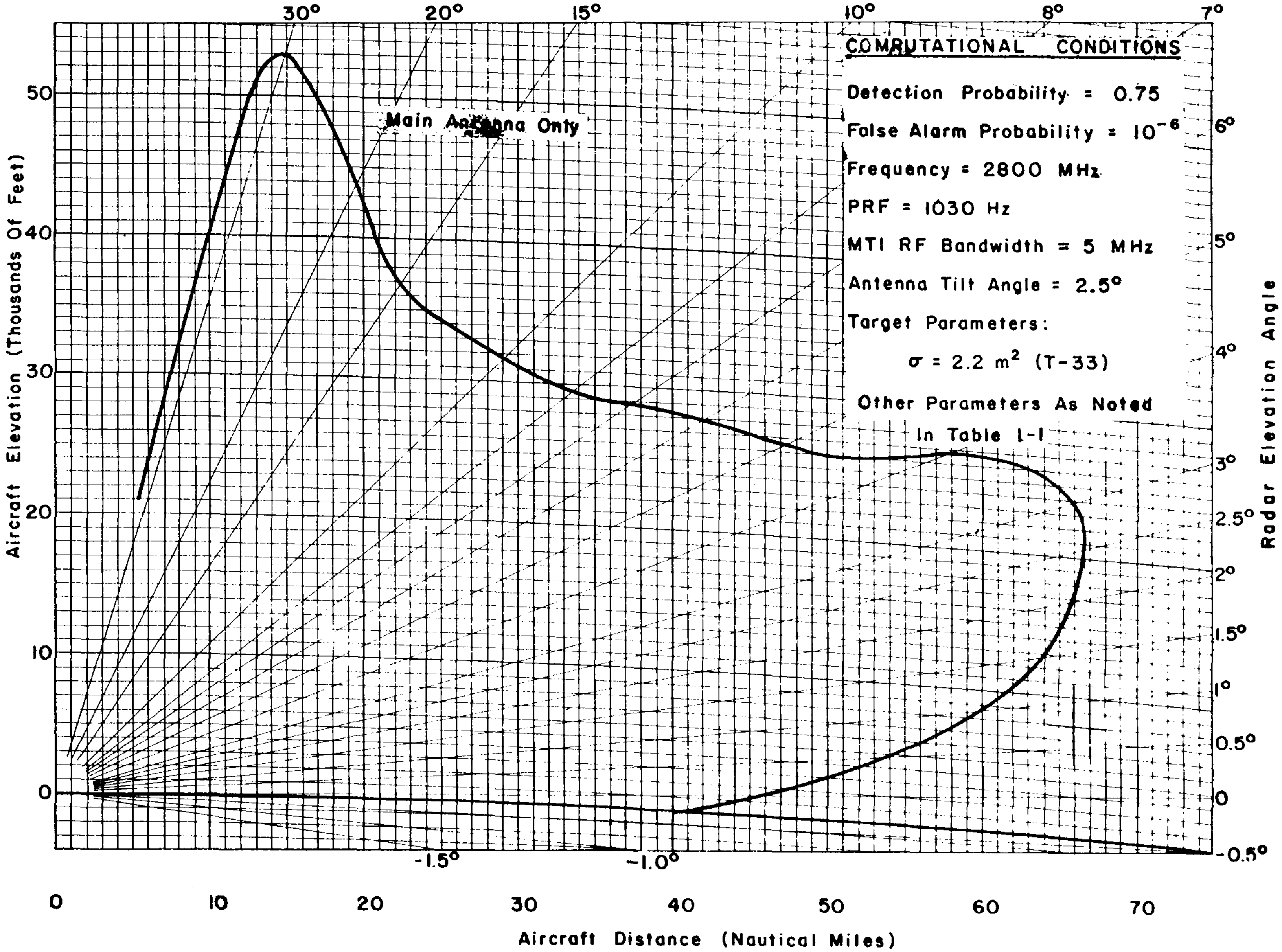
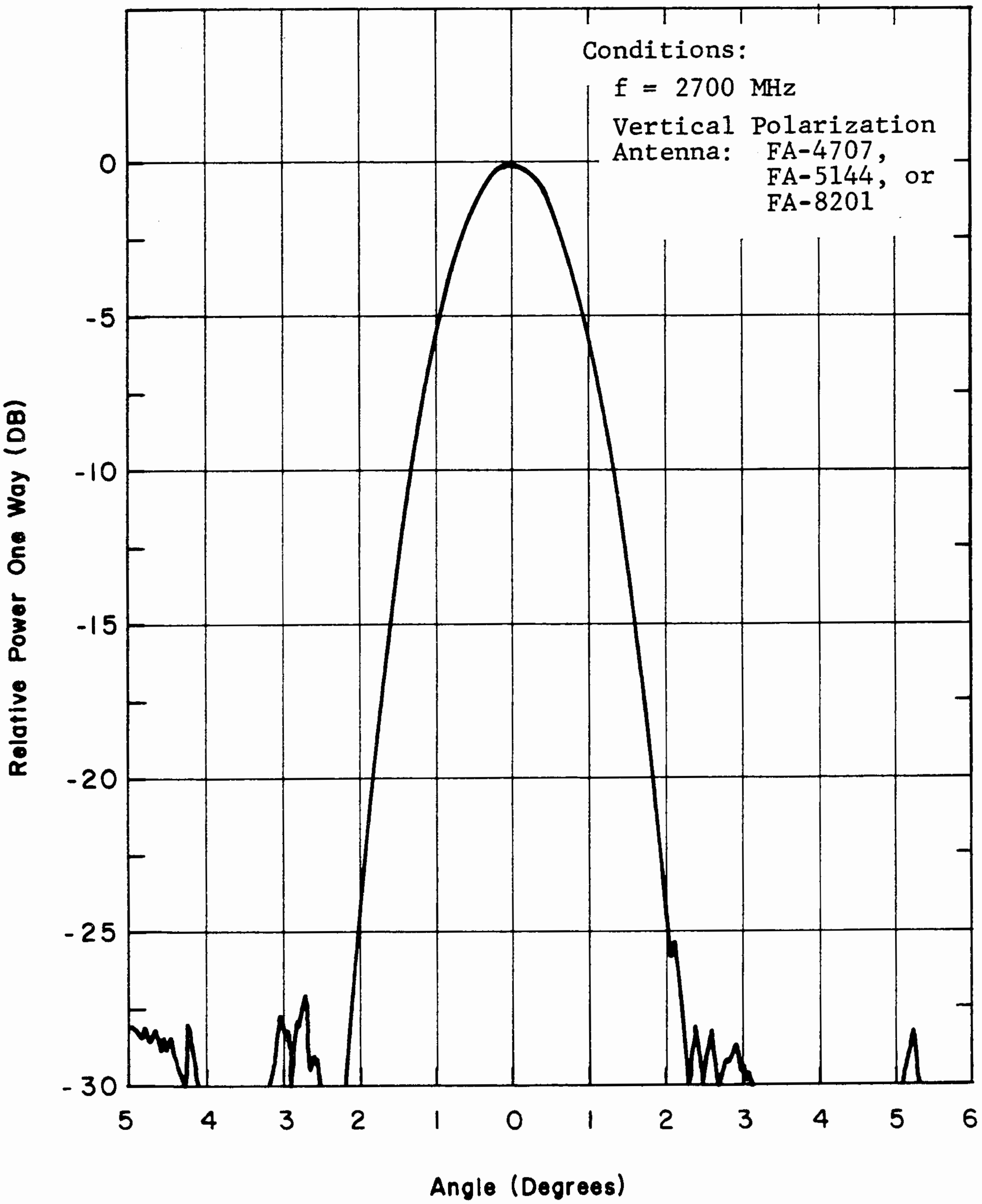


FIGURE 1-5. TYPICAL ASR FREE-SPACE ANTENNA AZIMUTH PATTERN



(c) Because of the broad elevation beam of the ASR antenna, target altitude cannot be determined. Other means are employed for acquisition of this important information. Antenna beamwidths for current ASR systems are tabulated in table 1-1.

(4) Polarization. The direction of polarization of an antenna is defined as the direction traced in a plane by the tip of the radiated electric field vector. Most radars are linearly polarized; that is, the direction of the electric field vector is constant as a function of time. The polarization may also be elliptical or circular. Elliptical polarization may be considered as the combination of two linearly polarized waves of the same frequency, traveling in the same direction, which are perpendicular to each other in space. The relative amplitudes of the two waves and their phase relationship can assume any values. If the wave amplitudes are equal, and if they are 90° out of (time) phase, the polarization is circular. Circular and linear polarizations are special cases of elliptical polarization. More details on polarization can be found in references 3 and 4. ASR radar equipment is arranged to operate in either vertical or circular polarization as selected by the radar operator. Linear polarization (lp) normally produces greater signal return because of higher values for the product of antenna gain and target cross section in this polarization. Circular polarization (cp) is used at times, however, to reduce clutter produced by rain, fog, or other weather disturbances. The impact of reduced radar range coverage during operation with cp and of its effect on tangential course problems should be considered when establishing a radar site. In the absence of conclusive experimental data indicative of the degree of cp coverage reduction for a given aircraft, the detection range with cp may be assumed to be approximately 75% of the range with lp. This is based upon an interpolation of data from p. 147 of reference 2.

(5) Scan Rate. The rate at which the ASR fan beam antenna rotates on its pedestal is called the scan rate. This rate is important to radar operation since it, together with prf and beamwidth, determines the number of radar pulses that will impinge upon a target during the passage of the search beam. Scan rate is equivalent to the data refresh rate supplied to the traffic controller. It is also important in this regard, since controllers normally desire a high refresh rate. The fixed scan rates for current ASR's are tabulated in table 1-1.

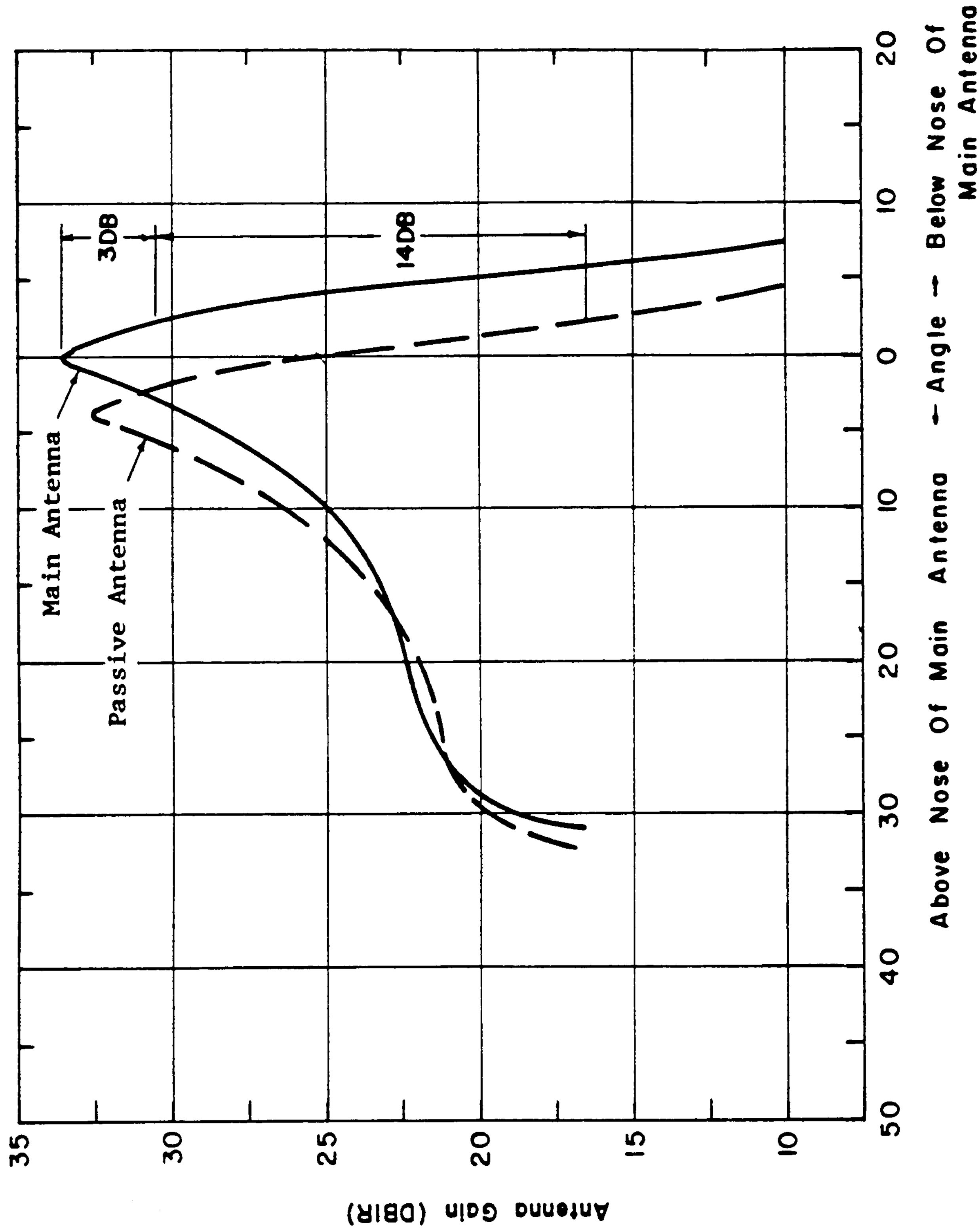
(6) Passive Horn.

(a) On ASR-8 equipment (as noted in table 1-1) a second feedhorn is employed with the radar reflector to provide an alternate receiving antenna pattern that achieves higher input signal-to-clutter ratios for close-in targets. The

* (7) Antenna Height

(a) The installation height of the ASR antenna is important to the overall radiation characteristics insofar as these are modified by the reflecting of the terrain surface. The electrical height for single beam antennas is defined by the horizontal center line of the feed horn. This height is approximately 8 feet above the tower platform. For dual beam antennas, the electrical height is defined as that point on the reflector with maximum energy concentration. This occurs at approximately 10.2 feet above the tower platform. *

FIGURE I-6. ASR-8 ANTENNA DESIGN PATTERN



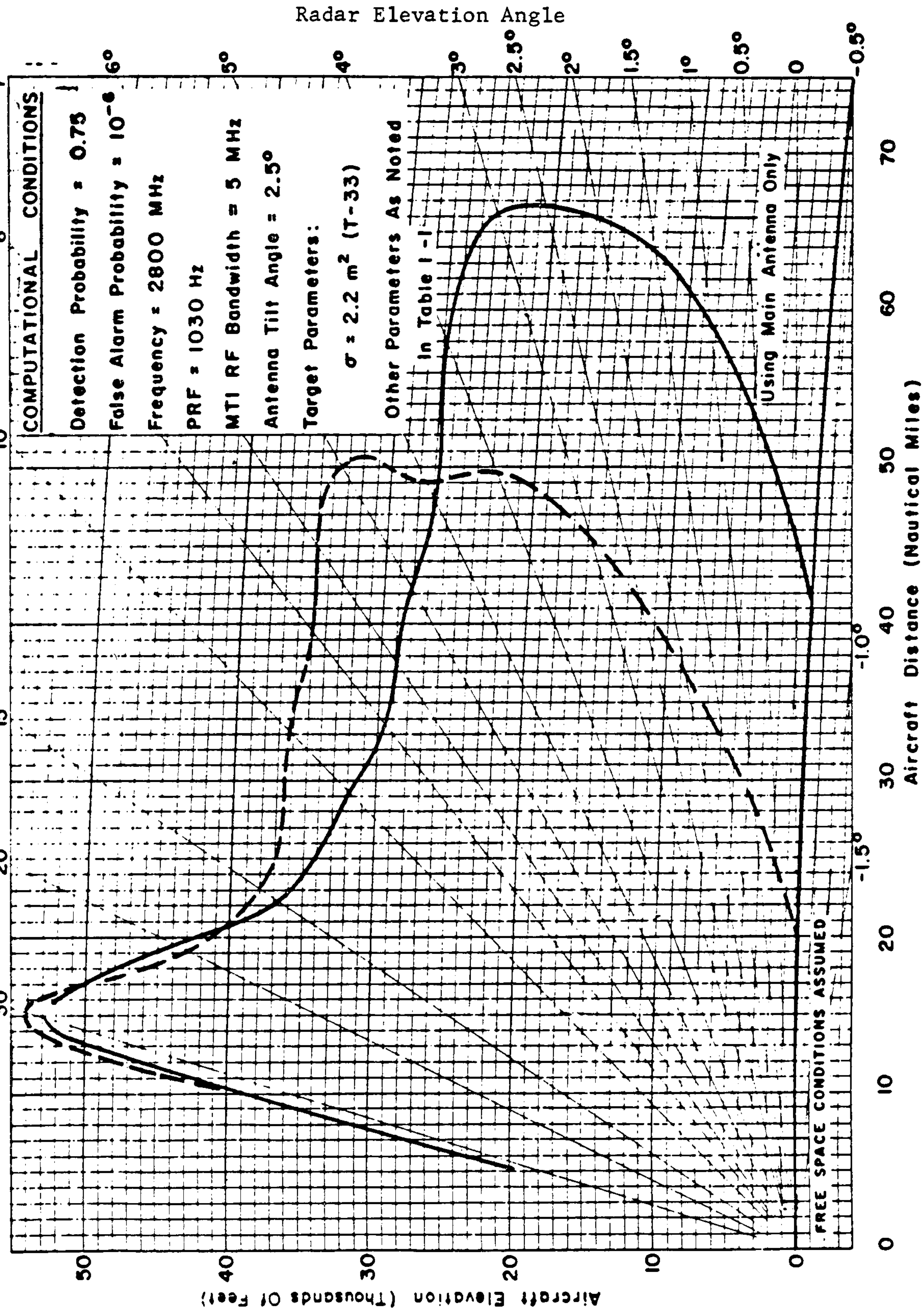


FIGURE I-8. ASR-8 RANGE COVERAGE OF T-33 AIRCRAFT-
MAIN AND PASSIVE ANTENNAS

b. Signal Characteristics.

(1) Frequency. The rf operating frequency of ASR equipment is adjustable over approximately 200 MHz as noted in table 1-1. Selection of the actual operating frequency for a given ASR installation should be made at the time of siting, based upon interference considerations. This may be done by collection of information on the operating frequency of all nearby radar and/or communications equipment and selection of a noninterfering ASR operating frequency. Selection should consider the harmonic content of potential interfering signals as well as the fundamental frequency. ASR frequency selection is made by regional Frequency Management Division personnel.

(2) Pulse Duration. The duration of the transmitted pulse establishes the range resolution capability of the radar, the range dimension of each illuminated ground clutter patch, the required receiver bandwidth, and the minimum range of the radar. Pulse duration is fixed for all FAA radar systems, as indicated in table 1-1.

(3) Pulse-Repetition Frequency (PRF).

(a) The number of radar pulses transmitted per second is known as the pulse-repetition frequency. PRF determines the maximum unambiguous range of the radar, beyond which second-time-around (or other multiple) echoes can appear as close-in targets. This is shown in figure 1-9. Ordinarily, however, surveillance radars are designed so as not to contain range ambiguities within the area of desired coverage. In addition to control of ambiguities, prf is important to mti performance and in determination of the number of pulses, M, impinging upon the target during a radar scan. This is found from the relationship

$$M = \frac{\theta_a f_r}{6\ w_r} \qquad (1\text{-}4)$$

where

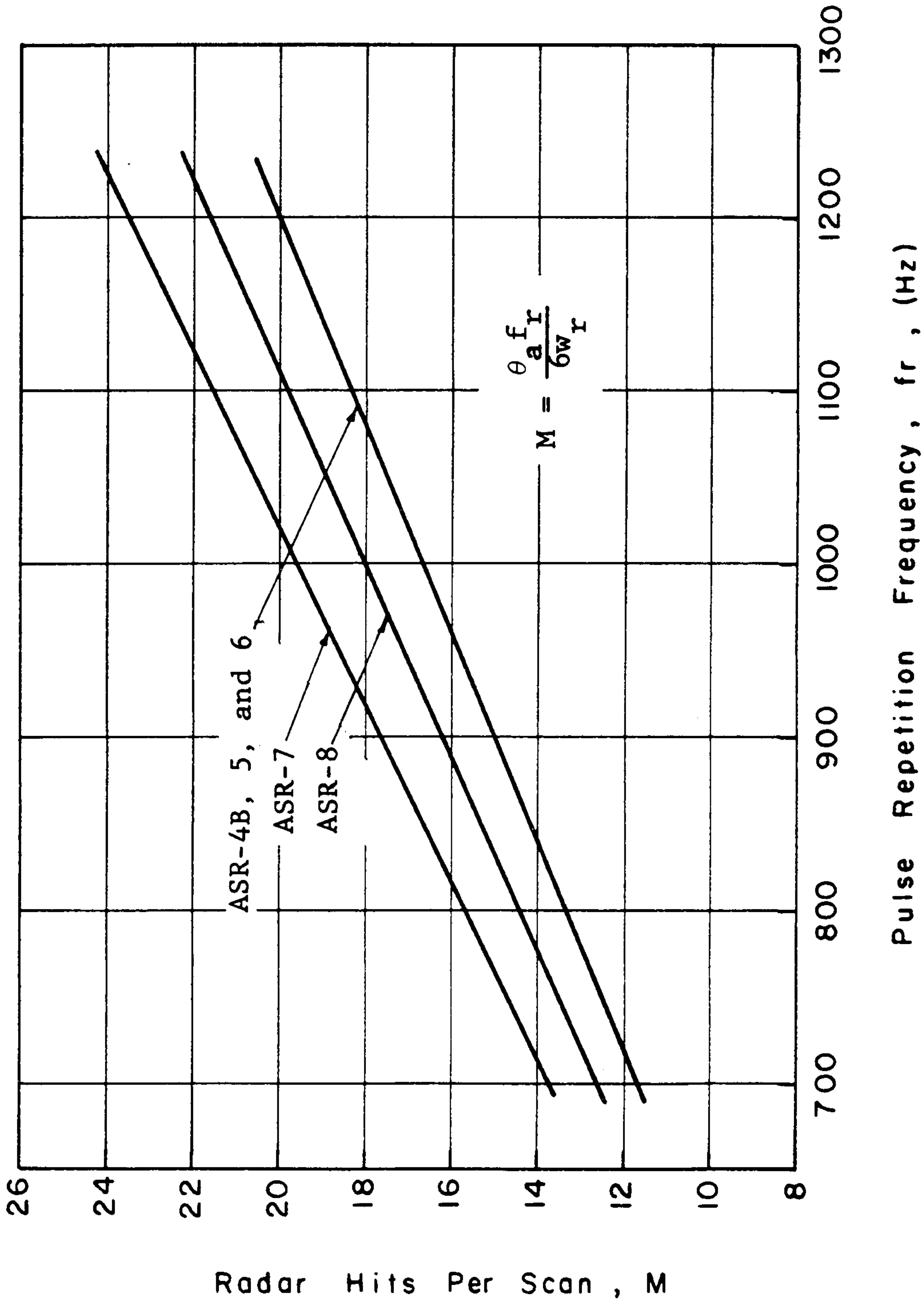
θ_a = antenna azimuth beamwidth (deg.)

f_r = radar prf (Hz)

w_r = scan rate (rpm)

A plot of this equation is shown in figure 1-10. As will be seen below, the number of pulses (hits) per scan is important to performance of the video integrator (enhancer).

FIGURE 1-10. HITS/SCAN VS. PRF FOR ASR EQUIPMENT



(b) Conventional single- or double-delay line cancelers produce response characteristics which are proportional to sin $(\pi f_d T)$ or $\sin^2 (\pi f_d T)$, respectively, as illustrated in figure 1-11. In order to alter canceler performance to more nearly approach the optimum situation, feedback networks are frequently employed to provide velocity shaping of the canceler frequency response characteristic. This technique is used in most ASR systems and is arranged in such a manner as to provide a degree of adjustment in the system velocity response.

(c) As may be noted, a conventional mti system has no response to return signals whose Doppler frequency is a multiple of the radar prf. This means that targets traveling at radial velocities corresponding to these frequencies cannot be detected in the mti receiver. The troublesome velocities are known as "blind speeds" and may be determined from the expression

$$v_{bn} = 291 \frac{nf_r}{f} \quad n = 1, 2, 3, \ldots \qquad (1\text{-}5)$$

where

v_{bn} = n^{th} blind speed (in knots)

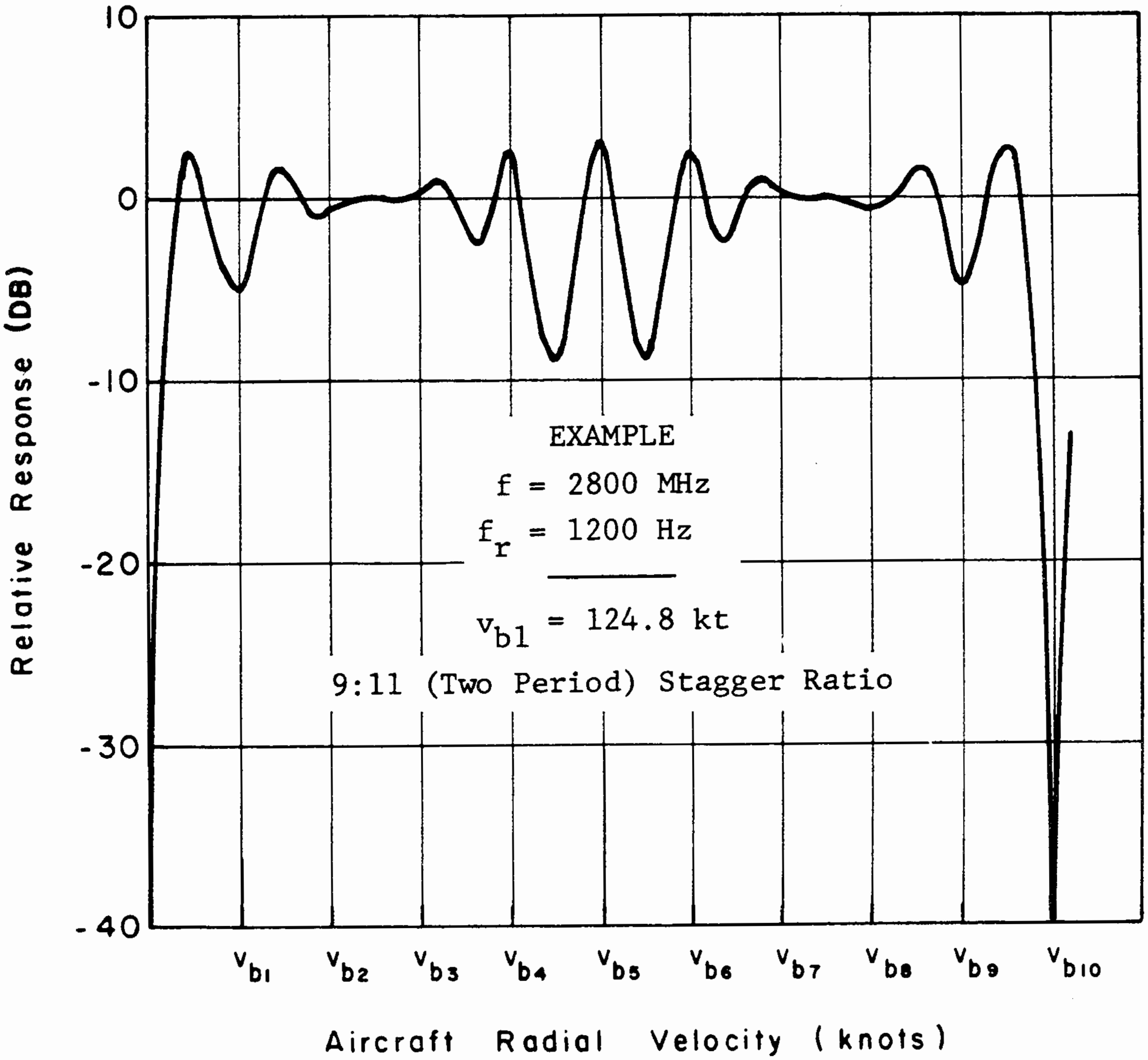
f_r = prf (in Hz)

f = radar rf (in MHz)

(d) Common ASR systems are blind to target radial velocities which are multiples of about 73-125 knots, well within the region of expected target velocities. Since this could present a severe problem to detection of certain targets in clutter, ASR systems employ a prf stagger wherein the repetition frequency is jittered on alternate pulses allowing elimination of many of the blind speeds. In prf stagger operation the first true blind speed of ASR systems occurs at approximately 800-1,250 knots, well beyond the velocity region of interest. This is illustrated in figure 1-12 which depicts the theoretical response for a 9:11 (two period) stagger ratio. It should be noted from the figure that while there are no target velocities of interest to which the radar is truly blind, the mti receiver response is by no means constant for all velocities. The response is markedly reduced, for example at v_{b1}. This reduction in response, which may exceed 10 dB in some cases, should be carefully considered during radar siting since it may influence range coverage for certain targets and approaches.

FIGURE 1-12.

TYPICAL MTI CANCELER RESPONSE WITH PRF STAGGER



conjunction with a $\csc^2\theta$ antenna creates some problems, however, in that coverage of targets at high elevation angles and extremely low elevation angles is significantly reduced. This effect is illustrated in figure 1-13 for a typical case.

(c) In most ASR systems, several types of sensitivity control are now employed which allow the radar gain to be varied as a function of R^{-N}, where N may be adjusted over some, or all, of the region between N = 1 and N = 4. As mentioned above, gain variation proportional to R^{-4} is the conventional form of stc. Some of the other gain contours (and variability in the range point where attenuation is introduced) were implemented for reducing the visibility of small unwanted targets. The features in these cases were called cross section sensitivity (css). Nomenclature has since been altered to refer to the various sensitivity control curves as stc-1, stc-2, etc.

(d) It is important that stc operation be considered at the time of radar siting. Selection of a radar site with minimum clutter will enable the stc technique to perform optimally in removing clutter without impairing radar coverage on targets of interest. In an ideal situation, clutter would be so low that only a minimal amount of stc would be required, enough to render small unwanted targets and the residual clutter invisible, but not enough to cause much deterioration in high angle coverage.

(5) Range/Azimuth Gating (RAG). New ASR-8 radar equipment will contain a rag generator which will generate a variety of programable azimuth/range windows, azimuth gates, and range gates. Some of these are outlined briefly below:

(a) Video Gating. The rag will provide for selection of one of two video signals on range/azimuth basis. This will normally be used for gating between mti and normal video. The rag will have the capability of generating 20 range/azimuth gating windows, beginning at zero range and adjoining in azimuth. Ten additional, adjustable, isolated gating windows will also be provided for this purpose.

(b) Antenna Beam Switching. As discussed above, the rag will also allow switching from high to low beam antenna at selectable range in eight contiguous azimuth regions and at four additional isolated range/azimuth gating windows.

(c) Stagger Operation. The rag will provide the capability for switching from a prf stagger to a nonstagger operation on an azimuth basis. Four isolated windows will be provided for this purpose.

The added capability of the ASR-8 provided by the rag should be considered at the time of siting, since it may allow an increase in the number of potentially acceptable site locations.

SECTION 3. AIR TRAFFIC CONTROL RADAR BEACON SYSTEM

6. FUNCTION.

a. The Air Traffic Control Radar Beacon System (ATCRBS) is designed to provide an enhanced radar detection and location capability for control of properly equipped aircraft. The system is employed at both terminal and enroute FAA radar sites and is of extreme importance to the efficient control of aircraft, especially during poor weather conditions.

b. With ATCRBS, detection of aircraft is dependent upon reception of reply signals from an airborne transponder device, a process normally much more reliable than conventional radar surveillance. The basic ATCRBS components include an interrogator, a transponder, and an indicator. The Air Traffic Control Beacon Interrogator (ATCBI) transmitter/antenna radiates short-coded pulses at a fixed frequency of 1030 MHz. This signal, when received and validated by an antenna/transponder unit aboard an aircraft, initiates generation of a reply pulse train at 1090 MHz.

c. Detection occurs when this replay signal is picked up by the interrogating antenna, processed, and displayed on a TRACON indicator. Target bearing and range are determined from the antenna pointing angle and signal propagation time, much as for a skin-track radar. The range determination takes into account the time delay introduced by the airborne transponder unit. ATCRBS and ASR transmissions are synchronized such that the video output from each can be displayed, in proper alinement, on the same indicator. Additional information can be provided by the beacon system since the reply pulse train need bear no particular relation to the interrogation signal. The reply signal is usually coded to provide the controller with aircraft altitude and/or identification information.

d. The ATCRBS has been designated as the SECONDARY RADAR to distinguish its function from other FAA radar equipment. As more and more aircraft become beacon-equipped, however, this designation is likely to be altered as the ATCRBS assumes a larger role in traffic control operations. Indeed, for many high density commercial terminals, ATCRBS is already the dominant factor in control operations. As such, ATCRBS should receive commensurate attention at the time of site selection.

* 7. EQUIPMENT PARAMETERS. The important parameters and functions of all ATCBI equipments commonly employed at FAA terminal facilities are tabulated in tables 1-2a and 1-2b. *

8. AREA COVERAGE.

a. The ATCRBS is capable of detecting aircraft within its line-of-sight at very long range. This is due to the high power capability of the equipment, required when it is used in en route applications, and the fact that propagation losses vary only as R^{-2} for a one-way beacon path, rather than the R^{-4} variation experienced by ordinary radar. In addition, the separate transmitting and reply frequencies eliminate ground clutter and weather return problems. The precise region of coverage provided by the ATCRBS is dependent upon (1) the parameters of the particular interrogator, (2) the nature of the airborne transponder, and (3) the radar site characteristics. The FAA is now using interrogators designated as ATCBI-3, 4 and 5. The pertinent parameters of these systems are presented in Tables 1-2a and 1-2b. *

b. Coverage may be determined from the characteristics of the link. This is taken up in some detail in chapter 2, but illustrated in figure 1-14. The plot shows maximum ATCBI range coverage (on the nose of the antenna beam) for various values of interrogator power and transponder sensitivity. Because of the dual (en route and terminal usage of ATCBI equipment, its area coverage capability is far beyond that required for terminal operation alone. For this reason, considerable power reduction is required with terminal ATCBI equipment to avoid interrogation of aircraft beyond the region of interest. Equipment should normally be operated at the lowest output power which will permit reliable coverage of the required terminal airspace. This practice will tend to minimize local interference and overinterrogation of aircraft transponders, and will reduce the fruit produced in more distant facilities.

9. CHARACTERISTICS PERTINENT TO SITE SELECTION.

a. Antenna Coverage. The purpose of the main ATCBI antenna system is to efficiently radiate the interrogation pulse energy in a directional beam and to receive returning transponder reply signals, sending them on to the ATCBI receiver for processing. The use of a tuned diplexer provides isolation between the transmitter and receiver sections of the interrogator since these operate at differing frequencies (1030 MHz and 1090 MHz respectively). A secondary omnidirectional transmitting antenna is also used in ATCBI installations. The characteristics of each are described below.

(1) Directional Antenna.

* (a) Antenna Pattern. The directional radiation of the main ATCBI antenna describes a fan beam pattern as illustrated in figures 1-15, 1-16, 1-17, 1-18, 1-18A, and 1-18B for the various antennas in use. *

(b) Antenna Gain. As mentioned above, the gain of an antenna is a quantitative measure of directivity compared to a

FIGURE 1-15. TYPICAL FREE-SPACE ELEVATION PATTERN FOR ATCBI-3 ANTENNA (FA-7202)

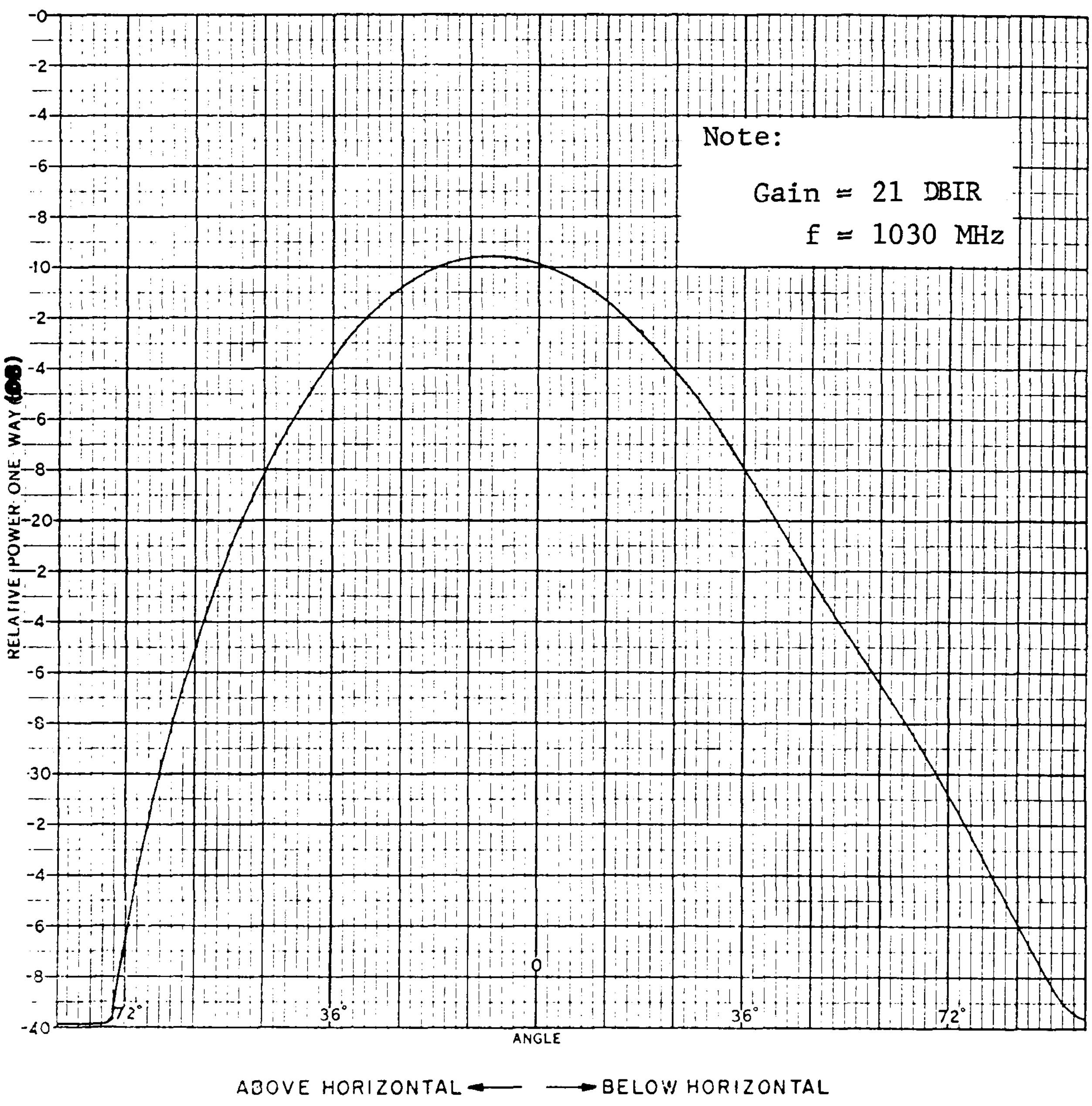


FIGURE 1-17. TYPICAL FREE-SPACE ELEVATION PATTERN FOR ATCBI-4 ANTENNA (FA-8043)

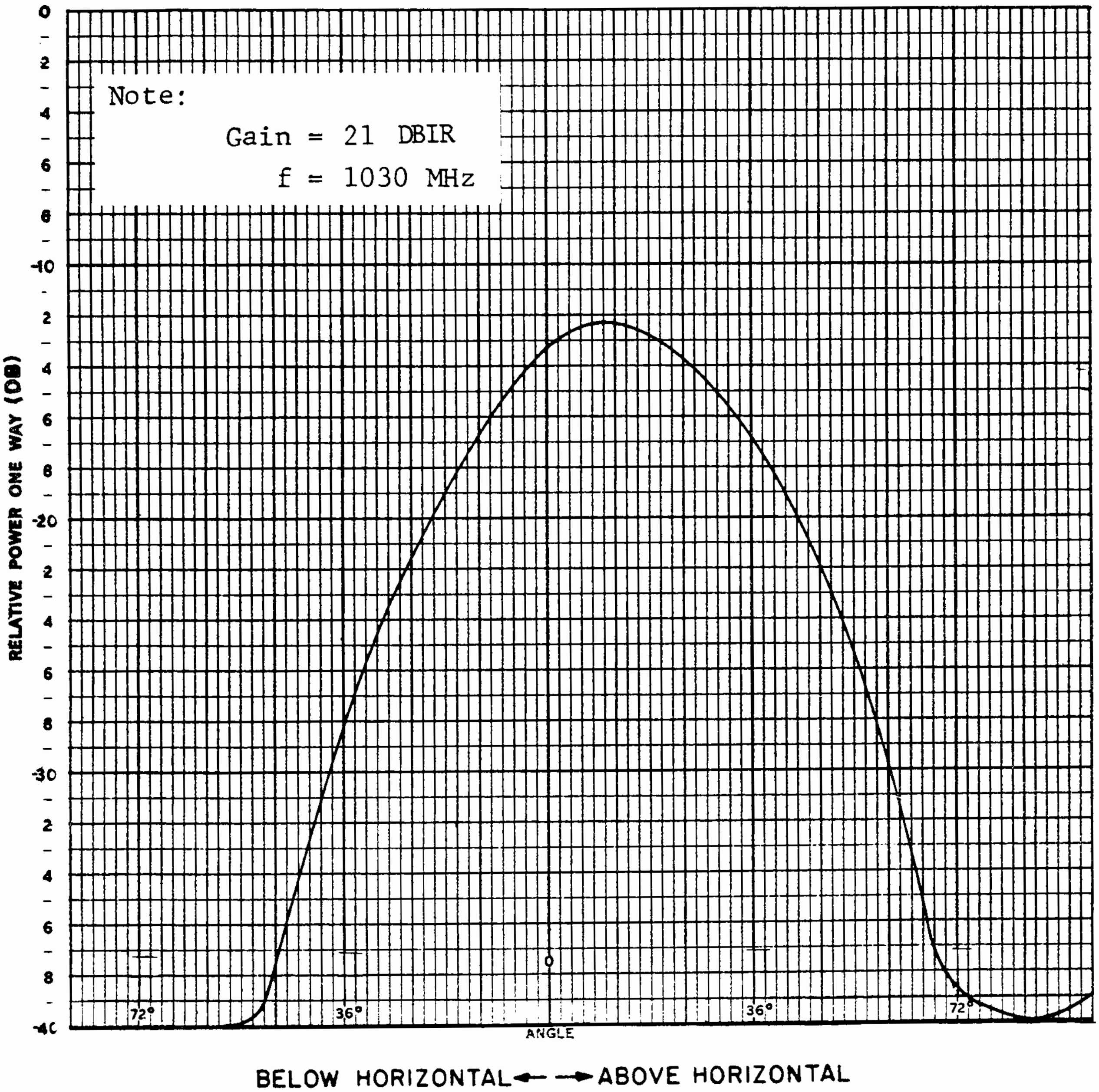
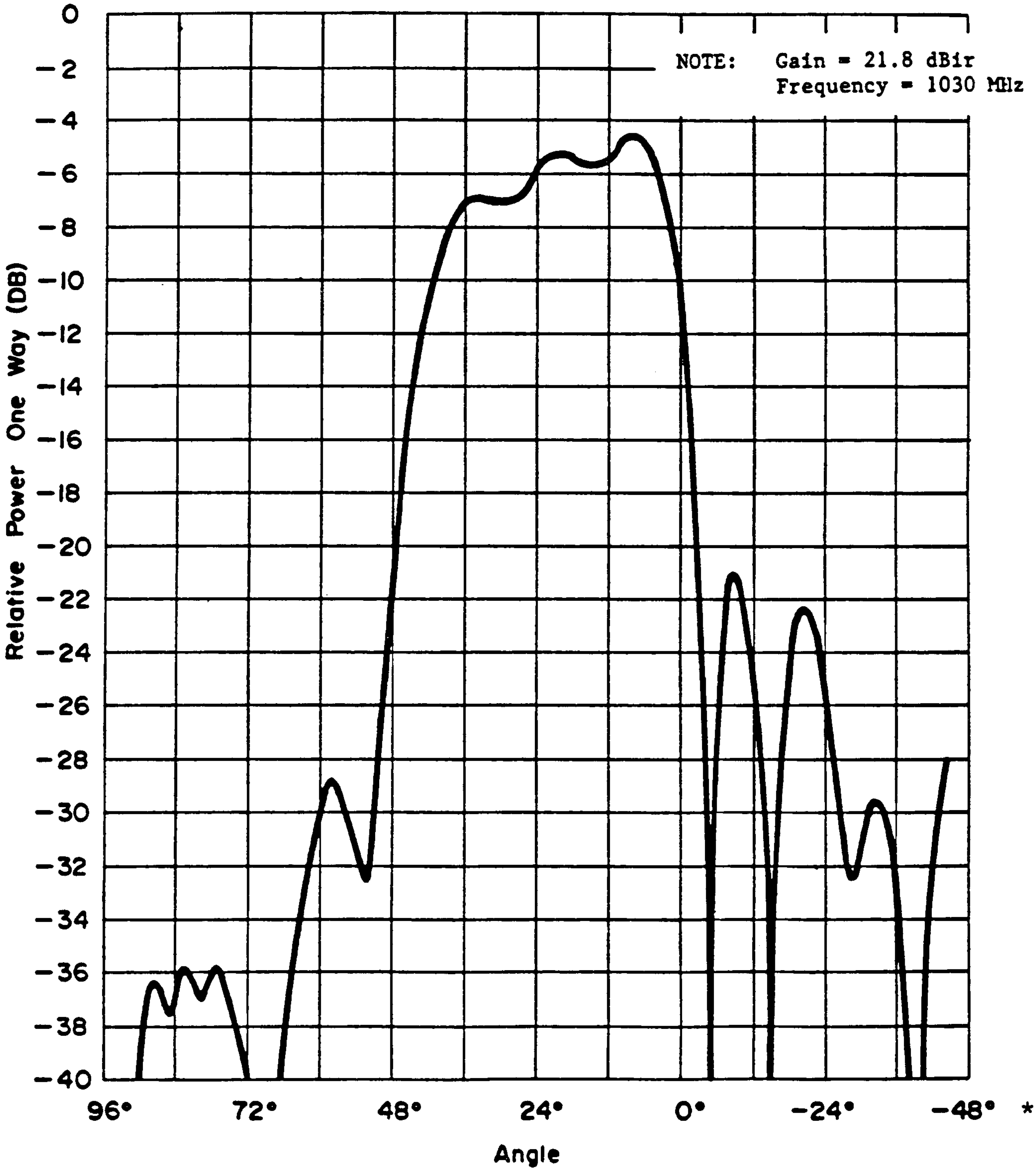


FIGURE 1-18A TYPICAL FREE SPACE ELEVATION RADIATION PATTERN FOR ATCBI ANTENNA FA-9764



reference standard (normally an isotropic radiator); its maximum value is used as a measure of antenna performance. As noted in table 1-2, current ATCBI antennas have a gain of 21 dBir.

(c) Beamwidth. Since ATCBI equipment must perform a function similar to that of the primary radar, antenna beamwidth requirements are also similar. The 3 dB azimuth ATCBI beamwidth is narrow (~ 2.35° for all of the antennas used) to provide good target resolution, and elevation beamwidth is broad (~ 36° to ~ 51°) for good vertical coverage of the surveillance area. $Csc^2\theta$ weighting is not used in the vertical fan beam. Due to the narrow vertical aperture, beacon coverage extends to much higher elevation angles than does ASR coverage. FAA's newest ATCBI antenna, FA-9764, has an increased vertical aperture (~ 5 ft) to achieve sharper cutoff of the radiation pattern at low elevation angles, thereby reducing reflected path target interrogations. Beacon target attitude information is derived from coded data in the reply signal.

(d) Polarization. ATCRBS equipment, because of the requirement for cooperative operation of both ground and airborne equipment, operates only with vertical polarization.

(e) Scan Rate. Because of its mounting atop the ASR antenna reflector, ATCBI scan rates are necessarily the same as that of the primary radar with which they are associated. In terminal installations this varies between 12½ and 15 rpm depending on the ASR system used.

(2) Omnidirectional Antenna. In all ATCBI installations a supplementary, fixed, omnidirectional antenna is employed in conjunction with the use of a side-lobe suppression (sls) system. SLS, which is described below, utilizes the omnidirectional antenna to suppress interrogations of properly equipped transponders via side-lobe transmission paths. In addition, use of improved sls suppresses interrogations of properly equipped aircraft transponders via reflections from nearby objects. The elevation pattern of this antenna is given in figure 1-19. Maximum gain is 4 dBir. The antenna is vertically polarized.

b. Signal Characteristics.

(1) Typical beacon interrogators transmit a sequential series of three 0.8 μs pulses, designated P1, P2, and P3, each at a frequency of 1030 MHz. The basic P1 and P3 interrogation pulse pair is radiated by the ATCBI directional antenna, and the spacing between these pulses determines the interrogation mode. For each interrogation, the elicited transponder reply (at 1090 MHz) comprises up to 16 pulses spaced at multiples of 1.45 μs. Two

of the pulses are always present to define the pulse train; the other pulses contain the coded data (usually identity or altitude) requested by the interrogator mode selection. (The specific aircraft identity code used is assigned by the air traffic controller through voice communication. Altitude data is an automatic standard digital coding of the aircraft pressure altimeter in 100-foot increments.)

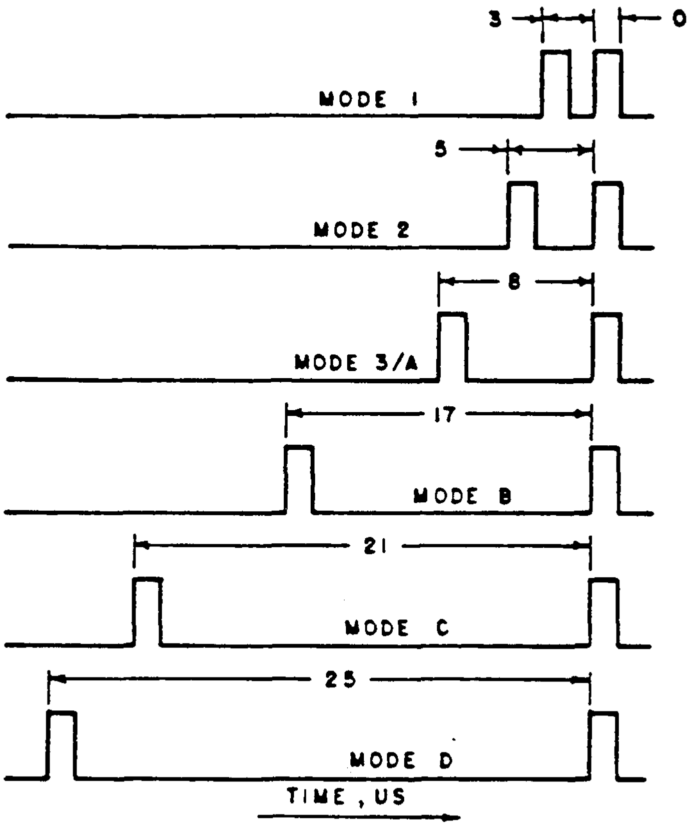
(2) Six possible modes (designated mode 1, mode 2, mode 3/A, mode B, mode C, and mode D), may be used, but usually only modes 3/A (common identity) and C (common altitude) are used in air traffic control. It is common to interlace these two modes on a 1:1 or 2:1 basis to update identity and altitude data on each scan of the ground based antenna. Special reply code provisions enable the pilot to declare an emergency or a communications failure. Also, one of the reply pulses can be used for special identification if the same identity code has been redundantly assigned to two or more aircraft within the surveillance volume. Details of interrogator and reply pulse spacing are tabulated in table 1-3. Example pulse trains are illustrated in figure 1-20.

(3) In addition to P1 and P3 transmissions via the ATCBI directional antenna, interrogators also radiate a P2 pulse via a colocated omnidirectional antenna. This is done as part of an sls system. In an improved version of sls, the P1 pulse is also radiated from the omnidirectional antenna. These special ATCBI features are discussed in a subsequent paragraph.

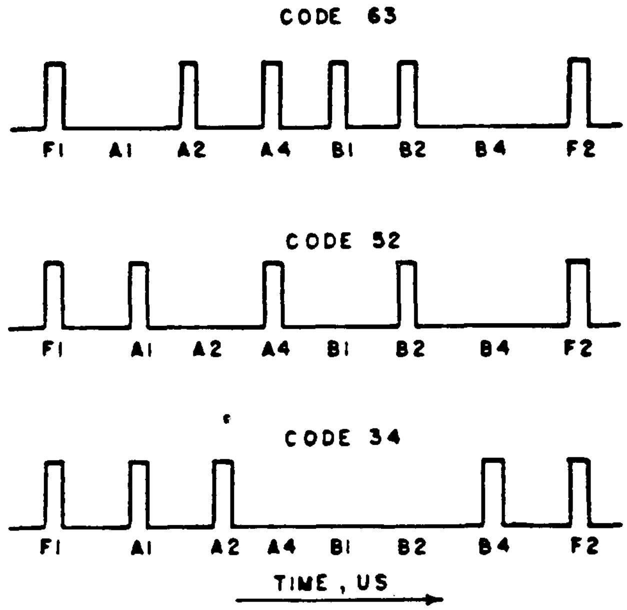
(4) The ATCBI transmitter generates coded pulse trains much as described above, at the rate of 150-450 interrogations per second. Beacon operation is arranged to complement that of the associated ASR equipment. In associated operation, the beacon antenna rotates in synchronism with the primary radar antenna and the beacon triggers are synchronized with the radar pretrigger. By spacing the primary radar and beacon interrogator transmissions in time, to allow for the different round-trip delays, it is possible to display the returns from both superimposed on the same plan position indicator (ppi) display. In this way, returns from aircraft without beacon capability can be viewed on the same display with the beacon returns.

(a) PRF. The rate at which the interrogation pulse program is transmitted is termed its prf. This rate is adjustable between 150 and 450 Hz. This adjustment is important to equipment installation insofar as it must be kept different from other ATCBI equipment in the vicinity. Selection of a unique prf for beacon operation enhances the capability of its video defruiting equipment, thereby resulting in improved ATCBI performance. In joint ASR/ATCBI installations,
* the ATCBI prf is derived by direct countdown (1/3,1/2,etc.) *
from the basic prf of the ASR equipment. Because of this

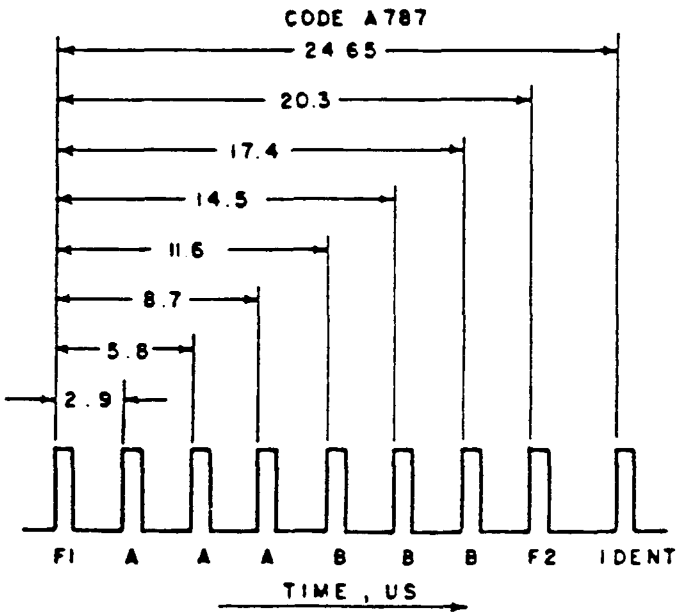
Figure--1-20. STRUCTURE OF INTERROGATION PULSE PAIRS AND REPLY CODE PULSE GROUP



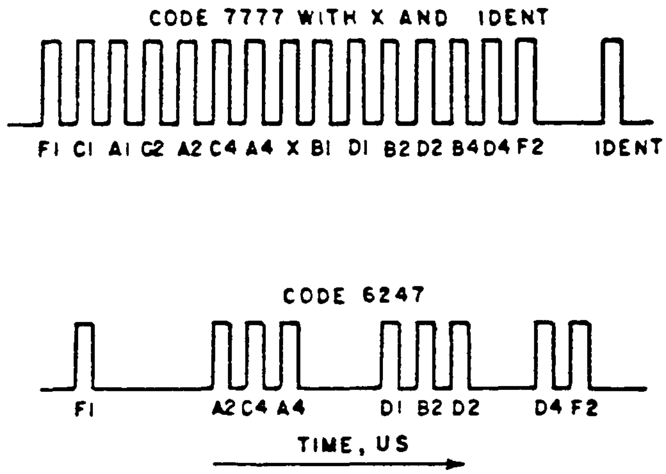
INTERROGATION PULSE PAIR FOR THE SIX MODES OF OPERATION (SHOWN WITHOUT SLS PULSE)



THREE OF THE POSSIBLE 64 COMMON SYSTEM REPLY CODE USING A AND B PULSE POSITIONS



COMMON SYSTEM REPLY CODE TRAIN CONTAINING ALL PULSES IN A AND B PULSE POSITIONS AND AN INDENT PULSE



TWO OF THE POSSIBLE 4096 REPLY CODE USING A, B, C AND D PULSE POSITION

(b) With the sls feature, normal directional radiation of P1 and P3 pulses is augmented by radiation of a control pulse, P2, from an omnidirectional antenna. The P2 pulse, which always follows the P1 pulse by 2 μs, is compared in amplitude with P1 in transponders equipped with sls circuitry. The pulse amplitude comparison is implemented by a desensitization technique. Upon receipt of a pulse more than 0.7 μs in duration, the transponder receiver is desensitized to a level which is within 9 dB of (but not exceeding) the amplitude of the desensitizing pulse. Recovery is approximately linear over a 15 μs interval.

(c) When the P1 pulse amplitude is 9 dB (or more) greater than the P2 pulse amplitude, indicative of main beam interrogation, the P2 pulse is not detected due to desensitization, and a transponder reply is generated after reception of the P3 pulse. If the P1 and P2 pulse amplitudes are equal, clearly indicating a side-lobe transmission path, the P2 pulse is detected despite receiver desensitization and the transponder's reply capability is suppressed for a period of 35 ± 10 μs. Figure 1-22 indicates the pulse timing and amplitude relationships of the sls system.

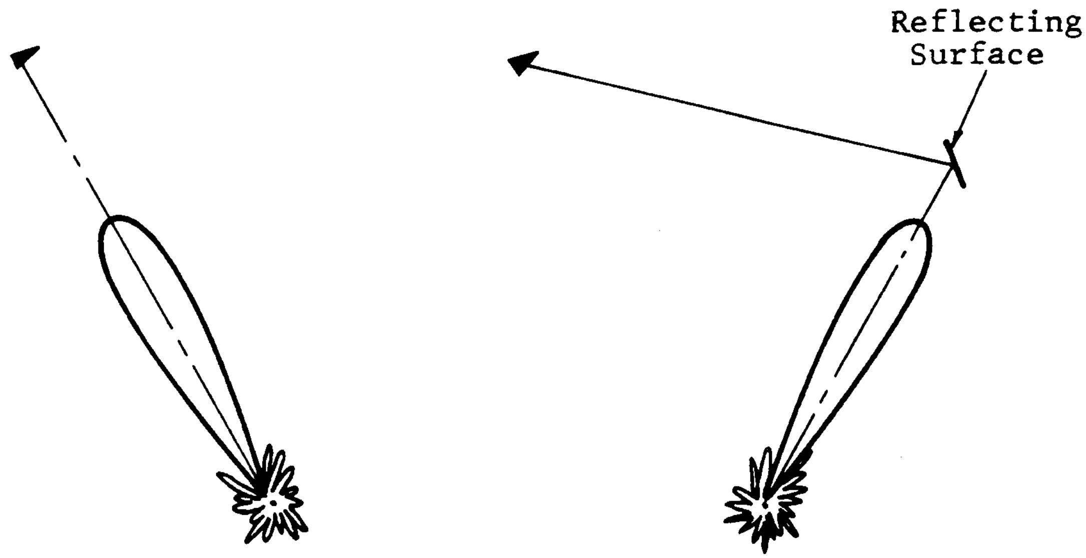
(d) Whereas ring-around is effectively controlled by sls, the technique is not as effective in removing the effects of reflections or multipath. Under this condition false targets are generated when main beam energy from the ATCBI directional antenna successfully interrogates a transponder via a reflected signal path. When this occurs, in addition to the proper target display, a false target is displayed at the azimuth of the reflected path and at a range corresponding to its length. This is illustrated in figure 1-23.

(e) Under the condition where the direct path sls P2 pulse and directional antenna side-lobe P1 and P3 pulses are received by the transponder, a 35 ± 10 μs suppression gate is generated which prevents some reflected path interrogations. This is illustrated in figure 1-24. Several conditions can occur, however, in which the sls system is not able to prevent successful reflected path interrogations. These include:

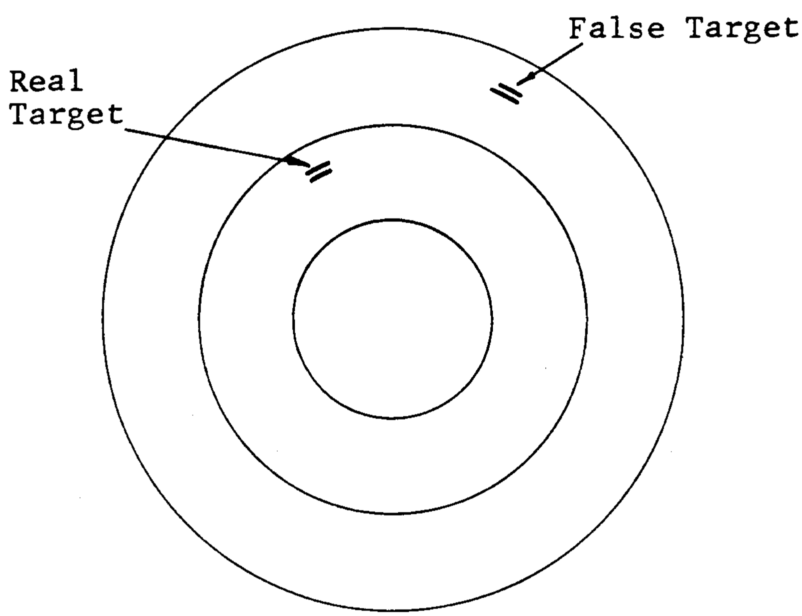
1. Target ranges where direct path main (directional) antenna side-lobe (P1 pulse) energy is below the transponder sensitivity threshold.

2. Path arrangements where the reflected pulses are received more than 35 ± 10 μs after direct path pulses.

FIGURE 1-23. EFFECT OF REFLECTED PATH BEACON OPERATION



a) Normal Interrogation b) Reflected Path Interrogation



c) Resulting PPI Presentation

3. Path arrangements where the reflected pulses are received less than 2 μs after direct path pulses.

(f) These situations are shown diagrammatically in figure 1-25. In each case, reflected false targets can be generated despite the presence of sls circuitry.

(2) Improved Side-lobe Suppression (ISLS).

(a) Most ATCBI equipment now incorporates an isls system designed to provide additional immunity against the effects of reflected path interrogation. This is accomplished by allowing the omnidirectional antenna to transmit the P1 interrogation pulse as well as the P2 control pulse. Directional antenna transmission is unchanged.

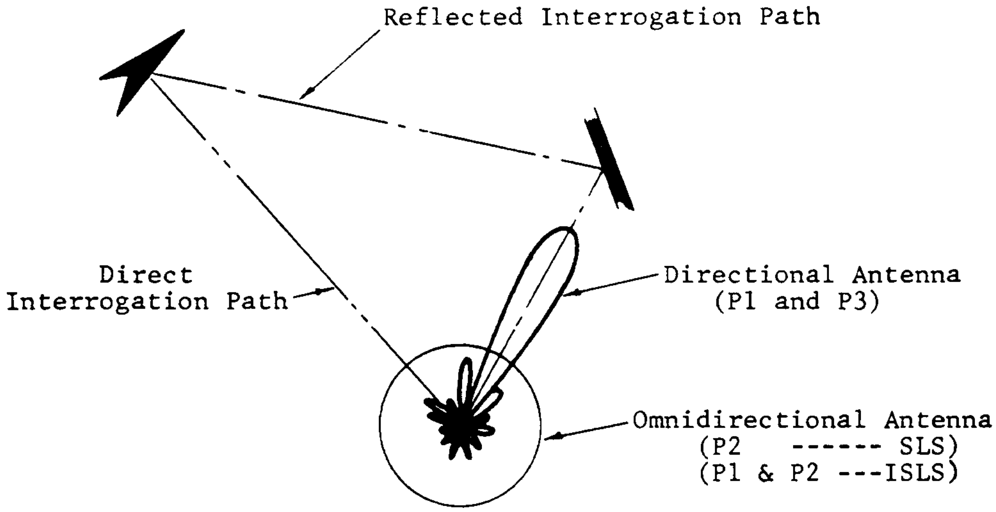
(b) In a reflected path situation, the isls provides the transponder with considerably higher direct-path P1 pulse amplitudes, thus more readily allowing the establishment of a suppression gate in the airborne unit. This effect is illustrated in figure 1-26; it reduces to a considerable degree the condition of unsuccessful sls operation described in subparagraph 9c(1)(e)1. The time-related sls deficiencies noted are unaffected by the incorporation of isls, however. It should therefore be noted that several conditions still occur for which the isls system is incapable of preventing successful reflected path interrogation, and hence false targets. These include:

1. Target ranges where direct path omnidirectional antenna energy is below the transponder threshold. This can occur due to blockage effects in addition to range attenuation. Assuming no blockage, the maximum range at which a suppression gate can be generated can be found from figure 1-27.

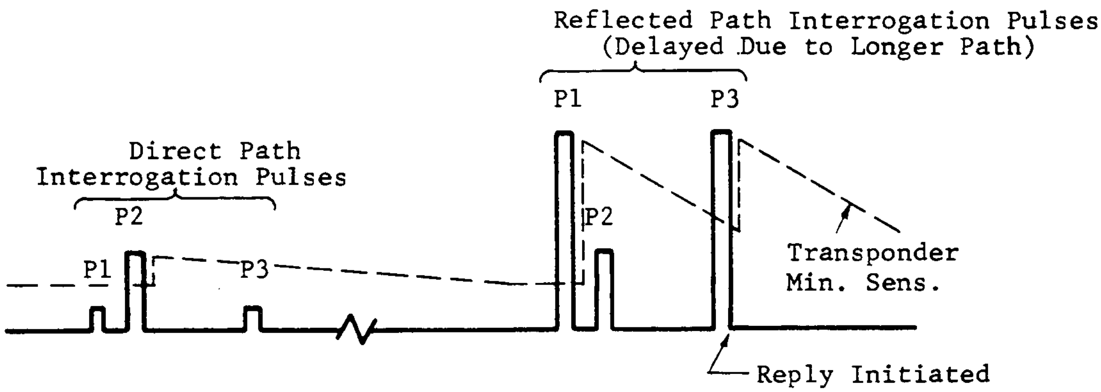
2. Path arrangements where the reflected pulses are received more than 35 ± 10 μs after direct path pulses (i.e., after the termination of a suppression gate). This effect may be determined from figure 1-28, which applies to both sls and isls operation.

3. Path arrangements where the reflected pulses are received less than 2 μs after direct path pulses (i.e., before a suppression gate can be formed). This effect may be determined from figure 1-29, which applies to both sls and isls operation.

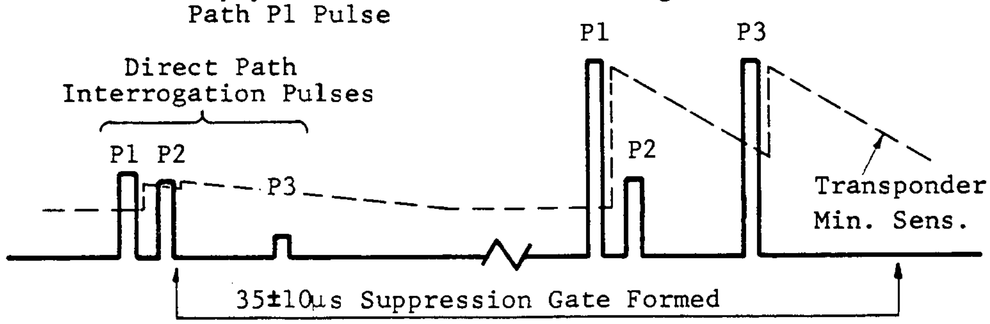
FIGURE 1-26. ISLS VS. SLS COMPARISON



a) Pictorial

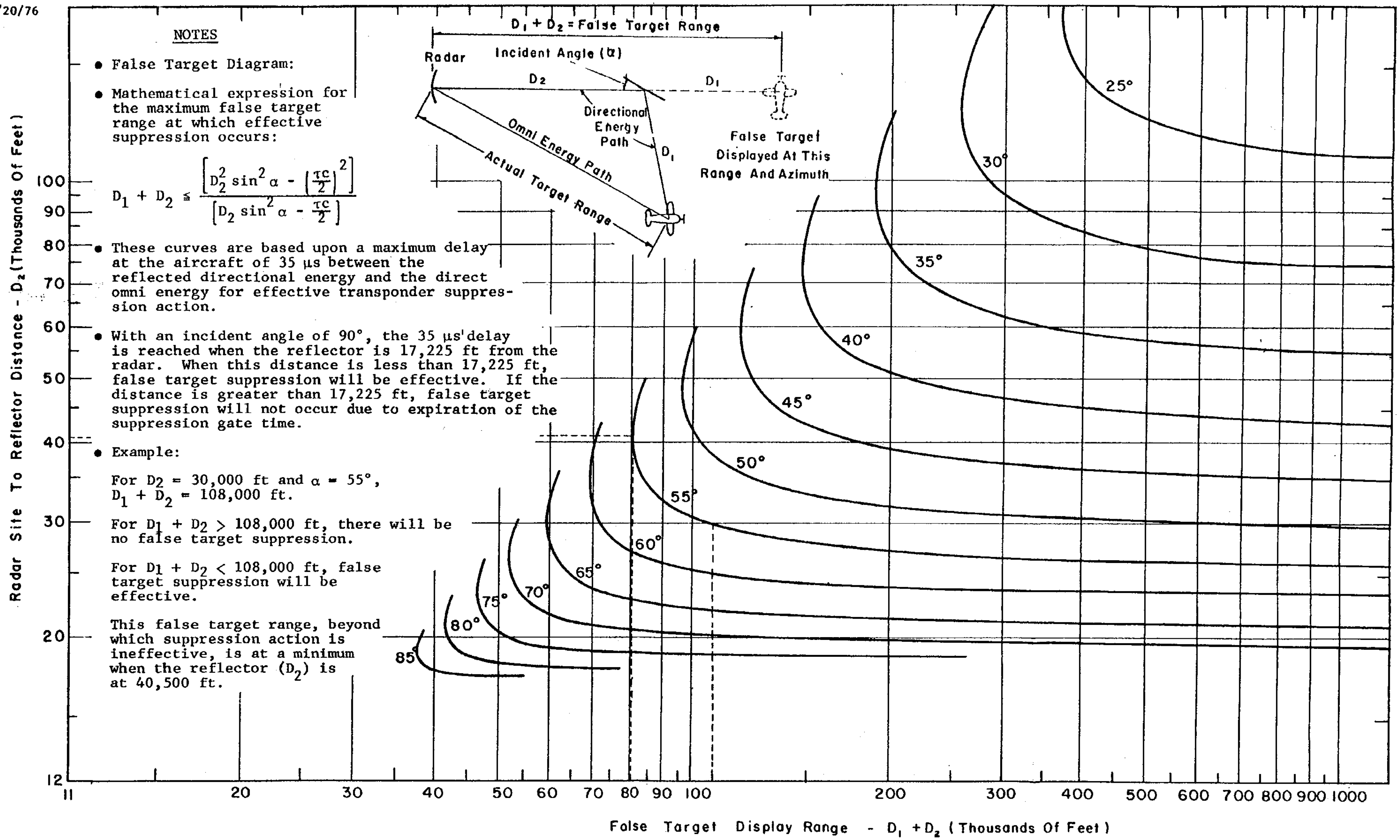


b) Transponder Interrogator with SLS - False-Target Reply Generated Due to Nonrecognition of Direct Path P1 Pulse



c) Transponder Interrogation with ISLS - Increased Input P1 Pulse Amplitude Causes Suppression. No Reply to Reflected Interrogation

Figure 1-28. SLS/ISLS FALSE TARGET SUPPRESSION CAPABILITIES FOR PATH DELAYS ≥ 35 µsec



NOTES

- False Target Diagram:
- Mathematical expression for the maximum false target range at which effective suppression occurs:

$$D_1 + D_2 \leq \frac{\left[D_2^2 \sin^2 \alpha - \left(\frac{\tau c}{2}\right)^2\right]}{\left[D_2 \sin^2 \alpha - \frac{\tau c}{2}\right]}$$

- These curves are based upon a maximum delay at the aircraft of 35 µs between the reflected directional energy and the direct omni energy for effective transponder suppression action.
- With an incident angle of 90°, the 35 µs delay is reached when the reflector is 17,225 ft from the radar. When this distance is less than 17,225 ft, false target suppression will be effective. If the distance is greater than 17,225 ft, false target suppression will not occur due to expiration of the suppression gate time.
- Example:

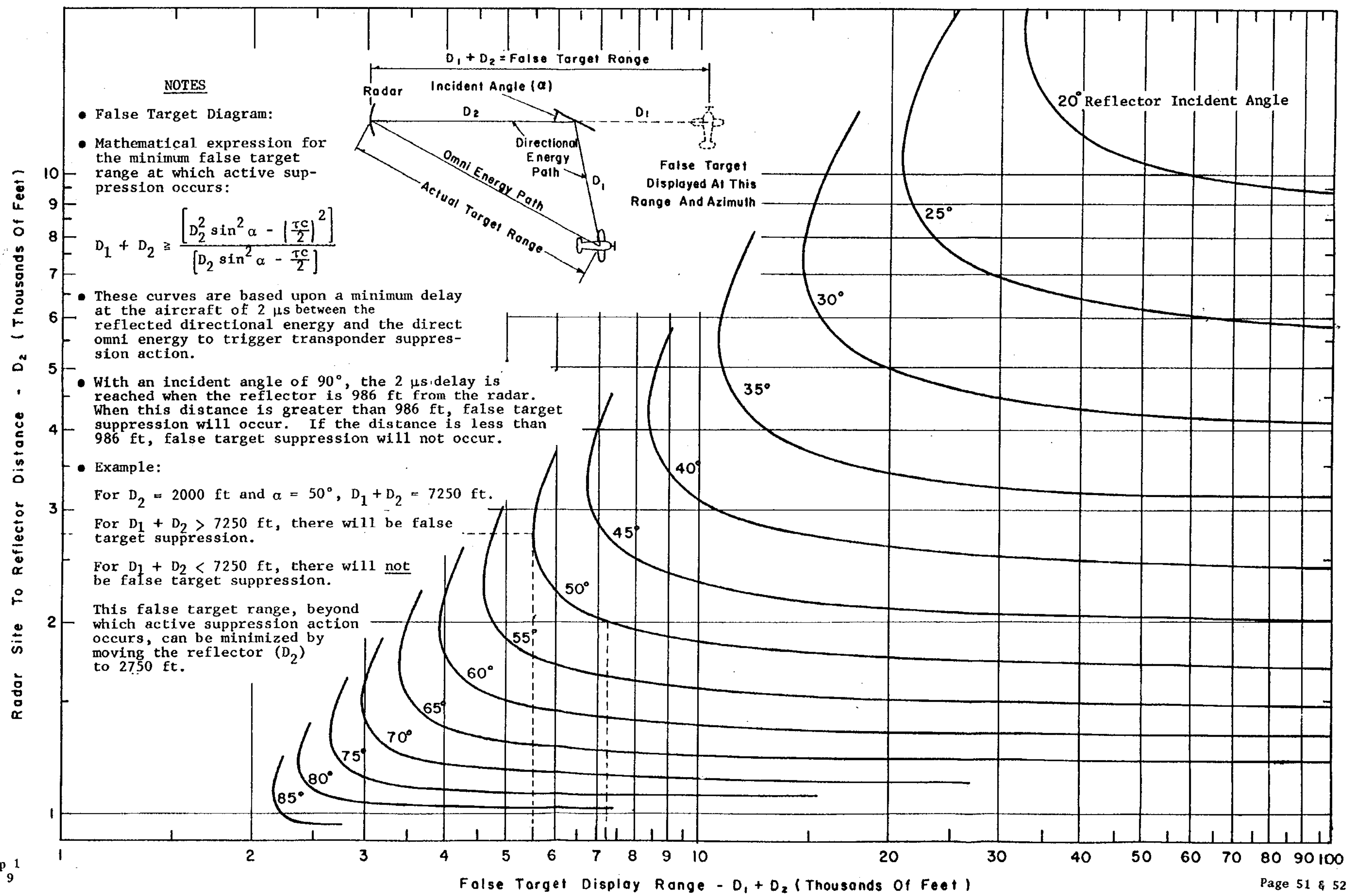
For D_2 = 30,000 ft and α = 55°, $D_1 + D_2$ = 108,000 ft.

For $D_1 + D_2 >$ 108,000 ft, there will be no false target suppression.

For $D_1 + D_2 <$ 108,000 ft, false target suppression will be effective.

This false target range, beyond which suppression action is ineffective, is at a minimum when the reflector (D_2) is at 40,500 ft.

Figure 1-29. SLS/ISLS FALSE TARGET SUPPRESSION CAPABILITIES FOR PATH DELAYS ≤ 2 μs



(c) While the isls technique has utility in many applications, its use and power level should be carefully weighed since it does increase the incidence of transponder suppression. During the suppression interval, a transponder is unable to respond to ANY interrogation, thus affecting its ability to reply to other ATCRBS interrogators desiring a reply. As a minimum, however, simple sls should be used to prevent ring-around and fruit caused by side-lobes.

(3) Reply Rate Limiting.

(a) The radar beacon system may suffer from the effects of overinterrogation on the single transmission frequency. An airborne transponder may be within line of sight of many ground stations and hence will receive many interrogations. An automatic overload control (aoc) circuit in the transponder protects the transmitter from overloading and tends to aid the system by reducing reply densities based on signal strength. AOC levels in a transponder are normally set at 1,200 replies per second. (Transponders used in aircraft that do not operate above 15,000 foot altitudes may not be capable of more than 1,000 replies/second. In this case the reply rate limiter is set to maximum.) Above this level, the sensitivity is reduced to discriminate against replies from weaker sources. This also discriminates against lower-level side-lobes, reflections, and more distant stations.

(b) A deadtime circuit is used in the transponder to eliminate the effect of transmitting overlapped codes in response to more than one interrogator; after receipt of a valid mode interrogation pair, the transponder is disabled until the reply code is transmitted. A second reply cannot be initiated until the deadtime gate is terminated. The probability of success for a particular interrogator to elicit a reply is given by

$$p_a = \left[e^{(f_{sls} T_s)} + f_i T \right]^{-1} \qquad (1\text{-}6)$$

where

f_{sls} = side-lobe interrogation rate from all other stations

T_s = sls suppression-gate duration (35 ± 10 μs)

f_i = interrogation rate of all other stations

T = transponder deadtime

(c) Transponder deadtime includes the duration of the coded reply transmission, plus an additional period of not more than 125 μs.

d. Receiver Characteristics. The ATCBI receiver detects the signals generated by a "visible" airborne transponder in response to any and all interrogators in the vicinity. It employs the special techniques of sensitivity time control and video defruiting to improve operations. These are discussed below.

(1) Sensitivity Time Control (STC). The stc feature is incorporated into ATCBI equipment for somewhat the same reason as is done in an ASR system, namely, control of the receiver operating characteristic. For beacon operation, the received power from a given transponder will vary inversely with the square of transponder range. An ATCBI receiver with stc characteristic, therefore, which compensates for this variation will tend to reduce the visibility of reflected path and side-lobe replies, and of other unwanted inputs, without impairing the detectability of legitimate beacon targets. STC adjustments are made by reducing receiver gain by 10-50 dB (below maximum sensitivity) at 15.36 μs after the leading edge of pulse P3. Gain is then allowed to recover at a suitable rate, the R^{-2} rate being standard for FAA facilities.

(2) Video Defruiting. The ATCBI video defruiter greatly reduces the amount of nonsynchronous interference which can appear in an output display. This is done through filtering of the raw video pulses at the output and passing only those pulses whose prf is the same as that of the interrogator to which it is connected. Asynchronous replies resulting from interrogations by other ATCBI equipment, second-time-around echoes (with jittered prf), interference pulses, etc., are rejected by the defruiting equipment while the legitimate synchronous replies are allowed to pass on to display units unimpeded.

SECTION 4. ANCILLARY EQUIPMENT

10. TRANSMITTER/RECEIVER BUILDING. The ASR and ATCBI transmitters, receivers, and a standby engine generator (if required) will be housed in a building (or van) at the selected site. A transformer substation will be installed adjacent to the building (or van) unless commercial electrical power can be furnished to the building at 120/208 volts. The building is one of three standard design structures, and is installed near the antenna tower as indicated on the appropriate site layout drawing. Building design details and standard site layout drawings should be available at all FAA regional offices. Site layout for ASR-4B, 5, and 6 systems are shown in FAA Drawing D-5409-1, and for ASR-7 on Drawing D-5825-1.

11. RADAR TOWER.

a. The radar antennas are mounted on a steel tower whose height is selected for optimum radar performance. The basic tower height is 17 feet, which may be augmented by the installation of up to six additional 10-foot sections to a maximum height of 77 feet. The single beam ASR antenna feedhorn is approximately 8 feet above the tower platform and the dual beam antenna maximum energy point is * approximately 10.2 feet above the tower platform. The ATCBI antenna height is approximately 13 feet above the tower platform when antennas FA-7202 or FA-8043 are used, and is approximately 14.8 feet above the platform when antenna FA-9764 is used. *

b. Tower height, as discussed elsewhere, is primarily selected based on screening, clutter, and vertical lobing considerations. It should be borne in mind, however, that efforts to shorten waveguide runs between transmitter and antenna will result in lower system rf losses. Waveguide attenuation may be assumed to be 1 dB/100 feet, resulting in a 2 dB/100 feet loss for two-way (transmit and receive) transit of the same waveguide. Provided priority coverage requirements are met, sites should be arranged such that ASR waveguide runs are kept as short as possible, not exceeding 130 feet in length.

12. REMOTING EQUIPMENT.

a. Landline Remoting. Communication of ASR and ATCBI output data and control signals between the radar site and the indicator site can be accomplished by landline, provided the cable length required for this connection does not exceed the shorter of lengths indicated in tables 1-1 and 1-2a for the ASR and ATCBI equipment to be installed.

b. Radar Microwave Link (RML) Remoting. Where landline remoting is not possible, signal communications via microwave link are required. When use of RML equipment is indicated, the radar siting operation should include siting of the necessary RML equipment. The cost of necessary RML equipment should also be included in siting estimates.

13. MTI REFLECTORS. For proper alignment of video maps, mti reflectors mounted at the end of runways should be visible to ASR equipment. As a consequence, each ASR/ATCBI site selection should include identification of potential sites for mti reflector installation. Line-of-sight visibility and adequacy of return signal-to-clutter ratio are of primary concern to this site selection. Locational requirements for mti reflectors are given in paragraph 17f of chapter 2.

CHAPTER 2. ASR AND ATCRBS SITING CRITERIA

SECTION 1. INTRODUCTION

14. INTRODUCTION.

a. The primary requirement when siting ASR and ATCRBS facilities is to provide the radar and interrogator coverage necessary to enable effective monitoring/tracking of aircraft in the terminal airspace. In the site selection process, a number of factors must be considered in order to recommend the most suitable site. These may be grouped into the following major categories:

(1) Coverage factors and facility requirements,

(2) Coverage capabilities of ASR and ATCRBS equipment,

(3) Operational limitations, and

(4) Installation requirements/limitations.

b. The coverage requirements, basic facility requirements, and the coverage capabilities of the ASR and ATCRBS equipment form the basis for selection of a few possible sites. This choice is further narrowed by considering the various physical restrictions such as land availability, cost, logistic support, etc. The effect of the site on operational radar performance must then be considered for each of the remaining sites. Generally speaking, all sites will have some operational disadvantages in terms of either reduced coverage or performance degradation. Therefore, a final choice is made on the basis of determining an optimum combination of adequate coverage (i.e., minimized degradation) and reasonable cost. The purpose of this chapter is to discuss, in detail, factors comprising each of the above four categories.

SECTION 2. COVERAGE FACTORS AND FACILITY REQUIREMENTS

15. GENERAL.

a. Specific coverage requirements relative to the air terminal being served are obtained from the regional Air Traffic Division (ATD). These requirements, which are the same for the ASR and ATCRBS, will usually be specified in terms of:

(1) Navigational fixes within the terminal airspace,

(2) Air-routes between fixes and expected variations,

(3) Handoff or transition points beyond outer fixes,

(4) Approach/departure coverage,

(5) Runway coverage, and

(6) Aircraft type/maneuvers/ground speed.

b. Ideally, the site selected should be such that all specified fixes and route corridors are operationally visible to both the ASR and ATCRBS. However, it should be pointed out that this will not always be possible, in which event a satisfactory compromise must be worked out with the ATD personnel.

c. The important coverage factors and facility requirements which must be considered in siting are discussed in the following paragraphs.

16. COVERAGE FACTORS.

a. Navigational Fixes. Navigational fixes are usually specified in terms of the minimum instrument mean sea level (msl) altitude, and the geographical coordinates of their projected location on an area map. These three dimensional coordinates of fixes are usually identified by air route intersections, VOR stations, important landmarks, ILS approach paths, departure paths, and handoff points between terminal and en route controllers. For terminal radar/beacon systems, these fixes must be located within a 55 nmi radius and within the radar line-of-sight from the selected site.

b. Minimum Obstruction Clearance Altitudes. The FAA flight safety regulations restrict traffic in the terminal airspace to certain minimum allowable altitudes in order to provide enough clearance from buildings, terrain variations, etc., in the vicinity of the airport. These minimum altitudes are established and maintained by local Air Traffic personnel in the form of minimum obstruction clearance altitude (moca) charts. These charts, together with the minimum obstruction altitude criteria established in Federal Aviation Regulations (FAR), part 77, for the airport vicinity, provide a convenient reference for establishing worst-case limits for low-altitude coverage in the terminal area.

c. Air-Route Coverage. Radar coverage data includes the routes which will be flown between the specified navigational fixes. Coverage of the routes beyond the outer fixes should be obtained so that the controllers will have maximum opportunity to identify aircraft prior to affecting handoffs to or from en route controllers using long range radars. This coverage should extend 3 nmi or 25% more than the distance from the antenna to the fix, whichever is greater.

d. Runway Approach/Departure.

(1) Although ASR/ATCRBS coverage of aircraft to or from the points of touchdown or take-off on the runways is highly desirable, the fundamental criteria for ASR/beacon coverage for approach and departure from the airport is based on: (a) coverage of

aircraft on final approach should be provided up to the missed approach point, and (b) departing aircraft should be picked up by the ASR/ATCRBS at a point no further than 1 nmi from the exiting runway edge.

(2) The missed approach point can vary from 0.75 nmi to 1.5 nmi (nominally 1 nmi) from the edge of the runway, depending on the particular airport flight procedures. The altitude of the missed approach point is almost always 300 feet above the extended runway surface. As a nominal rule then, the fundamental requirement for approach/departure coverage is to provide ASR/beacon coverage at distances 1 nmi and beyond, from the edges of all runways (especially instrument runways), at all altitudes down to 300 feet above the extended runway surface.

(3) It should be noted here, that the above requirement applies to the primary airport serving the terminal area. No compromise in this requirement should be made to otherwise improve or provide similar coverage for secondary (satellite) airports.

e. Runway Coverage. Although it is desirable to have the capability to monitor aircraft on any of the runways of the airport, this requirement should be considered secondary in importance relative to the above approach/departure coverage requirements. However, to make runway coverage possible, it is necessary that the antenna tower not be located within ½ nmi from the runways to be monitored since the ppi presentation within a ½ nmi radius may be unusable. This occurs due to receiver blanking and t/r system recovery characteristics.

f. Air-Route Variations.

(1) Variations in the air traffic routes within the terminal area can generally be expected to produce changes in the coverage requirements and siting criteria for both the ASR and beacon systems. New tangential course conditions can develop along with further coverage problems due to screening, cone-of-silence limits, lobing, false targets, etc. These route variations can be brought about by any or all of the following:

(a) Changes in weather conditions

(b) An increase/decrease in traffic density

(c) New runway or airport construction

(d) Changes in Federal Aviation regulations/procedures

(e) Changing socio-legal requirements (e.g., noise control, safety, home tv interference, etc).

(2) The first item above generally results in a day-to-day change in air traffic routes to the extent that approach routes become departure routes and vice versa. Route variations due to weather changes should be included in the coverage requirements specified by ATD prior to initial siting. The remaining items above, pertain to relatively long-term or future changes in traffic patterns and can be somewhat uncertain, or not altogether unknown. However, wherever possible, attempts should be made to identify planned or known changes of this type and determine their effects on future air route patterns. In this way, some potentially troublesome future problems can be taken into account during the initial siting effort.

g. Aircraft Type. The minimum radar target cross section of aircraft using the terminal airspace is a very significant factor in determining the maximum range capability of the ASR. In general, the smaller the aircraft, the smaller will be its radar cross section, thereby limiting the ASR detection range. Hence, for purposes of siting, it is necessary to know the smallest type of aircraft to be detected in order to determine if the range between the candidate site location and each navigational fix is within the range capability of the ASR. Except for unusual situations this implies that ASR coverage should be based upon detection of small general aviation and training aircraft which may utilize the controlled airspace. Frequently a T-33 is used for coverage calculations.

h. Aircraft Maneuvers. Unusual aircraft maneuvers such as a steep climb or sharp turn may be required in the terminal airspace to accommodate certain noise abatement regulations, missed approach go-arounds, curved approach path, etc. Such maneuvers can cause fadeouts of the ATCRBS operation due to shielding of the airborne transponder by the vehicle airframe. Hence, as part of the coverage requirements obtained from ATD, care should be taken to identify and locate where these maneuvers can occur in the airspace of interest. From this information, airspace where such shielding could result in any long-term ATCRBS fadeout can be identified.

i. Aircraft Ground Speed. The mti circuits of the ASR are based on the Doppler effect produced by aircraft motion relative to the ASR site. To determine this relative motion, the nominal ground speeds of aircraft over each air route designated in the terminal airspace should be obtained from ATD.

17. ATC FACILITY OPERATIONAL REQUIREMENTS. Certain criteria to be used in the selection of an ASR/ATCRBS site will be dictated directly or indirectly by other ATC facilities and/or their operations in or about the airport vicinity and terminal area. These criteria and how they relate to particular ATC facilities and/or operations are discussed below.

a. Equipment/Structure Clearance. It is desirable that a minimum separation of 1,500 feet be provided between the ASR/ATCRBS antenna and any above ground structures or rf generating equipment that may cause reflections[1] or otherwise interfere with radar/beacon operation. This clearance recommendation is especially applicable to airport-based equipments/structures such as ATC towers, ILS equipments, PAR's, hangars, terminal buildings, airport surface detection equipment, VOR installations, marker beacons, etc. In addition, the site shall not be less than ½ mile from Weather Bureau radars and radiosonde equipment. Violation of the latter criteria requires a Washington waiver. Further details on reflection effects are presented in paragraphs 22e and 23f.

b. Aircraft Reflection Avoidance. With the advent of the newer wide-bodied aircraft, such as the 747, there arises the problem of strong reflections occurring from these aircraft while parked or awaiting takeoff. To avoid this, it is recommended that the ASR/beacon system be located no closer than 1,500 feet from the edge of taxiways, holding bays, or terminal areas where such aircraft are known to remain for sustained periods of time.

c. Cable Length.

(1) Cable distance between the transmitter-receiver building and the indicator site should not exceed the maximum allowable cable lengths specified in tables 1-1 and 1-2 for the type ASR/beacon system being sited.

(2) It should be noted that a special low-loss cable may be required for cable lengths greater than 12,000 feet. Because of its greater cost, experience has shown that there may exist a cable length, beyond which the cost of its installation exceeds that of a RML. This cost cross-over distance will vary depending on the material/construction/labor costs and the detailed requirement of the particular installation.

d. Airport Obstruction. Where installed on or in the vicinity of the airport, the maximum physical height of the ASR/beacon structure should not constitute an obstruction as defined in FAR, part 77. These regulation define imaginary surfaces above and about the airport property which no building or installations may penetrate without a special waiver from the Administrator, FAA.

---

[1] Although desired minimum separation distances are indicated here, false targets may be produced by large reflecting surfaces at considerably greater distances (up to 6 miles in some instances). Each case should be judged independently using the techniques described in paragraph 22e.

e. Other Radar/Beacon Facilities.

(1) Other terminal and en-route radar systems operating within a vicinity of 200 miles may provide partial if not total coverage of the terminal airspace to be served by the new ASR/beacon system being sited. The resulting overlap in coverage is useful in establishing handoff or transition zones between terminal and/or en-route traffic controllers. It also can result in mutual interference with the operation of the proposed ASR/beacon installation. To prevent this, the frequencies of all ATC radar/beacon systems in the area are assigned in accordance with official Frequency Management procedures. Regional FAA Frequency Management personnel should be contacted regarding possible interference between the ASR/beacon system and other radar facilities in the area.

(2) Of special concern when adding a beacon interrogator in a terminal area is the possible increase in interrogation rate that aircraft operating in the terminal airspace can be expected to experience. If this effect is severe, overinterrogation can result, saturating airborne transponders to the extent that they cannot reliably reply to any interrogator. Areas where such beacon interference is excessive (i.e., over 1,000 interrogations per second) are commonly referred to as "hot-spots". The DOT Transportation Systems Center (TSC) and the DOD Electromagnetic Compatibility Analysis Center (ECAC) have each developed digital computer techniques which are capable of assessing the impact of adding a beacon interrogator in any location in the continental United States. Before siting of an ASR/ATCRBS, in regions where "hot-spot" problems are suspected, it is advisable that a computer analysis of the increased interrogation rate resulting from installation of a new beacon interrogator in the area be carried out. Arrangements for computer services by ECAC or TSC must be made by written request to the FAA Radar/Automation Engineering Division, code AAF-300, Washington, D.C. Further details on the capabilities and input requirements of these computer techniques may be found in appendix 5, along with the capabilities of other computer programs of possible benefit to radar site selection.

f. MTI Reflectors.

(1) The mti reflector is a fixed target which provides a radar echo simulating that received from a moving aircraft. These radar reflections play an important role in the functional operations of the ASR, in that they permit radar video map or map overlay alinement along with range mark alinement. This is important to maintenance personnel, and is used by ATC operators to check video map alinement on the display indicator.

(2) Although siting criteria/requirements for the ASR/ATCRBS take precedence, certain guidelines for the location of mti reflectors have been devised which should be given due consideration when selecting an ASR/ATCRBS site location. These guidelines are outlined below:

(a) Five reflectors will usually be provided for use with any specific ASR. Special cases may arise, however, where fewer or more reflectors will be required. For example, only three mti reflectors are furnished with radar systems using the TRACAB configuration.

(b) The reflector locations must be within the visibility limits, and within 5 nmi of the ASR.

(c) The height of the poles used to elevate the reflectors must not constitute an obstruction as defined in FAR, part 77.

(d) MTI reflectors should be located on airport property, if at all possible. These locations are preferred since they offer the best protection from future encroachment and obstruction.

(e) Specifically, the preferred reflector locations are as follows:

1. Runway Approaches. One mti reflector is to be installed on the extended runway centerline of each instrument runway and approximately 1 nmi from the end of the runway. The 1-nmi criterion may not always be feasible, however, due to line-of-sight (los), land availability, and range limitations.

2. For Range Markers. One reflector is to be installed at a range of 2 nmi from the ASR site. If possible, this reflector should also be installed on the extended centerline of one of the runways. In case of conflict between these criteria, however, the 2-nmi range requirement takes precedence.

3. Remaining Reflectors. The remaining reflectors, if applicable, are to be installed on the extended centerlines of other runways, preferably on the opposite ends of the instrument runways.

(3) All mti reflector siting must be coordinated with local Airway Facilities Division and Air Traffic Division personnel.

SECTION 3. ASR/ATCRBS COVERAGE CAPABILITIES

18. INTRODUCTION. Basic coverage capabilities of the ASR and ATCRBS equipment were briefly illustrated in chapter 1. These capabilities are described and illustrated more fully in the following paragraphs. It should be noted, however, that all radar and beacon coverage capabilities presented in this section are determined for free-space conditions and do not include the modifying effects of such phenomena as screening, vertical lobing, ground clutter, false targets, etc. The latter effects, which usually degrade coverage, are considered in section 4 of this chapter. All of these effects should receive consideration when assessing ASR/ATCRBS coverage capabilities from a particular site location.

19. ASR COVERAGE.

a. Coverage capability for ASR systems has been determined utilizing the methodology presented in reference 6. Radar range, R, is given in nautical miles by the expression:

$$R = 129.2 \left[\frac{P_t \tau G_t G_r \sigma}{f^2 T_s (S/N) C_B L} \right]^{1/4} \qquad (2\text{-}1)$$

where

P_t = peak power transmitted (in kW)

τ = pulse duration (in μs)

G_t = transmitting antenna gain in the target direction

G_r = receiving antenna gain in the target direction

σ = target radar cross section (in square meters)

f = radar frequency (in MHz)

T_s = system noise temperature (in ^{o}K)

S/N = signal-to-noise power ratio

C_B = bandwidth correction factor

L = loss factor

P_t, τ, G_t, G_r, and f are determined directly from table 1-1 and the system antenna patterns. Computations performed here used actual measured antenna pattern data, but similar results can be obtained

* using the patterns shown in chapter 1. A sample of coverage range computation is given in appendix 7. *

b. Noise temperature, T_s, for these computations, was taken to be

$$T_s = 290\ (F_n - 1) + T_a \qquad (2\text{-}2)$$

where

$10 \log F_n$ = receiver noise figure (in dB) shown in table 1-1

T_a = antenna noise temperature (assumed 124°K)

c. Transmission line losses are ignored in this determination since these are included elsewhere in the computation.

d. The signal-to-noise (s/n) ratio is determined from the Swerling detection model for Case I target fluctuation at a 0.75 probability of detection and 10^{-6} false alarm probability. The number of integrated pulses for this determination is derived from equation 1-4 (p. 17). For 18 hits/scan, s/n is approximately 7.4 dB.

e. The bandwidth correction factor, C_B, is found from the expression:

$$C_B = \frac{B\tau}{4}\ \left(1 + \frac{1}{B\tau}\right)^2 \qquad (2\text{-}3)$$

where for a conservative result:

B = mti receiver if bandwidth (in MHz)

τ = pulse duration (in μs)

f. System loss factor, L, is taken to be

$$L = L_\alpha L_p L_{tr} \qquad (2\text{-}4)$$

In this expression, L_α is a propagation absorbtion loss factor, assumed to be unity in this free-space calculation. L_p is an antenna pattern beamshape loss factor to account for changes in gain as the antenna scans past a target. L_p is assumed equal to 1.6 for this calculation, as per reference 6. L_{tr} is a general rf loss factor to account for plumbing losses in waveguide, rotary-joint, etc. For this computation, L_{tr} is assumed as follows:

	ASR-4B, 5, 5E, 6, 6E, 7	ASR-7E	ASR-8
40 feet RG 75/U waveguide loss[1] (dB).	0.8	0.8	0.8
Rotary joint loss[1] (dB)..............	0.4	0.4	0.4
Radar internal plumbing loss[1] (dB)...	2.0	2.0	1.0
Diplexer loss[1] (dB)..................		1.0	
Total plumbing losses (10 log L_{tr})..	3.2 dB	4.2 dB	2.2 dB

*

The radar cross section, σ, used in computation was selected to cover virtually all targets of interest to siting engineers. Values used are labeled in dB on the plotted results, to correspond with those indicated in table 2-1.

g. Computed radar coverages for ASR-4B, 5, 6 and 7 are shown in figures 2-1, 2, 3 and 4. The diagrams shown assume lp and an antenna tilt angle of 0.5° referred to the lower 3 dB point. The equivalent angle of 2.5° referred to the nose of the beam is indicated in the diagrams. Similar computed radar coverages for dual beam antenna systems, ASR-5E, 6E, 7E and 8 are shown respectively in figures 2-2A, 2B, 4A, 4B, 5 and 6. These diagrams assume lp also and reception on the lower beam. The tilt angle referred to the lower 3 dB point for the lower beam is assumed 0° for ASR-5E, 6E and 7E and 0.5° for ASR-8. * Basic free-space coverage with cp will be on the order of 75% of lp coverage. This results from an approximate 5 dB reduction in target cross section for cp (reference 2). Other performance degrading factors related to radar siting are covered in Section 4.

20. ATCBI COVERAGE.

a. Coverage capability of ATCBI equipment has been determined based on transponder interrogation. This is the limiting factor in terminal beacon operation as seen from appendix 2.

b. Beacon interrogation range coverage is given by:

$$R = \left[\frac{P_d G_i G_t \lambda^2}{(4\pi)^2 S_{min} L_t}\right]^{1/2} \qquad (2\text{-}5)$$

where:

R = interrogation range in meters

P_d = ATCBI output peak power (measured at antenna) in watts

S_{min} = transponder minimum sensitivity in watts

G_i = interrogator antenna gain in direction of target

G_t = transponder antenna gain in direction of radar site

L_t = transponder losses (cables and connectors, ≈ 5.5 dB)

λ = wavelength (0.291 meters)

*

1/ These are two-way losses.

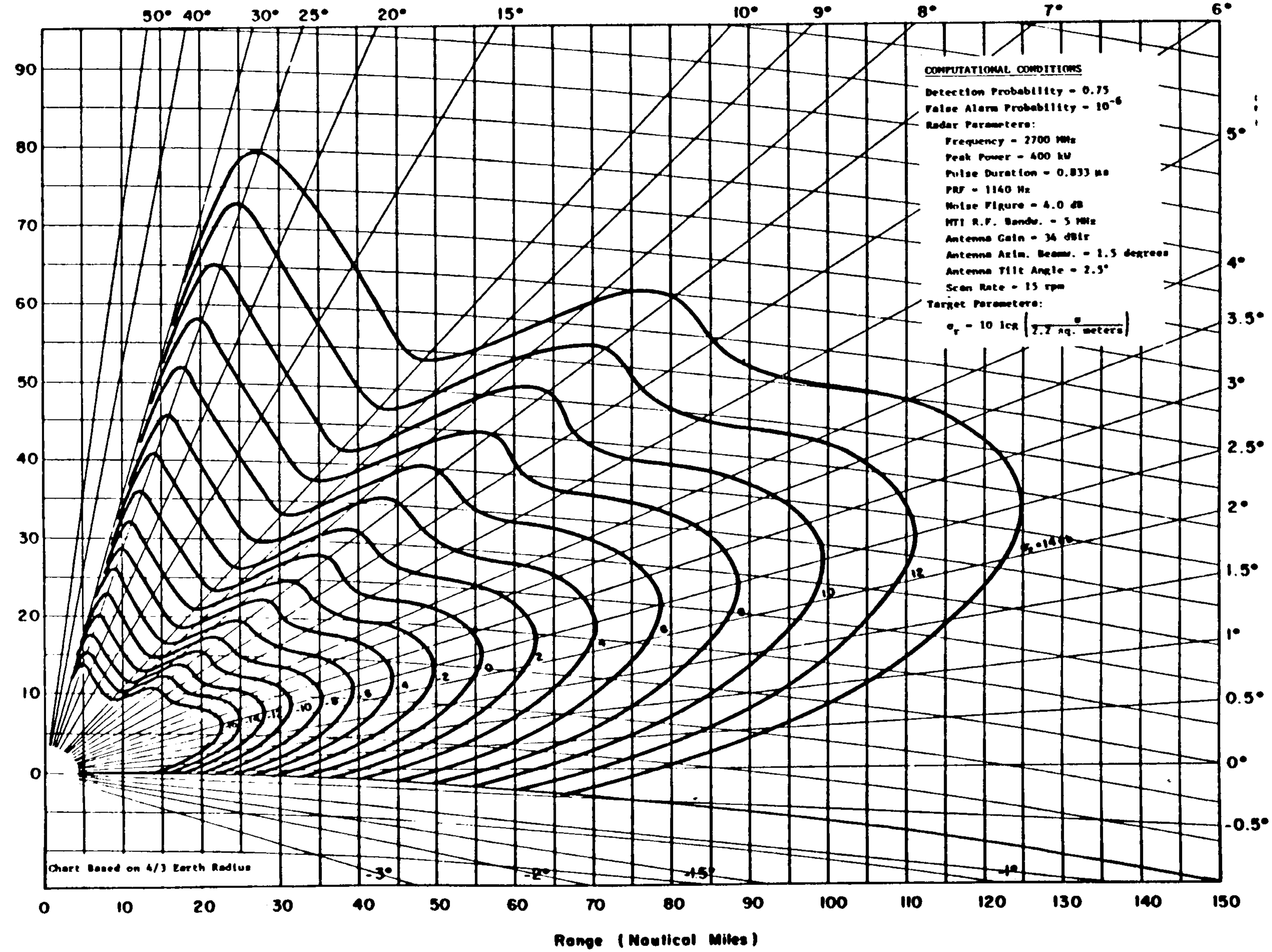
TABLE 2-1

TYPICAL AIRCRAFT AVERAGE CROSS SECTION (Linear Polarization)

Aircraft Type	Radar Cross Section	
	sq. meters	dB, rel to 2.2 m^2
Military		
B-52	21.9	+10
C-47	11	+ 7
C-54	27.5	+11
C-97	69.3	+15
C-121	21.9	+10
C-135	13.8	+ 8
F-84	2.2	0
F-86	2.8	+ 1
F-100	3.5	+ 2
F-104	2.8	+ 1
F-106	4.4	+ 3
F4	2.8	+ 1
T-33	2.2	0
T-38 [1]		
Commercial		
Constellation	21.9	+10
Convair	21.9	+10
DC-3	11	+ 7
DC-7	27.5	+11
DC-8	17.4	+ 9
DC-9 [1]		
DC-10 [1]		
707	13.8	+ 8
727 [1]		
737 [1]		
747 [1]		
General Aviation		
Comanche [1]		
Cessna 180 [1]		

[1] No reliable data available at this time.

* FIGURE 2-1. RANGE COVERAGE CAPABILITY OF ASR-4B, 5 AND 6 *
(FREE SPACE CONDITIONS)



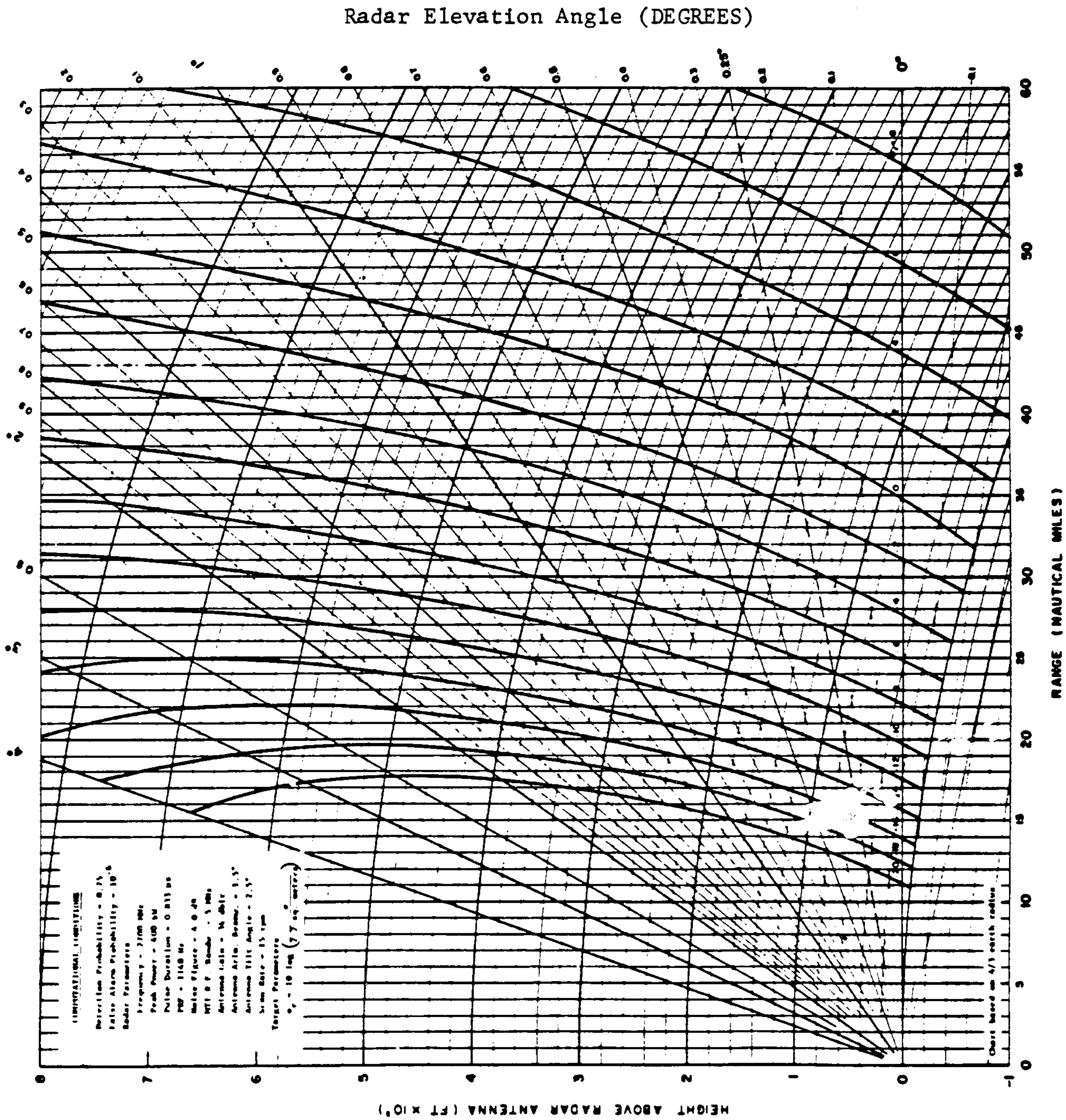
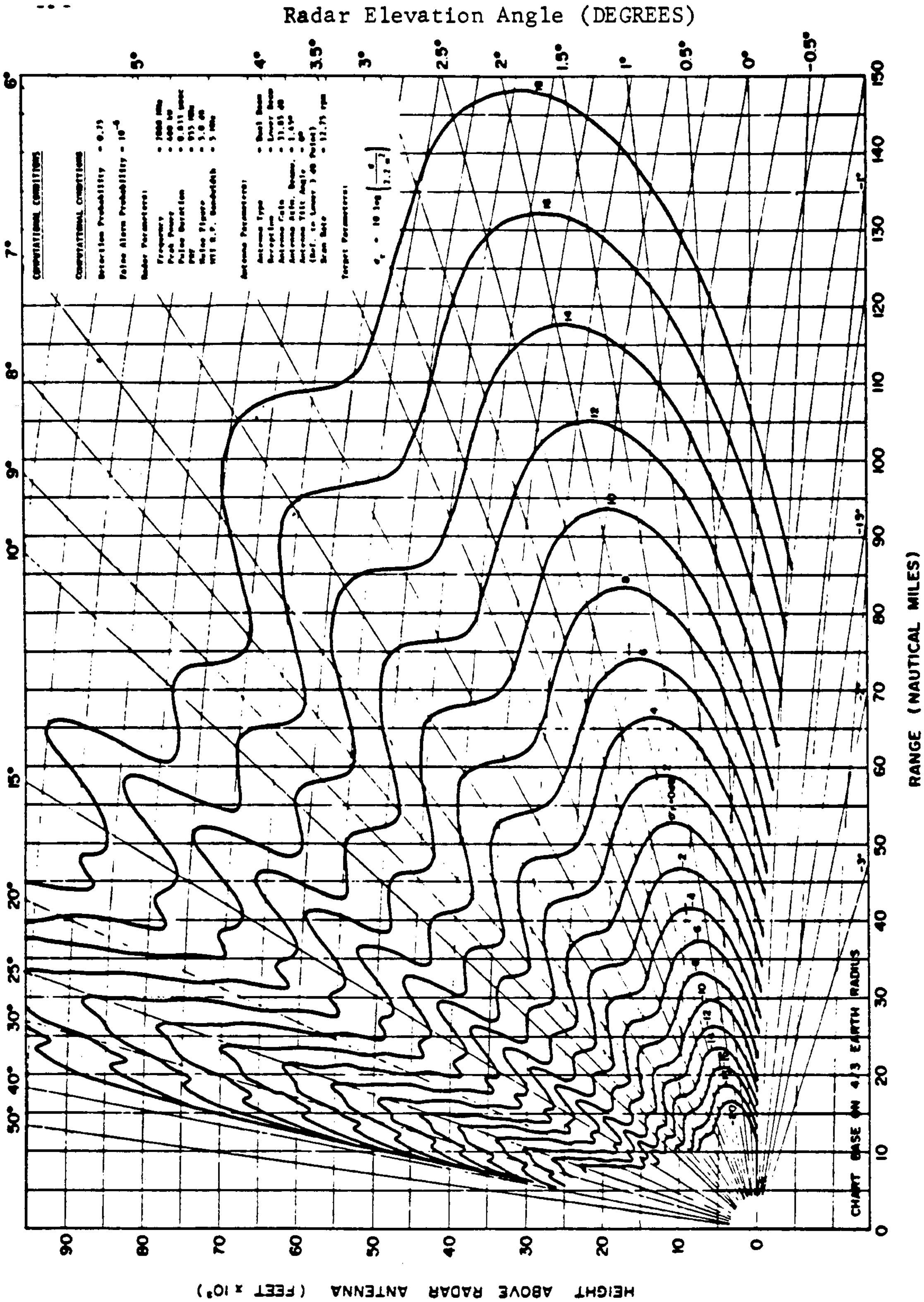


FIGURE 2-2. RANGE COVERAGE CAPABILITY OF ASR-4B, 5 AND 6 (FREE SPACE CONDITIONS — EXPANDED SCALE)

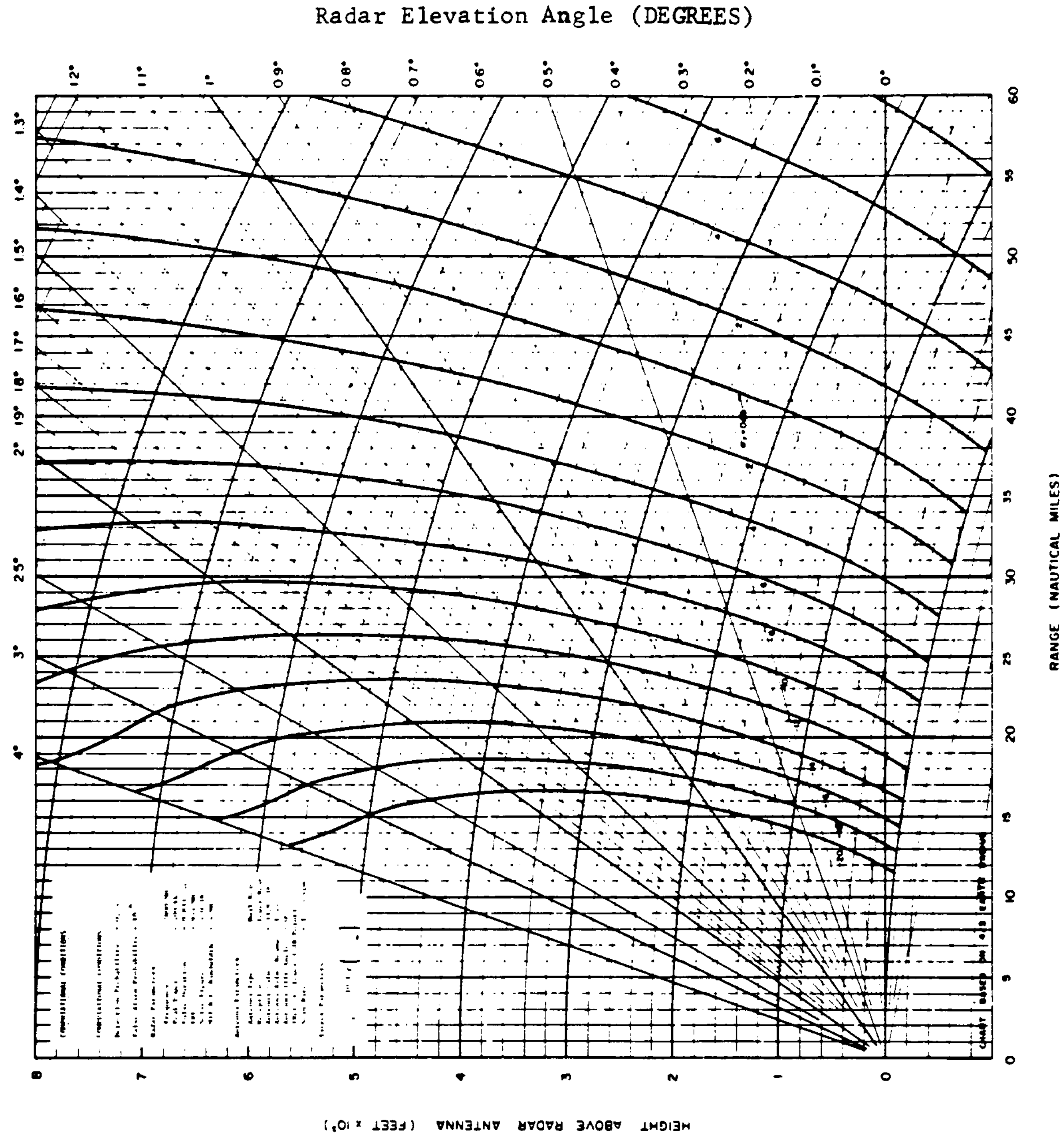


* FIGURE 2-2A. RANGE COVERAGE CAPABILITY — ASR-5E AND 6E (FREE SPACE CONDITIONS—RECEPTION ON LOWER BEAM) *

--- -

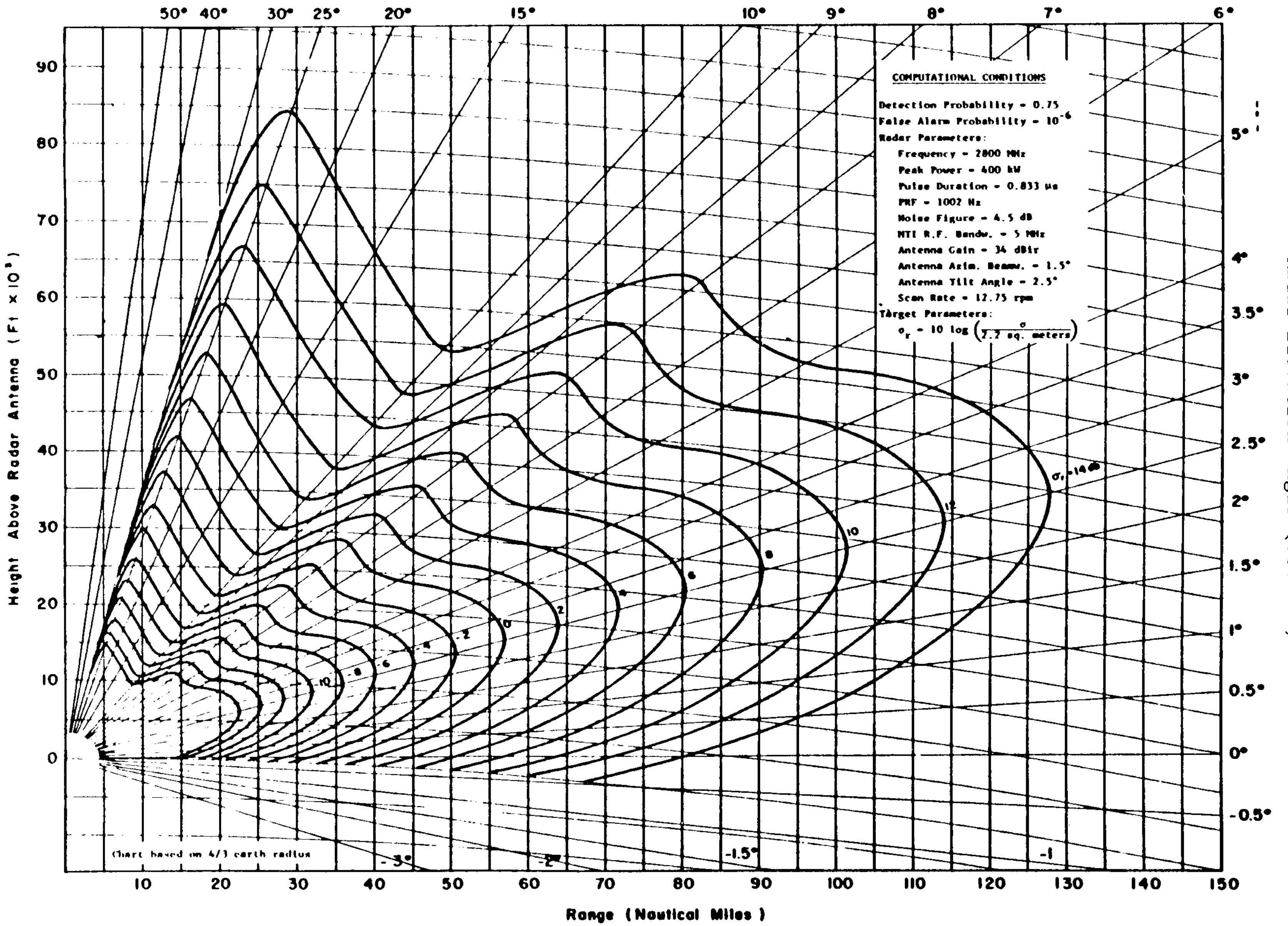
*

FIGURE 2-28. RANGE COVERAGE CAPABILITY — ASR-5E AND 6E
(FREE SPACE CONDITIONS - RECEPTION ON LOWER BEAM - EXPANDED SCALE)



*

* FIGURE 2-3. RANGE COVERAGE CAPABILITY OF ASR-7 (FREE SPACE CONDITIONS) *



*

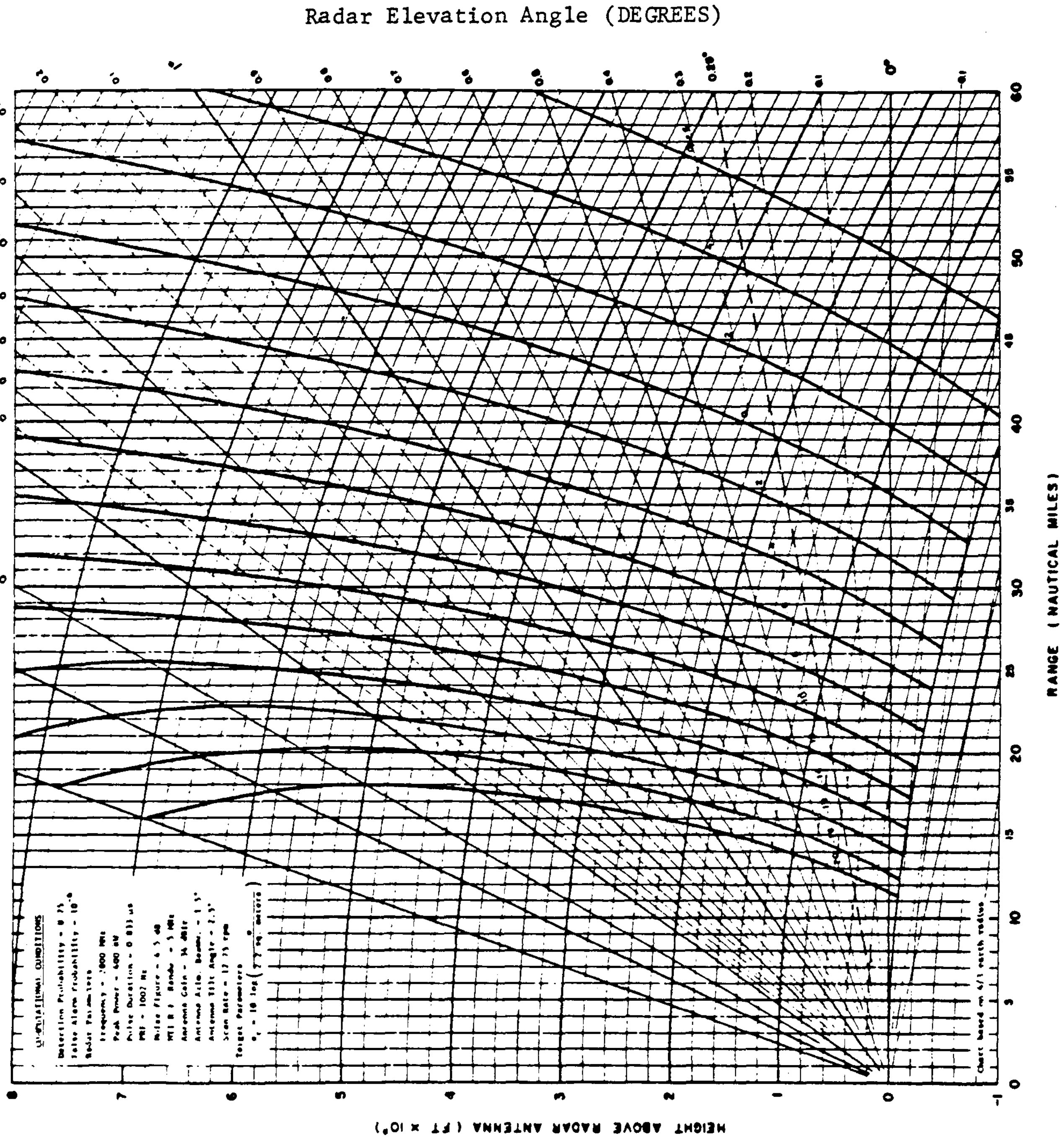
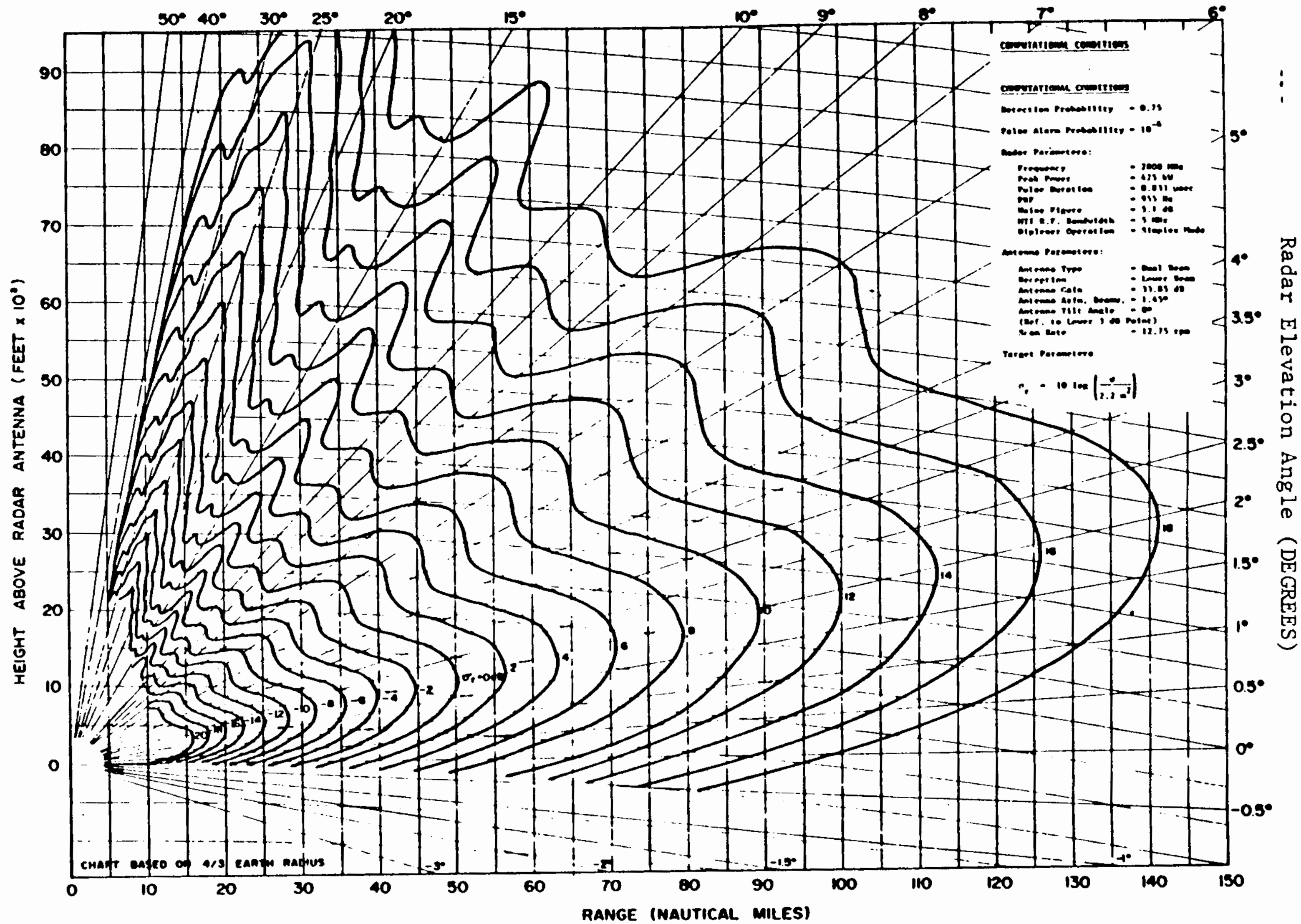


FIGURE 2-4. RANGE COVERAGE CAPABILITY OF ASR-7 (FREE SPACE CONDITIONS - EXPANDED SCALE)

*

*

FIGURE 2-4A. RANGE COVERAGE CAPABILITY — ASR-7E
(FREE SPACE CONDITIONS—RECEPTION ON LOWER BEAM)



*

*

Radar Elevation Angle (DEGREES)

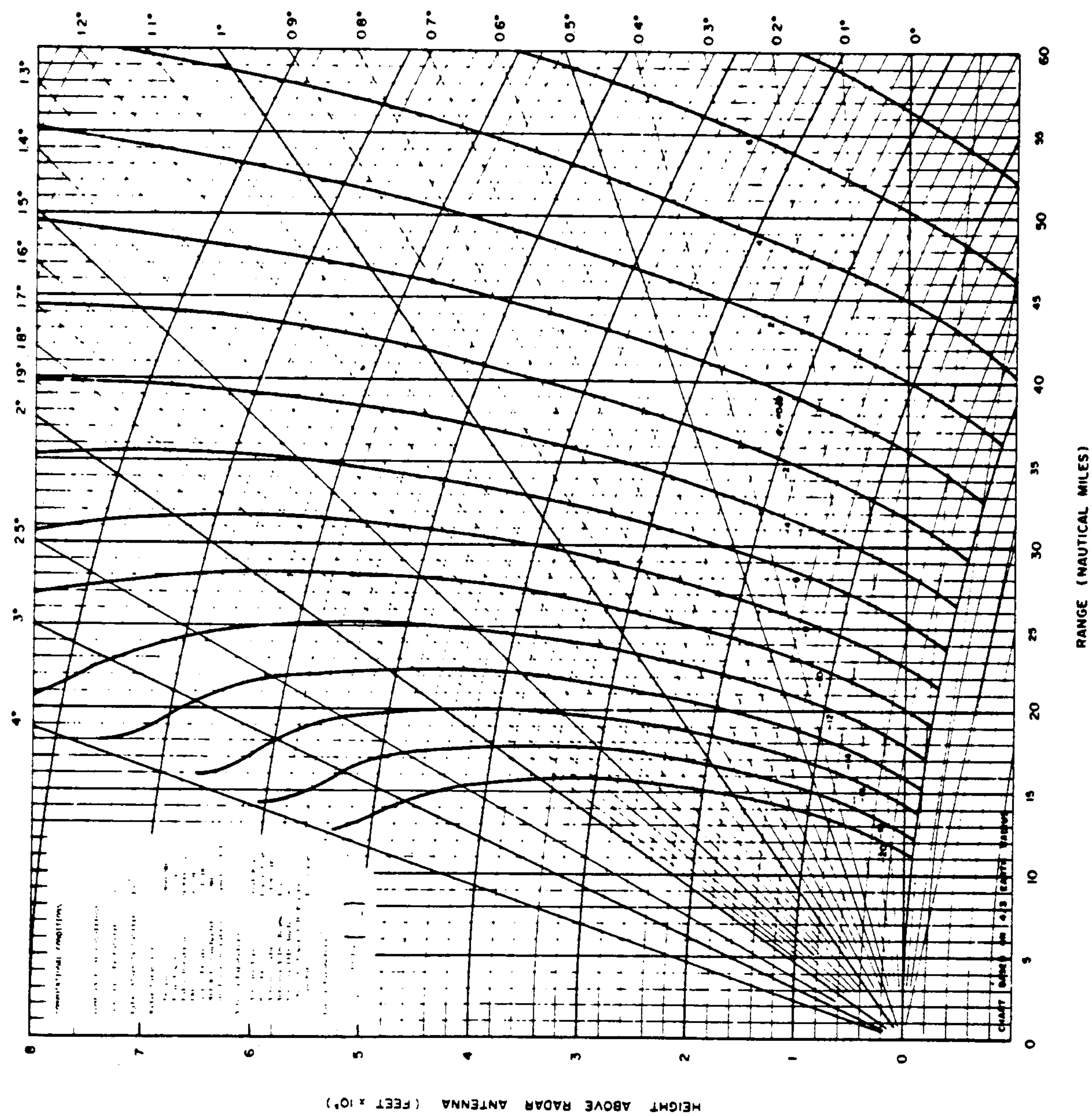
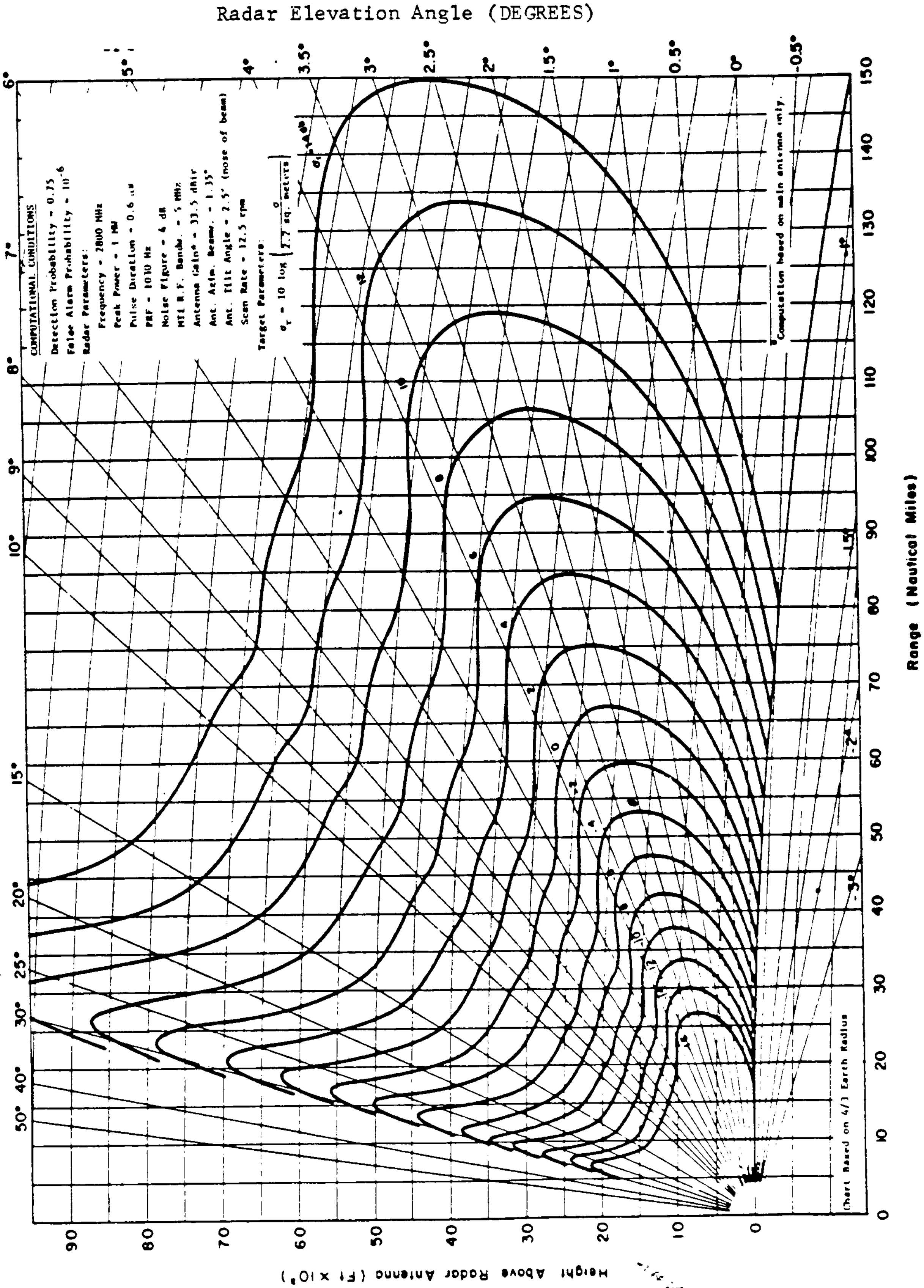


FIGURE 2-48 RANGE COVERAGE CAPABILITY - ASR 7E (FREE SPACE CONDITIONS - RECEPTION ON LOWER BEAM - EXPANDED SCALE)

*

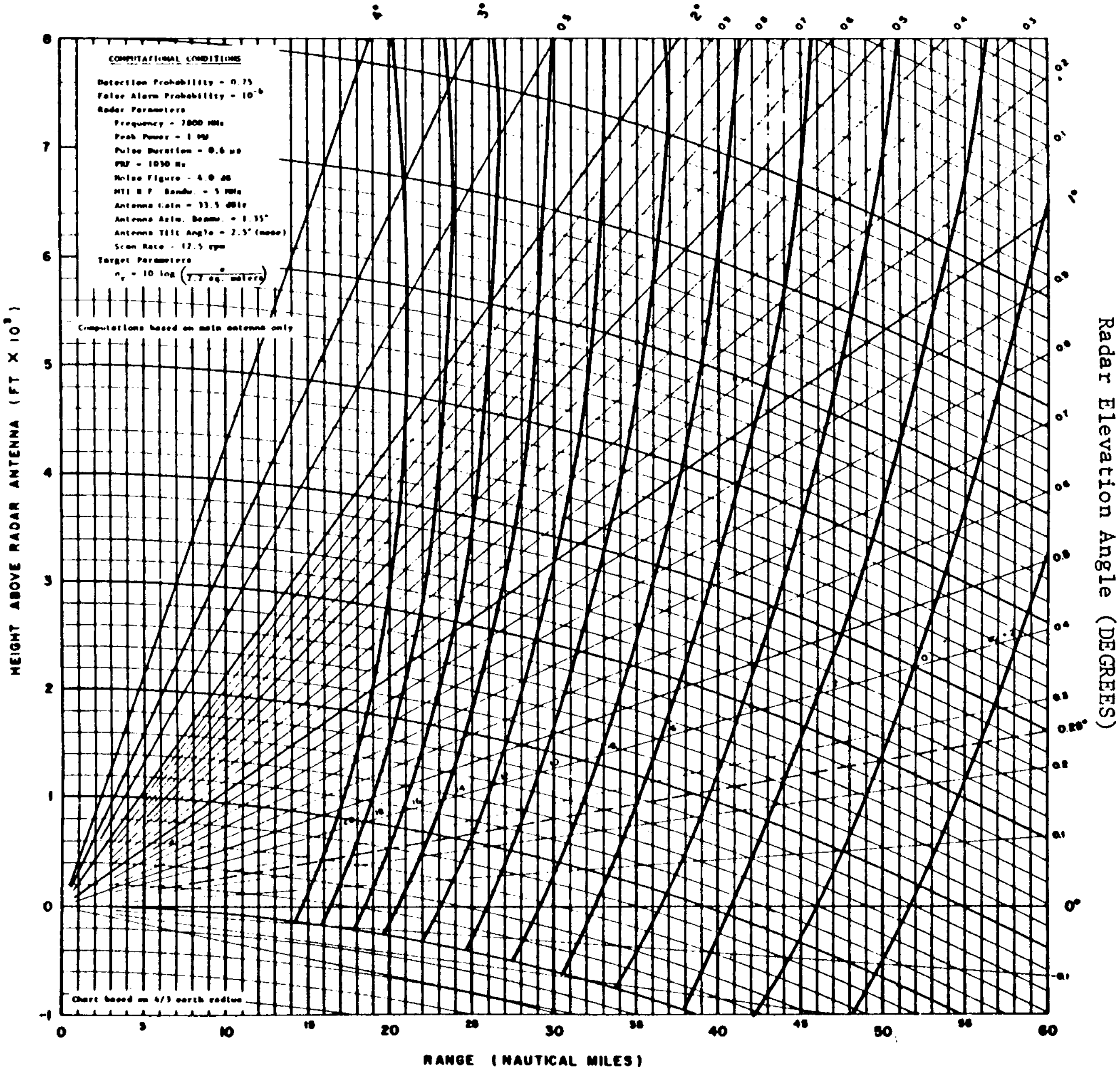
*

FIGURE 2-5. RANGE COVERAGE CAPABILITY OF ASR-8 (FREE SPACE CONDITIONS — RECEPTION ON LOWER BEAM)



*

FIGURE 2-6. RANGE COVERAGE CAPABILITY OF ASR-8
(FREE SPACE CONDITIONS – RECEPTION ON LOWER BEAM – EXPANDED SCALE)



c. For purposes of calculation it is assumed that:

* (1) G_i varies substantially as shown in figure 1-15 for the ATCBI-3 antenna, figure 1-17 for the ATCBI-4 antenna, and figure 1-18A for ATCBI-3, 4, 5/antenna FA-9764, with a maximum gain of +21 dBir minimum. *

(2) $G_t = L_t$

(3) $S_{min} = -69$ dBm; this corresponds to a low sensitivity transponder and provides a conservative computed result.

* d. Coverage determined under these conditions is plotted in figures 2-7, 2-8 and 2-8A, with P_d as a parameter. Again, it should be noted that the coverage determined here is for free-space conditions and does not include the effects of screening, vertical lobing, etc. These effects must be included, however, when establishing a radar site; means for so doing are discussed in the following section. *

SECTION 4. OPERATIONAL LIMITATIONS

21. INTRODUCTION. In any installation, the free-space theoretical radar and beacon coverage is affected, usually adversely, by the operational environment. The local terrain features can produce radar screening, vertical lobing, ground clutter, and false targets. In addition, coverage may be degraded generally by the effects of precipitation and interference, and in specific areas due to tangential courses. Each of these effects is important and must be carefully considered at the time of siting. These effects and their sources are discussed in the following paragraphs.

22. DEGRADED PERFORMANCE EFFECTS.

a. Screening.

(1) Within the range and scan limits of the radar/beacon system, there exist regions of ground terrain and navigable airspace which are not illuminated by the radar or beacon system. Those regions are created by the screening or shadow effects of ground terrain features and/or any of a variety of man-made structures about the ASR/ATCRBS site. For purposes of ASR/ATCRBS siting, two types of screening are of interest. One concerns the screening of portions of the navigable airspace where aircraft may be present but remain undetected. The other involves the deliberate use of screening to shield ground, terrain, structures, roads, etc., from the ASR/beacon illumination. The latter is very important as a technique for reducing if not eliminating many of the operational shortcomings (i.e., clutter, lobing, false targets, etc.) of the ASR/ATCRBS produced by reflections from ground terrain, buildings, etc.

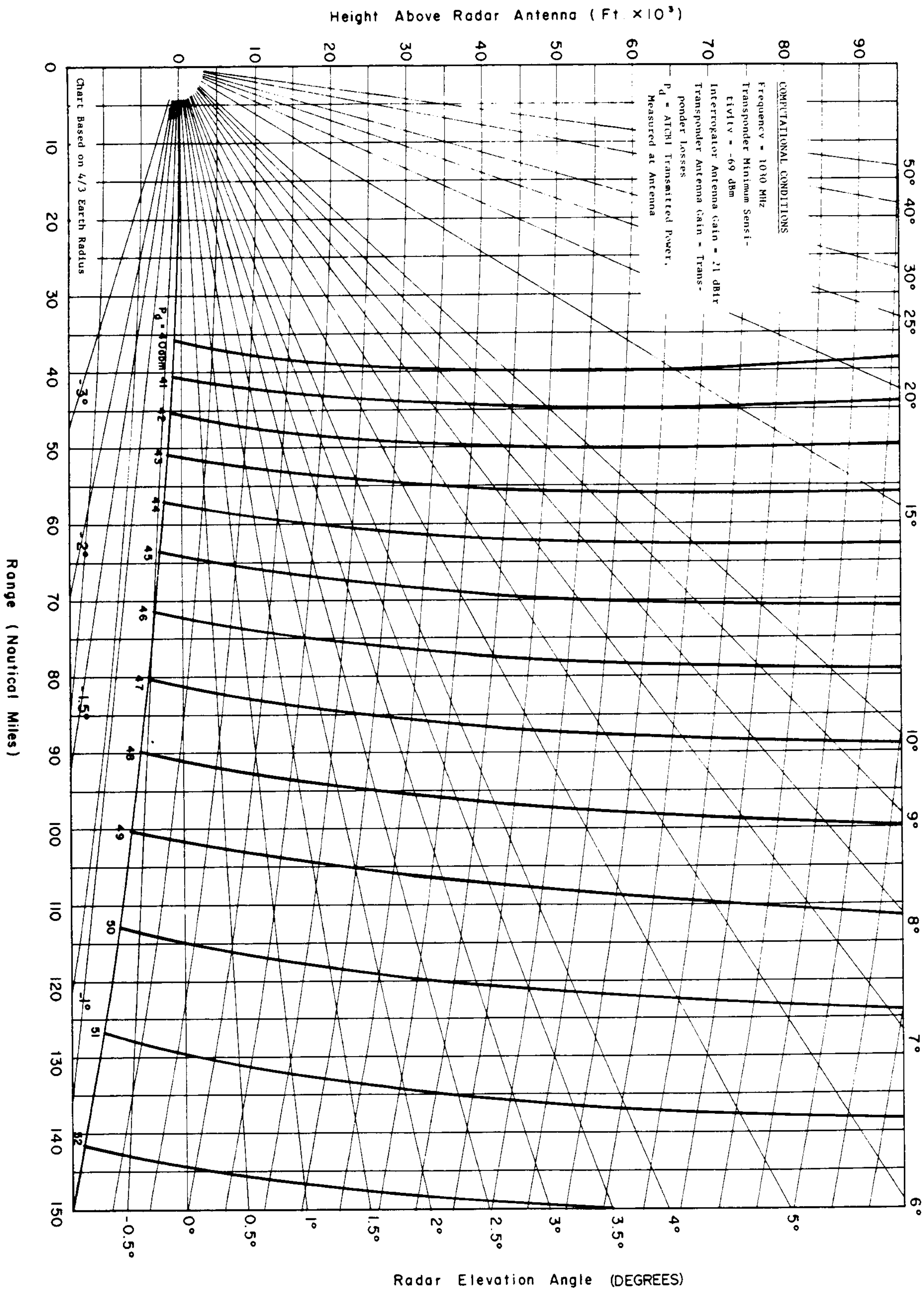
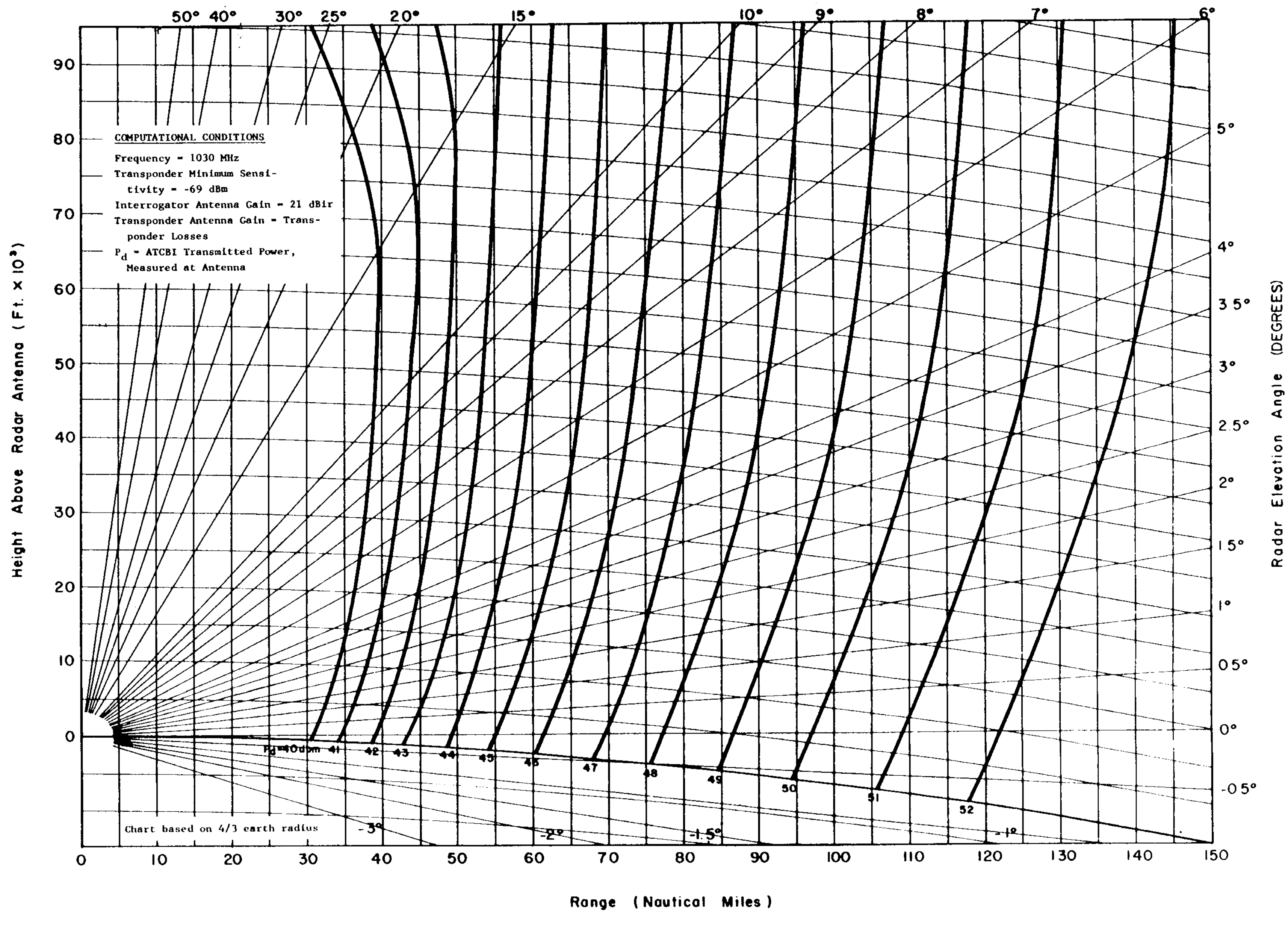


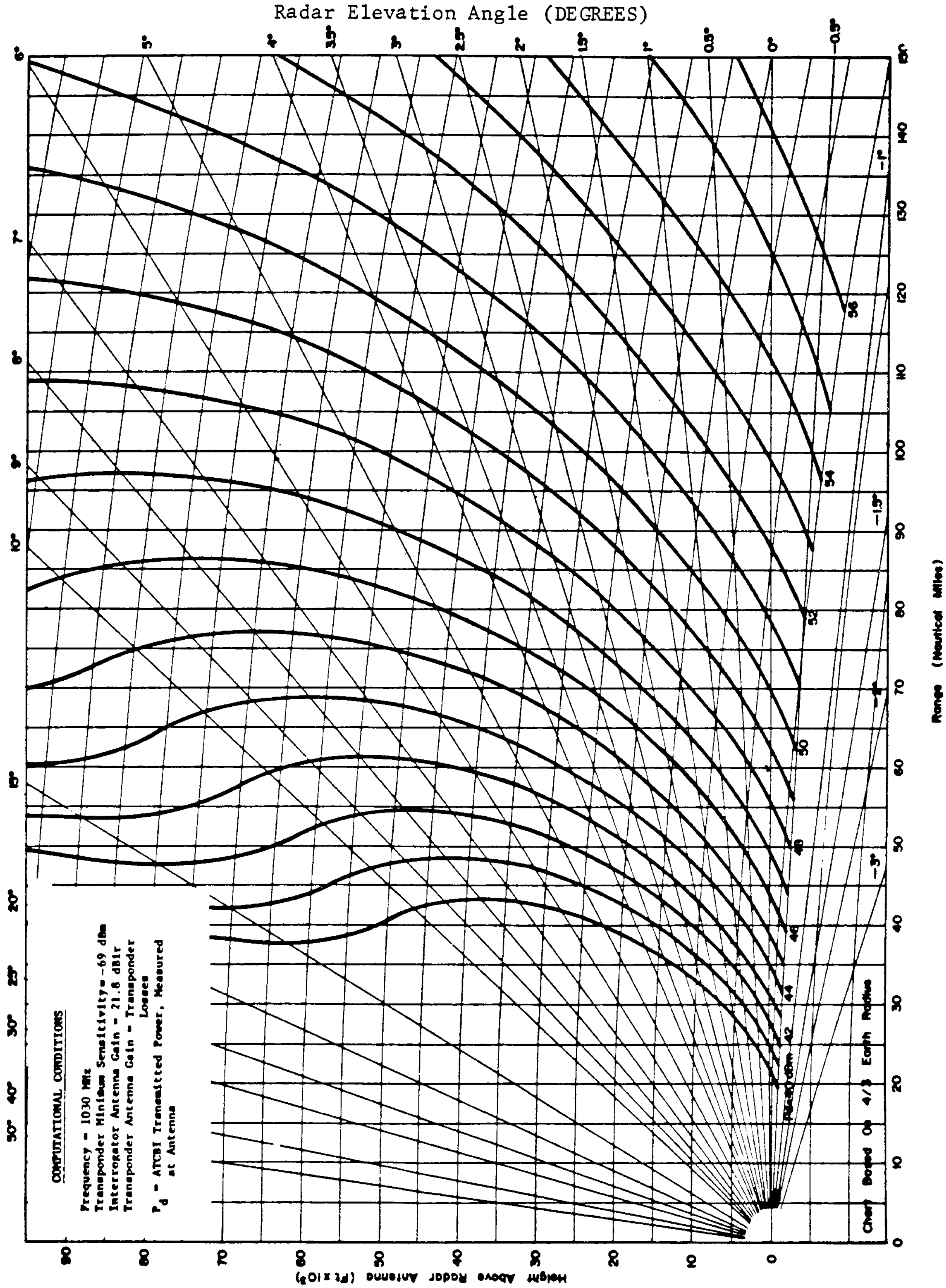
Figure 2-7. ATCRBS RANGE COVERAGE CAPABILITY - FREE - CONDITIONS

Figure 2-8. ATCBI-4 AND 5 RANGE COVERAGE CAPABILITY - FREE - SPACE CONDITIONS



*

FIGURE 2-8A ATCBI-3,4,5 / ANTENNA FA-9764 RANGE COVERAGE CAPABILITY — FREE-SPACE CONDITIONS



*

(2) The effects produced by screening are determined from geometric considerations only. When the earth is smooth, the curvature of the earth causes the area beyond the horizon to be invisible to the radar beam, as shown in figure 2-9. If there are hills, mountains, or man-made objects in the radar path above the horizon, the screened area is increased and the radar visibility is reduced, as shown in figure 2-10. On the earth's surface the three principal parameters for determining screen effects are the msl height of the antenna, the msl height of the screen object, and the distance between the antenna and screening object. Frequently, these parameters are combined to determine a screening angle that is used extensively in assessing los coverage.

(a) Radar Line-of-Sight.

1. The signal path from the radar antenna to the upper limit of a screening object, whether it be a hill, a structure, or the horizon is called the radar los. Over the earth's surface, this los path is curved, usually downward, as shown in figure 2-11, due to refraction by the earth's atmosphere. This curved signal path can be considered a straight line, as shown in figure 2-12 and appendix 3, by replacing the actual radius of the earth, a, by an equivalent earth of radius ka, where k = 4/3 for a standard earth atmosphere. Any change in atmospheric conditions which results in a change in the standard curvature of the radar path can be accounted for by a change in the value of k.

2. The radar los establishes the maximum theoretical range obtainable at a given altitude and is used to determine the airspace coverage about the radar/beacon site. This range or cutoff is generally measured along the radar los to the intersection with the altitude curve of interest shown in figure 2-10. However, for assessing los coverage about the site location, the projection of this range onto the surface of the earth is preferred. This range projection is indicated in figure 2-10, as the altitude cutoff distance.

(b) Screening Angle. The amount of screening associated with radar/beacon site can be expressed in terms of the screening angle (θ_s). This is the angle formed by the radar los and the horizontal reference line at the radar antenna as shown in figures 2-9 and 2-10. The angle may be positive or negative depending on the elevation of the antenna site and the range and elevation of the screening object.

Figure 2-9. CURVED EARTH SCREENING

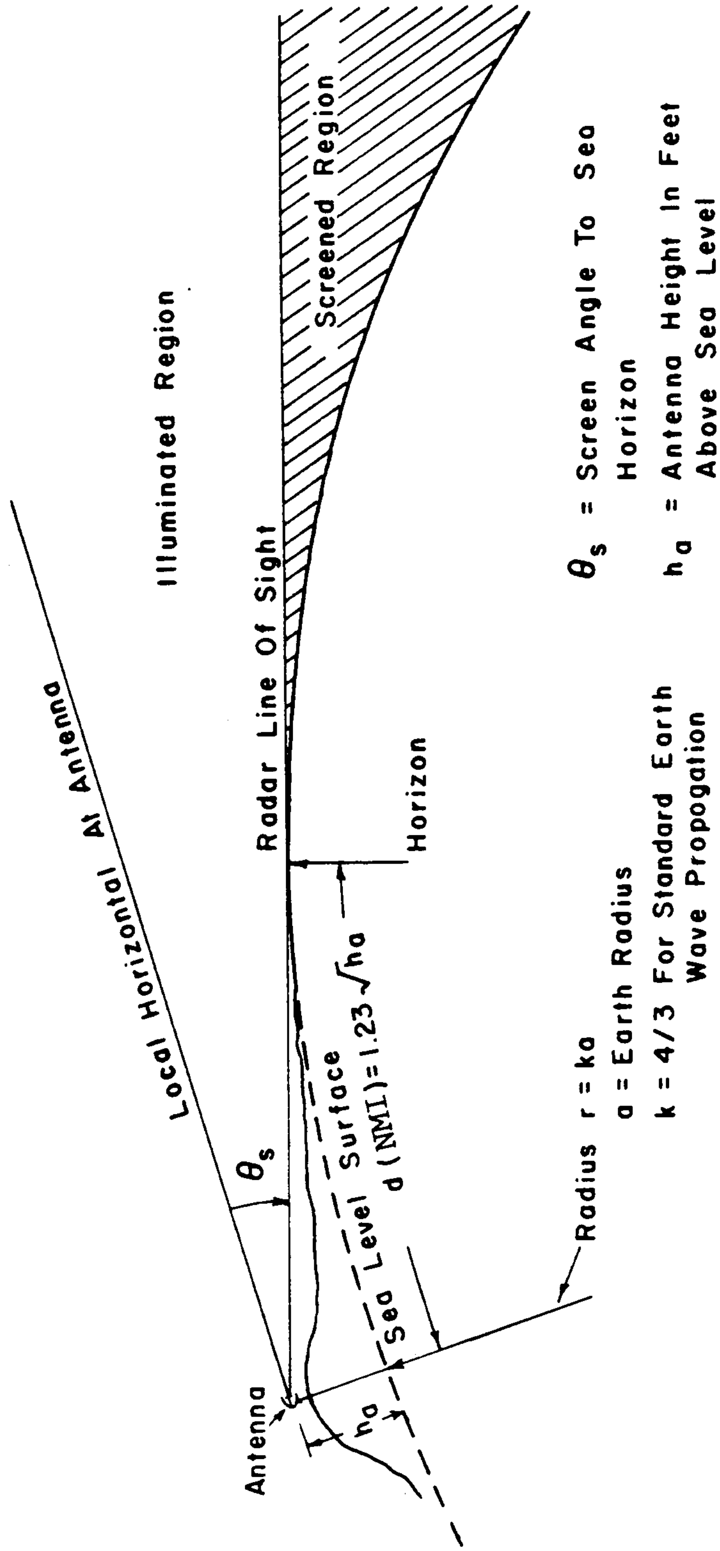


Figure 2-10. OBSTACLE SCREENING

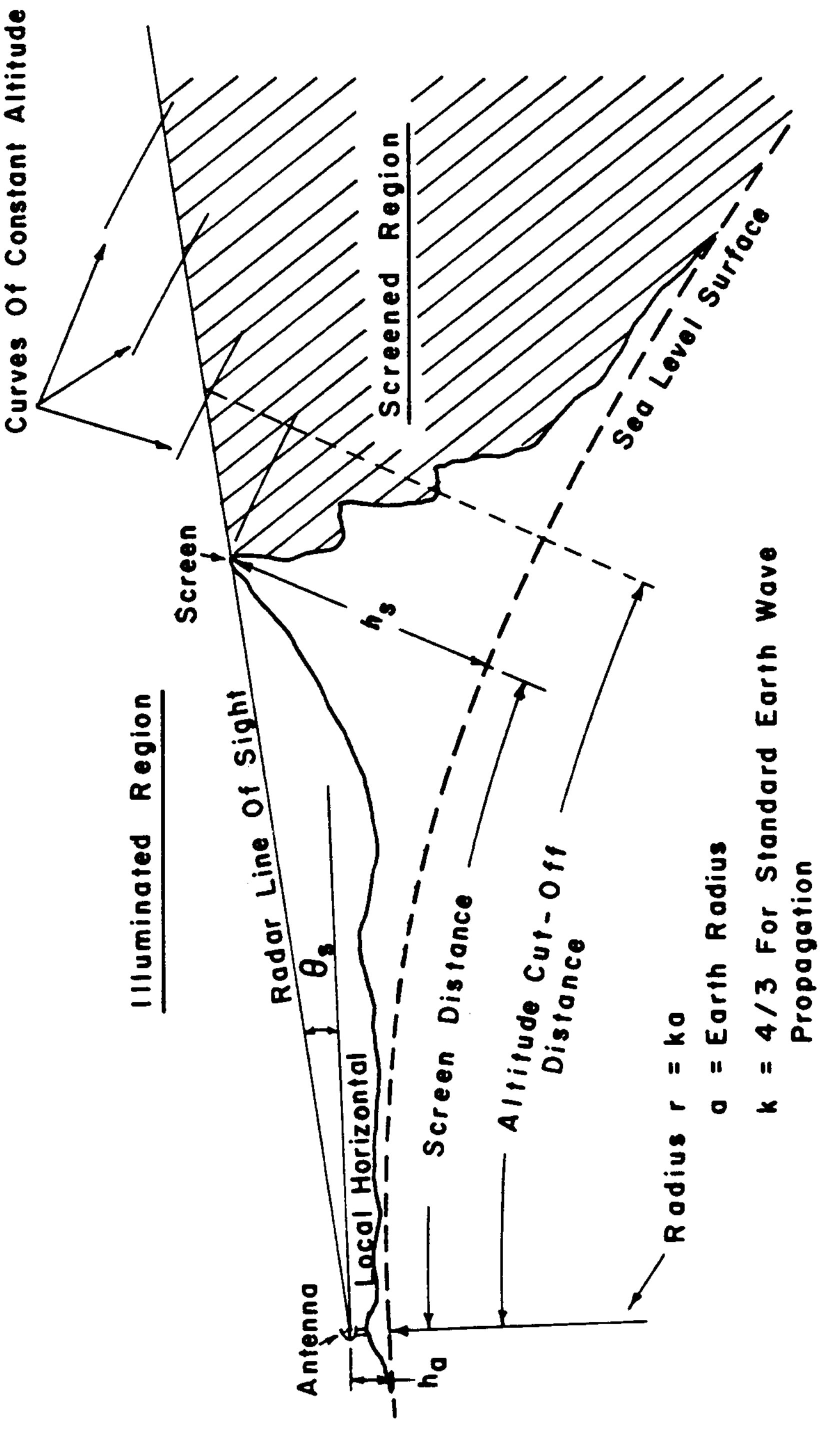


FIGURE 2-11. BENDING OF ANTENNA BEAM BECAUSE OF REFRACTION (TRUE EARTH RADIUS, a)

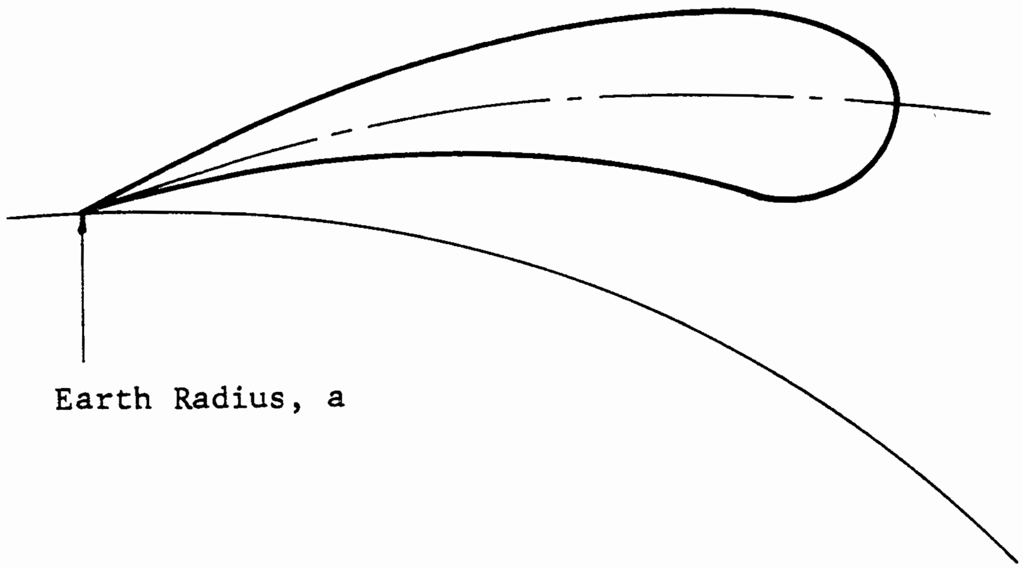
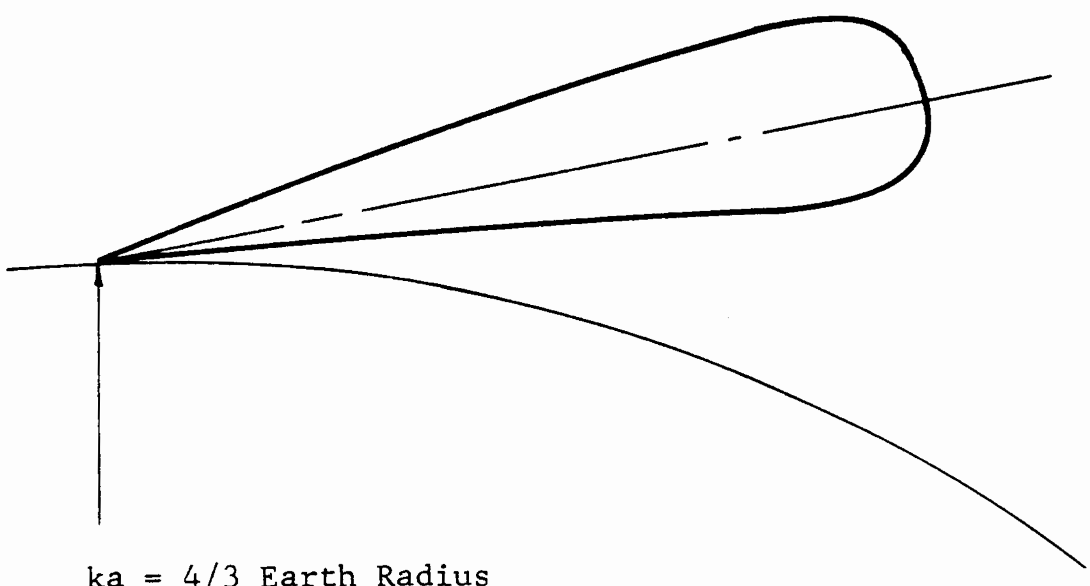


FIGURE 2-12. SHAPE OF ANTENNA BEAM IN EQUIVALENT EARTH REPRESENTATION (RADIUS = 4/3 a)



(c) Curved Earth Screening.

1. As illustrated in figure 2-9, the curvature of the earth causes screening of the airspace beyond the horizon. The range to the sea horizon for a given antenna height is given by the relationship

$$d = 1.0634 \sqrt{k\ h_a} \qquad (2\text{-}6)$$

where

d = distance in nautical miles to the sea horizon

h_a = antenna height in feet (msl)

k = equivalent earth radius factor

2. Comparing the optical los distance, $d_{7/6}$ (for which $k = 7/6$ to account for optical refraction), and the radar los distance, $d_{4/3}$ (where $k = 4/3$ for standard atmosphere), we see that:

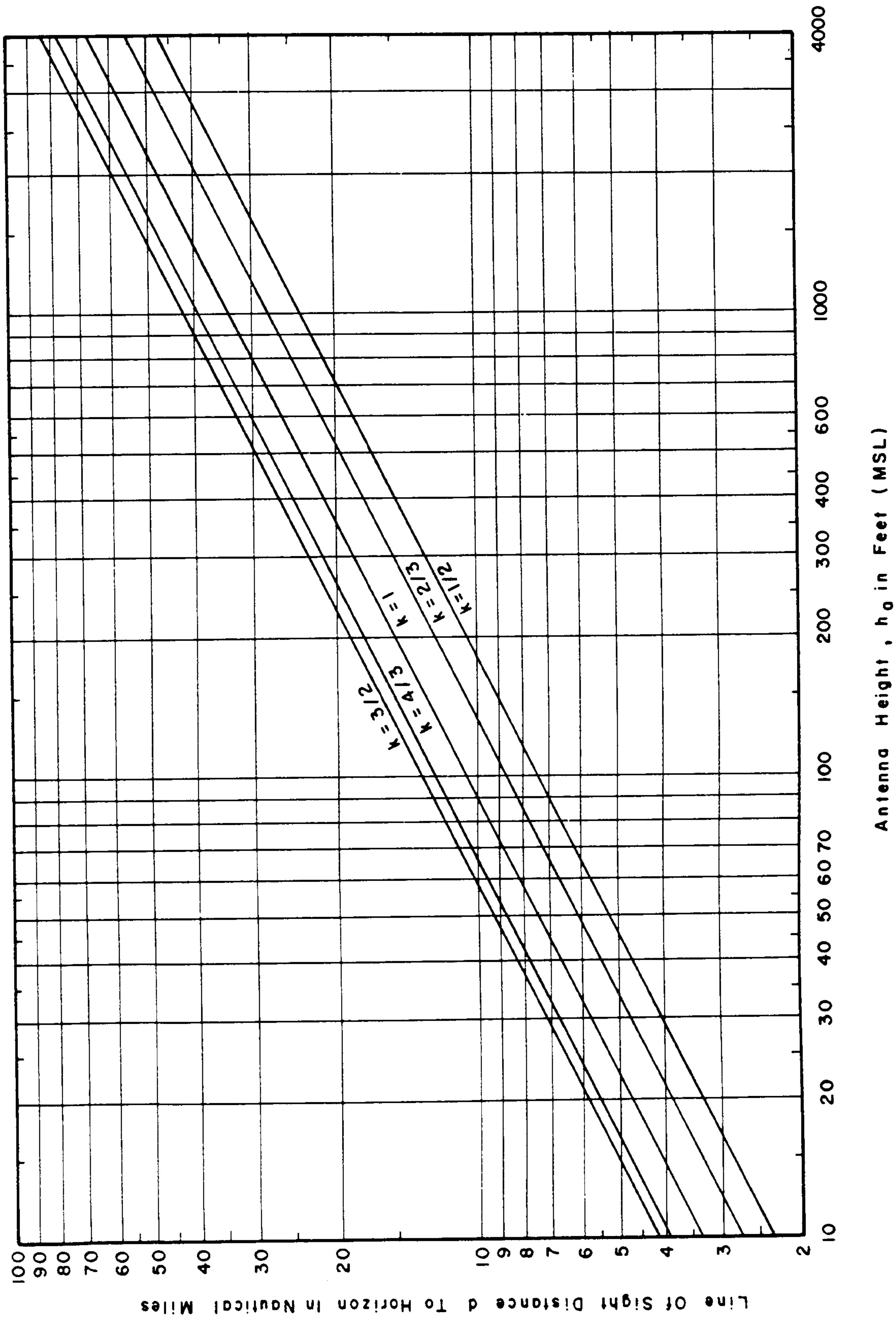
$$d_{4/3} = 1.07\ d_{7/6} \qquad (2\text{-}7)$$

3. Hence, because of the bending of the radio waves, the visible radar horizon is extended 7% beyond the optical sea horizon. For other values of k, this radar los distance will be proportionally larger or smaller. Figure 2-13 provides a graphical means for determining radar range, d, to the sea horizon as a function of antenna height for several values of k. In this plot, the antenna height is the elevation of the antenna relative to the msl. For a smooth earth where the ground terrain is above sea level, these curves can be used to determine range to the horizon by referring them to the effective antenna height, that is, the height above the elevation of the earth terrain.

(d) Obstacle Screening.

1. The effect of raising the radar los, and thereby the screening angle, is to reduce the maximum range at which aircraft at a given altitude are visible. This effect is illustrated in figure 2-14. In the figure the antenna height is at sea level and the maximum range at which the 5,000 feet altitude level is visible for a 0° screen angle is 87 nmi. If the radar los is changed to produce a screening angle of $+1^\circ$, the limit for 5,000 feet altitude is reduced to 38 nmi--a reduction in range of 49 nmi, or 56%.

Figure 2-13. LOS DISTANCE VS. ANTENNA HEIGHT



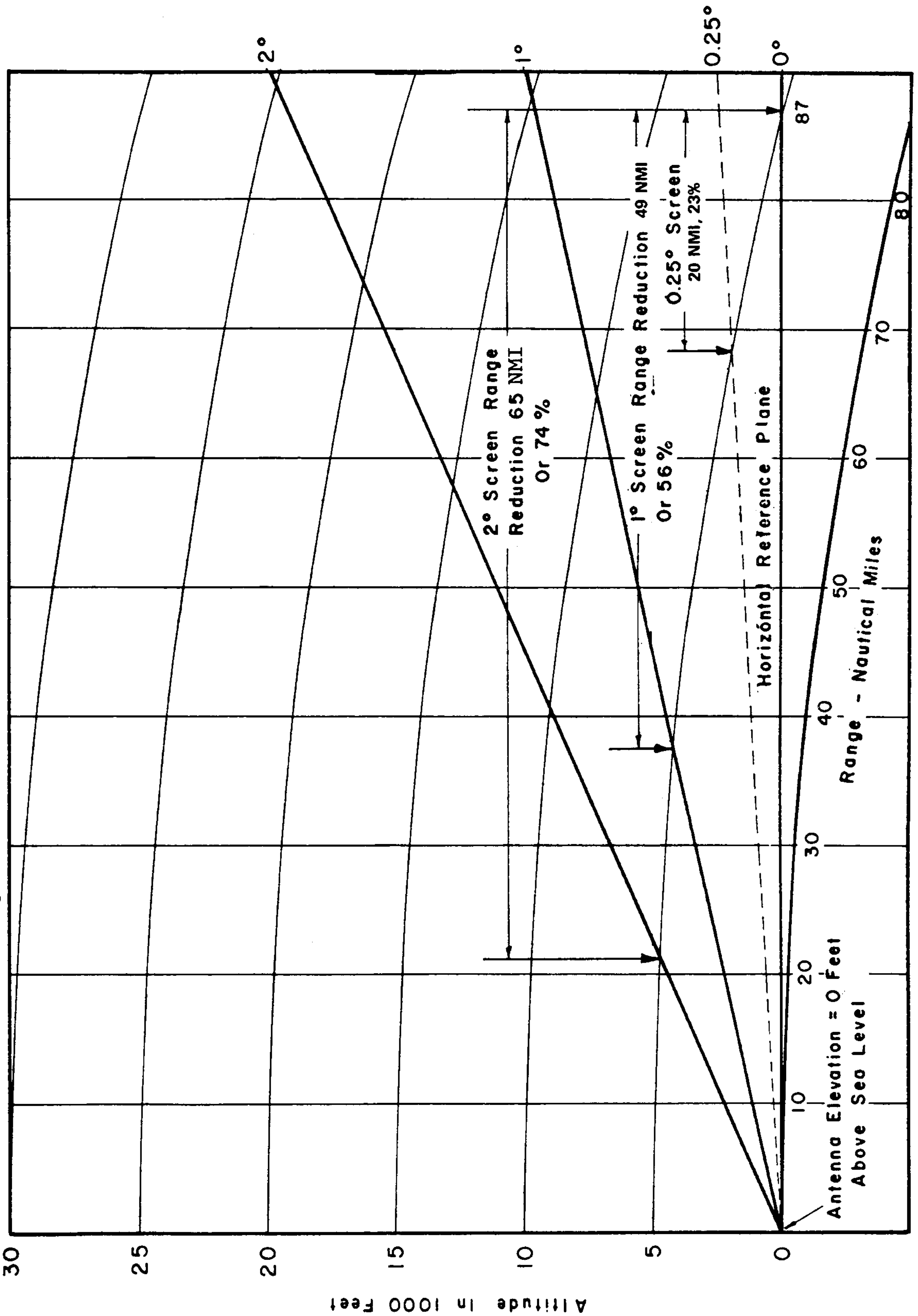


Figure 2-14. SCREENING ANGLE VS. RANGE

2. For the type of obstacle screening depicted in figure 2-10, the los boundary between the illuminated and screened airspace is defined by the following equation (these equations are also the basis for figure 2-14, see appendix 3 for derivation).

$$\tan \theta_s = \frac{h_s - h_a}{6080\ d_s} - \frac{d_s}{6874\ k} \qquad (2\text{-}8)$$

which for small angles (i.e., $\theta_s < 10^o$) can be written approximately as:

$$\theta_s = \frac{h_s - h_a}{106\ d_s} - \frac{d_s}{120\ k} \qquad (2\text{-}9)$$

where

θ_s = screening angle in degrees

h_s = msl elevation of the screening object, or any other desired point, in feet

h_a = msl elevation of the antenna phase center center in feet

d_s = ground distance in nautical miles between antenna and screening object

k = equivalent earth radius factor.

3. By inspection, this equation shows that the value of the screen angle, θ_s, depends on the equivalent earth radius factor, k, for a given antenna height, and screening object distance and height. If the value k = 7/6 is used, the angle obtained represents the screen angle established by the optical los to the screening object. If k = 4/3, the value obtained corresponds to the screen angle established by the radar los to the object. Since screening angles are measured optically during site surveys, it is of interest to compare these two angles. If equation 2-9 (above) is solved using k = 7/6, the optical screen angle, θ_{os}, is given by:

$$\theta_{os} = \frac{h_s - h_a}{106\ d_s} - \frac{d_s}{140} \qquad (2\text{-}10)$$

and, if k = 4/3, the equivalent radar screen angle, θ_{rs}, is:

$$\theta_{rs} = \frac{h_s - h_a}{106\ d_s} - \frac{3d_s}{480} \qquad (2\text{-}11)$$

which can be written as:

$$\theta_{rs} = \theta_{os} + \frac{d_s}{1120} \qquad (2\text{-}12)$$

4. From this relationship (which is plotted in figure 2-15), it is seen that the radar screen angle is always more POSITIVE (i.e., higher) than the corresponding optical screen angle. This should not be interpreted, however, to mean that because of this increase in radar los angle the airspace screened from the radar is increased. The airspace screened by the optical los is measured relative to the curved surface of an equivalent 7/6 earth radius, whereas the airspace screened by the radar los is measured relative to the curved surface of an equivalent 4/3 earth radius. Because of this difference in the two curvatures the screened airspace beneath the radar los is actually less than the optically screened area.

5. One consequence of this reduced radar screening region is that it is sometimes possible to get radar returns from objects beyond the screening obstacles that are not visible optically. Also, it is possible for the radar to detect aircraft at altitudes that are below the optical los. This difference in altitude coverage is attributable to the bending of the radar signals through the earth's atmosphere which is accounted for in terms of the equivalent earth radius factor k. Mathematically, this difference in altitude coverage can be expressed by the relationship (see appendix 3):

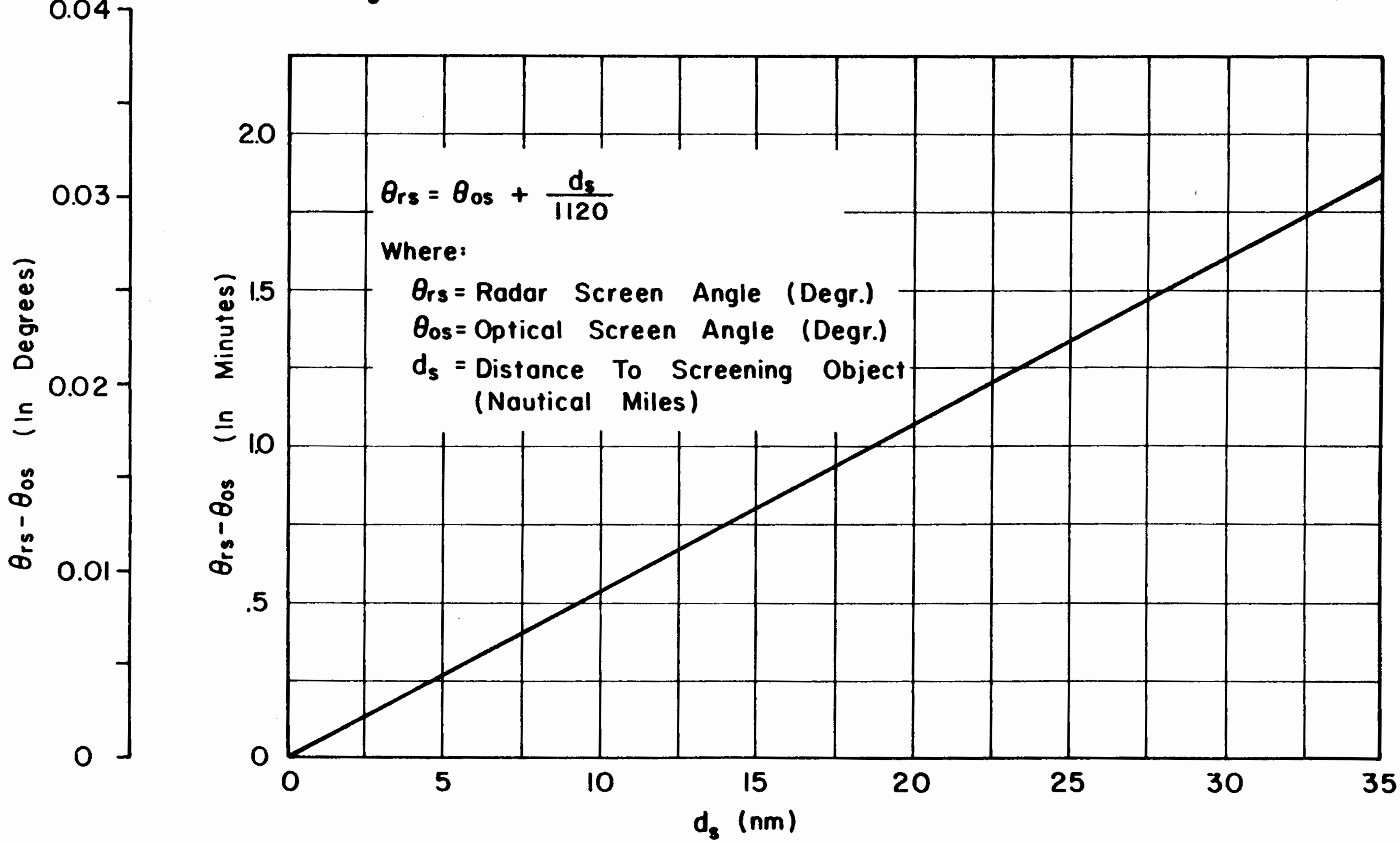
$$h_o - h_r = \frac{0.758\ d(d-d_s)\ (k-7/6)}{k} \qquad (2\text{-}13)$$

where

h_o = altitude or object height in feet along the optical los

h_r = altitude or object height in feet along the radar los

Figure 2-15. RADAR - OPTICAL SCREENING ANGLE CORRECTION



d_s = ground range to screening object in nautical miles

d = ground range in nautical miles ($d > d_s$)

6. If the distance, d_s, to the screen object is assumed to be 10 nmi, then the difference between the optical and radar altitudes visible at a cutoff range d = 50 nmi is

$$h_o - h_r = \frac{1516(k-7/6)}{k} \text{ feet} \qquad (2\text{-}14)$$

which for k = 4/3 is

$$h_o - h_r = 189.5 \text{ feet.}$$

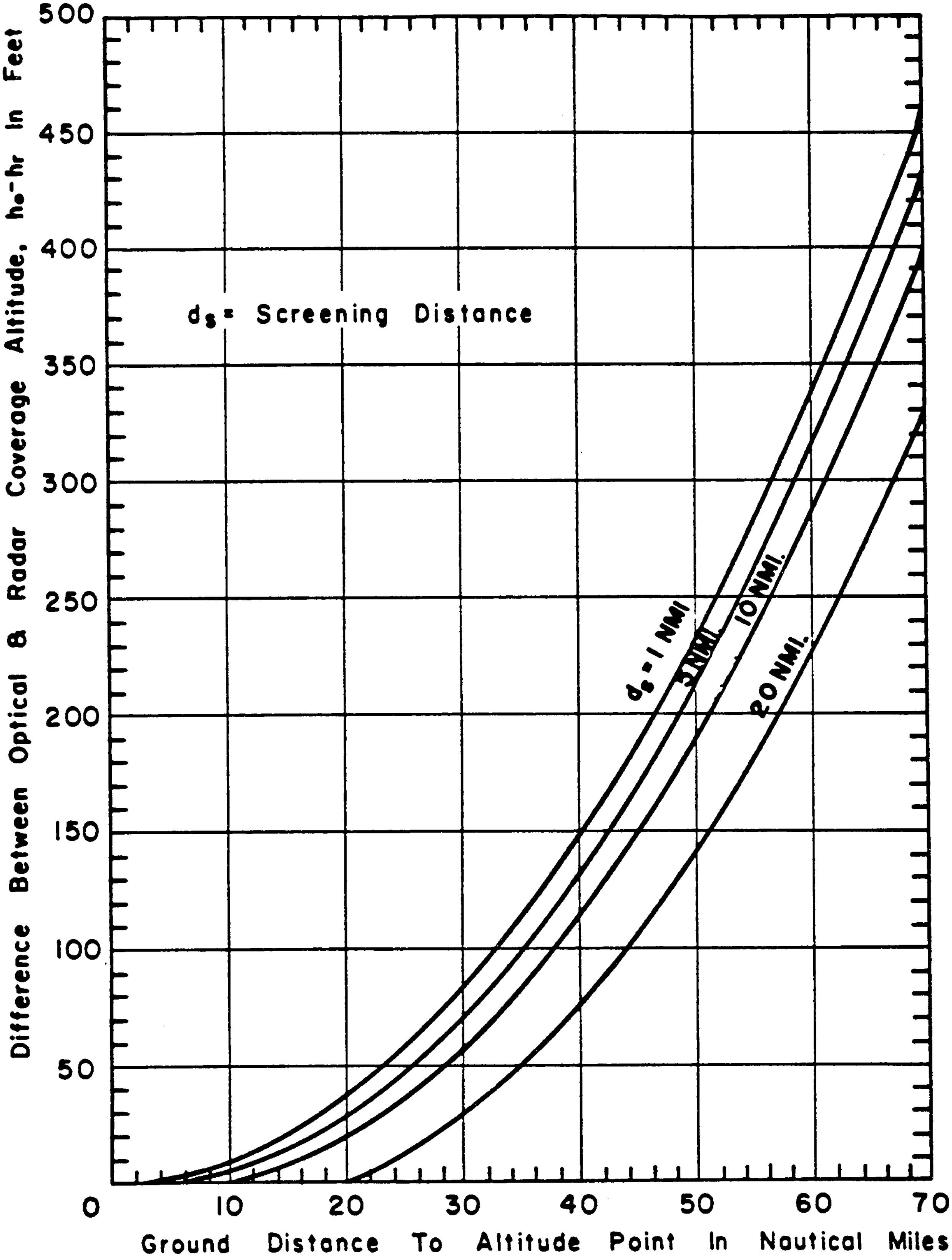
7. This shows that at a range of 50 nmi the altitude coverage for the radar is 189.5 feet below that which is optically visible. Hence, if the minimum altitude that is optically visible at 50 nmi is 5000 feet, then the radar can "see" objects down to (5000-189.5) or 4810.5 feet. Figure 2-16 shows plots of this altitude coverage difference for various screen object distances. As can be seen in these plots, the difference in altitude visibility is most pronounced when the screen objects are close to the radar site. For distant screen objects, the effect is still present, however not as great.

(e) Shielding.

1. Terrain, fixed structures, and surface traffic within visual range of the ASR/beacon antenna system reflect radar energy which can degrade performance of the ASR/beacon system. Such reflections can produce lobing of the ASR and ATCBI radiation patterns, severe ASR ground clutter, and false-target displays for both the ASR (due to moving traffic) and beacon. It is, therefore, desirable to minimize the extent of the ground surface and obstacles surrounding the site which are directly exposed to illumination by the ASR and beacon. A site surrounded by close-in screening objects, or terrain where these obstacles cast shadows on the ground surface and objects beyond them, is highly desirable for these purposes. Where these screening or shielding objects are relatively close to the site
* (within 2 nmi), the screening angle can generally be controlled by choice of the effective antenna height (25-85 feet in 10-foot increments for the ASR-4B, 5, 6 and 7, and 27.2-87.2 feet in 10-foot increments for the ASR-5E, 6E, 7E and 8). This is important since too great a *

FIGURE 2-16.

DIFFERENCE BETWEEN RADAR AND OPTICAL SCREENING



screening angle can result in a significant loss in airspace coverage. For example, each one-tenth of a degree increase in screening above the horizon sacrifices about 600 feet of vertical coverage at a distance of 60 nmi, as can be seen in figure 2 of appendix 3.

2. Shielding up to 0.25° screening angle above the local horizontal may, in certain cases, be considered worth the sacrifice in coverage to reduce ground reflections. If a screen angle of 0.25° is selected, the range reduction at an altitude of 5,000 feet is 20 nmi as shown in figure 2-14. However, whatever the value actually selected, due consideration should be given to the resulting loss in airspace coverage with respect to the operational coverage requirements.

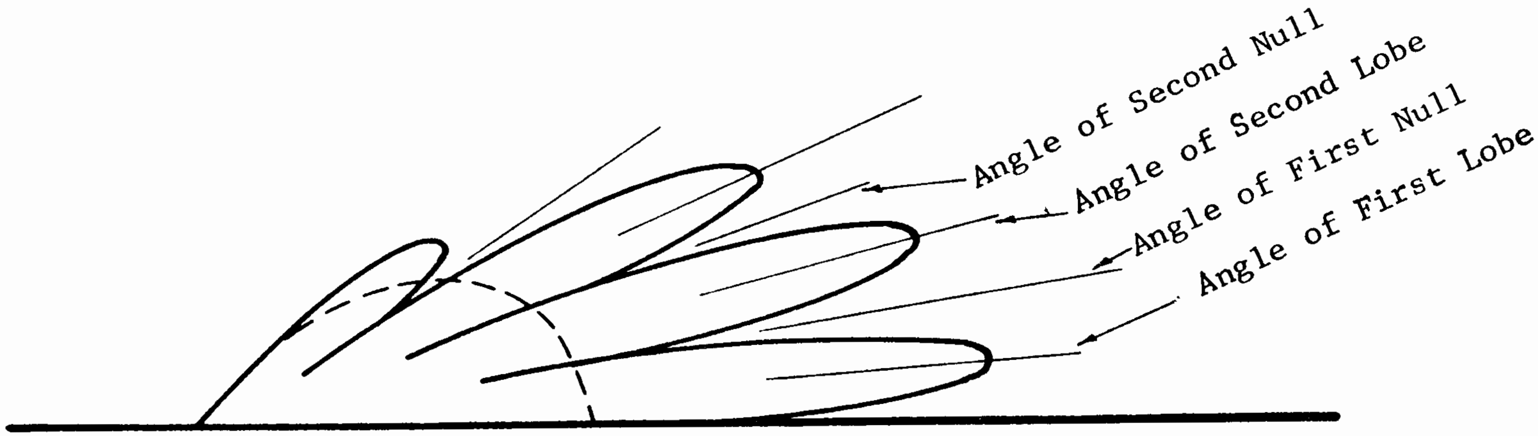
3. The use of obstructions close to the antenna for shielding, although not affecting low angle coverage, may still create problems due to diffraction. Special attention should be given to this effect when selecting sites with obstructions (towers, fences, buildings, etc.) closer than 2,500 feet. The effects of diffraction are more pronounced from obstructions and/or shielding objects close to the antenna.

b. Vertical Lobing.

(1) Ground reflection occurs when the beam radiated from the antenna strikes the surface of the earth and bounces upward. The vertical coverage of a radar can vary greatly due to ground reflections since the reflected wave may arrive at the target in a phase relationship which will either aid or oppose the direct wave. This effect causes a decrease in the overall amount of power striking the target at certain altitudes and an increase in the amount of power striking the target at other altitudes. The algebraic addition of the reflected wave and the direct wave phasors creates a vertical radar coverage pattern consisting of areas of minimum power, called nulls, and maximum power, called lobes, as shown in figure 2-17.

(2) Ground reflection is a variable factor, depending mainly on the type of terrain. Reflection is greatest when the reflecting surface is smooth, such as a calm sea. When the reflecting surface is uneven, such as encountered on land or a choppy sea, reflection is decreased. Uneven land areas, trees, grass, or a choppy sea, may absorb a large portion of the radiated energy or cause a scattering of the energy, thus

FIGURE 2-17. TYPICAL VERTICAL RADIATION PATTERN WITH GROUND REFLECTION



LEGEND:

DOTTED LINE = FREE-SPACE PATTERN

SOLID LINE = GROUND REFLECTED PATTERN

reducing the amount of reflected energy adding to or subtracting from the direct wave.

(3) The vertical lobing pattern resulting from ground reflections is dependent upon the radar design characteristics, and upon several factors determined at the time of site selection. The latter are:

(a) Antenna height above the reflecting surface,

(b) Antenna tilt angle, and

(c) Surface reflection characteristics.

(4) Careful consideration should be given to these factors so as to minimize the occurrence of lobing, and to control the location of unavoidable lobes such that overall radar and beacon performance is not impaired. Means for considering these factors are discussed below.

(a) Lobing Analysis. (A more detailed treatment may be found in reference 7.)

1. Consider an antenna mounted at height, h_a, above a smooth, flat reflecting surface, and a target at range R, and altitude, h_t, as shown in figure 2-18. Energy radiated by the radar antenna arrives at the target by two separate paths--the direct path and the path reflected from the plane surface. Modification of the field strength at the target caused by the presence of the ground may be expressed by the ratio (sometimes called earth gain factor):

$$\eta = \frac{\text{field strength at target in presence of ground}}{\text{field strength at target if in free space}} \qquad (2\text{-}15)$$

2. The phase difference between direct and reflected signals corresponding to the difference in path length is

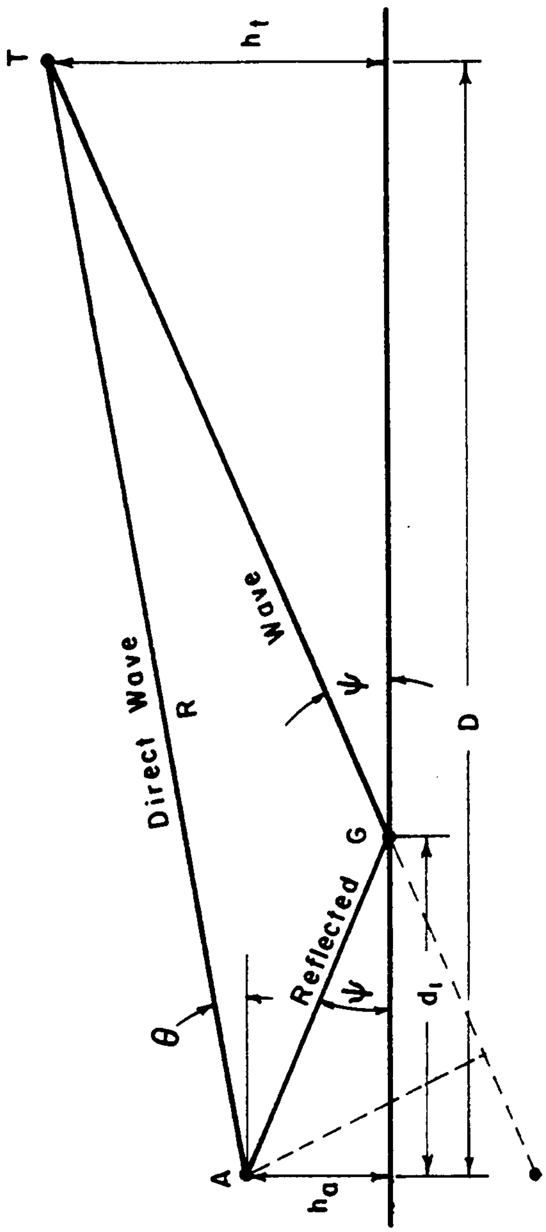
$$\phi_d = \frac{2\pi}{\lambda} \frac{2h_a h_t}{R} \qquad (2\text{-}16)$$

3. This is based on assuming (1) $h_t \gg h_a$, (2) $\theta = \psi$, (3) θ & ψ are small angles. Under these conditions

$$\sin \psi = \tan \psi = \psi$$

$$\psi = \theta = \frac{h_t}{R}$$

Figure 2-18. VERTICAL LOBING PATH GEOMETRY



4. To ϕ_d must be added the phase shift resulting from the reflection of the wave at the ground. The reflection coefficient, Γ, of the ground may be written as

$$\Gamma = \rho \, e^{-j\phi_r} \tag{2-17}$$

where ρ represents the amplitude change, and ϕ_r represents the phase change upon reflection. Determination of Γ, which may entail some difficulty, is dependent upon signal polarization and terrain characteristics. This is dis- * cussed in a subsequent subparagraph. For purposes of this analysis, a conservative result is obtained by assuming $\rho = 1$, $\phi_r = \pi$. This gives *

$$\phi = \phi_d + \phi_r = \frac{4\pi}{\lambda} \; \frac{h_a h_t}{R} + \pi \tag{2-18}$$

5. The resultant, E_r, of two signals with field strength amplitudes E_1 and E_2 and phase difference ϕ is

$$E_r = (E_1^2 + E_2^2 + 2\, E_1 E_2 \cos \phi)^{1/2} \tag{2-19}$$

6. Therefore, the ratio of signal incident on the target to that which would be incident if the target were located in free space is

$$\eta = \frac{E_r}{E_1} = \left[1 + \frac{E_2^2}{E_1^2} + 2\, \frac{E_2}{E_1} \cos \left(\frac{4\pi \; h_a h_t}{\lambda \; R} + \pi \right) \right]^{1/2}$$

which reduces to

$$\eta = \left[1 + \frac{E_2^2}{E_1^2} - 2\, \frac{E_2}{E_1} \cos \left(\frac{4\pi \; h_a h_t}{\lambda \; R} \right) \right]^{1/2} \tag{2-20}$$

7. The field strength ratio is related to the antenna gain ratio by $E_2/E_1 = \rho \sqrt{G_2/G_1}$, which for $\rho = 1$ reduces to:

$$\frac{E_2}{E_1} = \sqrt{\frac{G_2}{G_1}} \tag{2-21}$$

where

G_1 = numerical antenna power gain in direction of target

G_2 = numerical antenna power gain in direction of reflection point.

Hence

$$\eta = \left[1 + \frac{G_2}{G_1} - 2\sqrt{\frac{G_2}{G_1}}\cos\left(\frac{4\pi\ h_a h_t}{\lambda\ R}\right)\right]^{1/2}$$

and since under the assumptions made previously

$$\therefore \theta = \frac{h_t}{R}$$

$$\eta = \left[1 + \frac{G_2}{G_1} - 2\sqrt{\frac{G_2}{G_1}}\cos\left(\frac{4\pi\ h_a\theta}{\lambda}\right)\right]^{1/2} \quad (2\text{-}22)$$

8. Minimum values of η occur when

$$\cos\left(\frac{4\pi\ h_a\theta_{min}}{\lambda}\right) = 1 \quad (2\text{-}23)$$

or when

$$\frac{4\pi\ h_a\theta_{min}}{\lambda} = n\ \pi \qquad n = 0, 2, 4....$$

9. Rearranging for use with common units and noting that $\lambda = c/f$, η_{min} occurs when

$$\theta_{min} = \frac{14098n}{h_a\ f}\ (\text{deg}) \qquad n = 0, 2, 4.... \quad (2\text{-}24)$$

where

h_a = antenna height in feet

f = frequency in MHz

10. Under this condition

$$\eta_{min} = \left[1 + \frac{G_2}{G_1} - 2\sqrt{\frac{G_2}{G_1}}\right]^{1/2} \quad (2\text{-}25)$$

θ_{min} is plotted in figures 2-19 and 2-20 for ASR and ATCBI frequencies and η_{min} is plotted in figure 2-21 as a function of G_2/G_1.

11. In a similar manner, maximum values of η occur when

$$\theta_{max} = \frac{14098n}{h_a\ f}\ (\text{deg}) \qquad n = 1, 3, 5 \qquad (2\text{-}26)$$

where

h_a = antenna height in feet

= frequency in MHz

12. At these angles

$$\eta_{max} = \left[1 + \frac{G_2}{G_1} + 2\sqrt{\frac{G_2}{G_1}}\right]^{1/2} \qquad (2\text{-}27)$$

θ_{max} and η_{max} are plotted in figures 2-22, 2-23, and 2-24.

13. Squaring equation 2-15 (p. 91) shows that η^2 represents the ratio of POWER at the target with and without ground * reflection. Therefore, η^2 may also be used to determine the effect on range coverage when the transmitted power is held constant. *

14. ATCBI Case. For beacon operation, the minimum detectable transponder input is reached at a free-space range (terms defined as in equation 2-5, p. 66):

$$R_f^2 = \frac{P_d G_i G_t \lambda^2}{(4\pi)^2\ S_{min}\ L_t} \qquad (2\text{-}28)$$

With ground reflections this range becomes R_r where

* $$R_r^2 = \eta^2\ R_f^2$$ *

or

$$\frac{R_r}{R_f} = \eta \qquad (2\text{-}29)$$

Figure 2-19. NULL ANGLES AT 2800 MHz

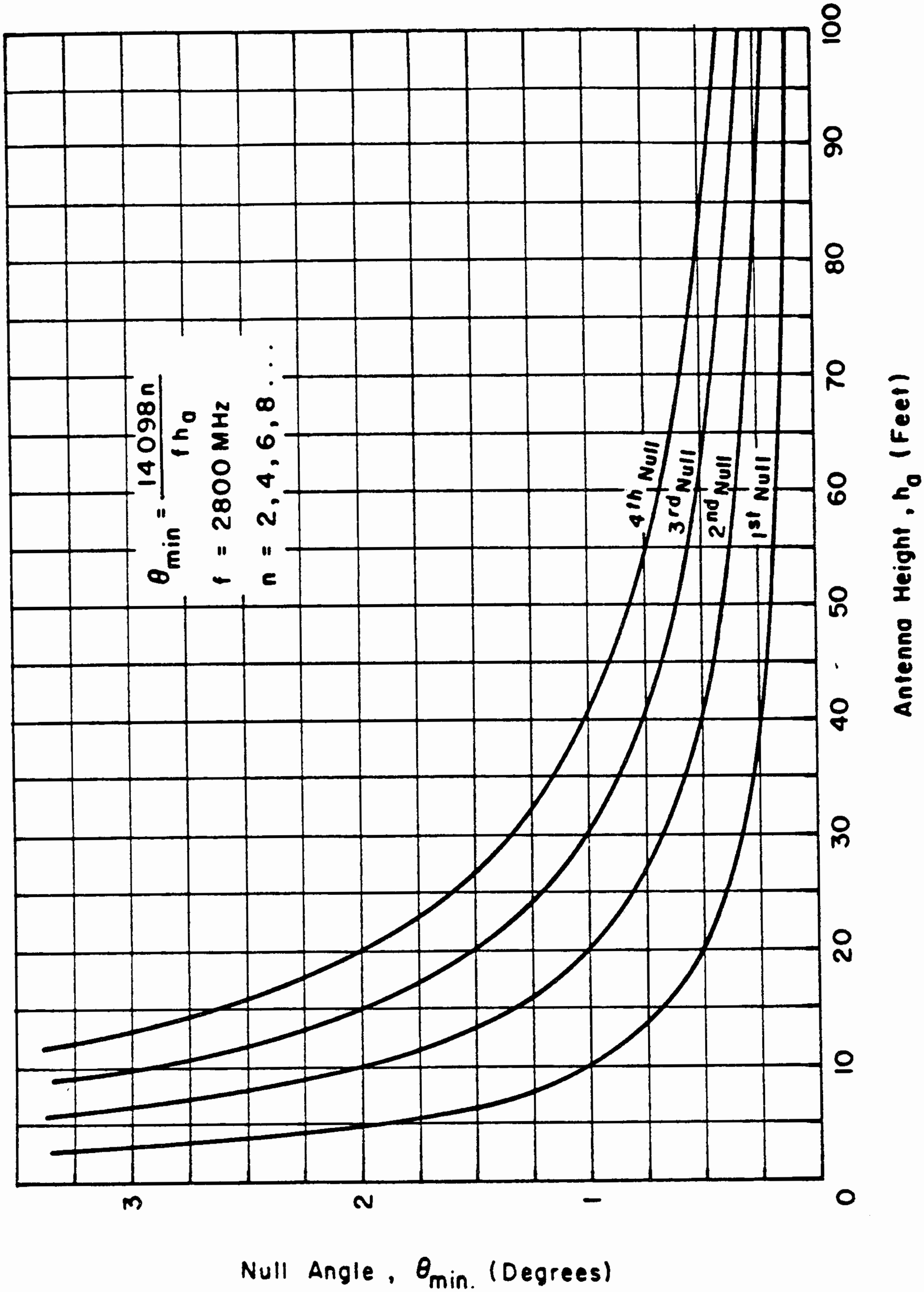


Figure 2-20. NULL ANGLES AT 1030 MHz

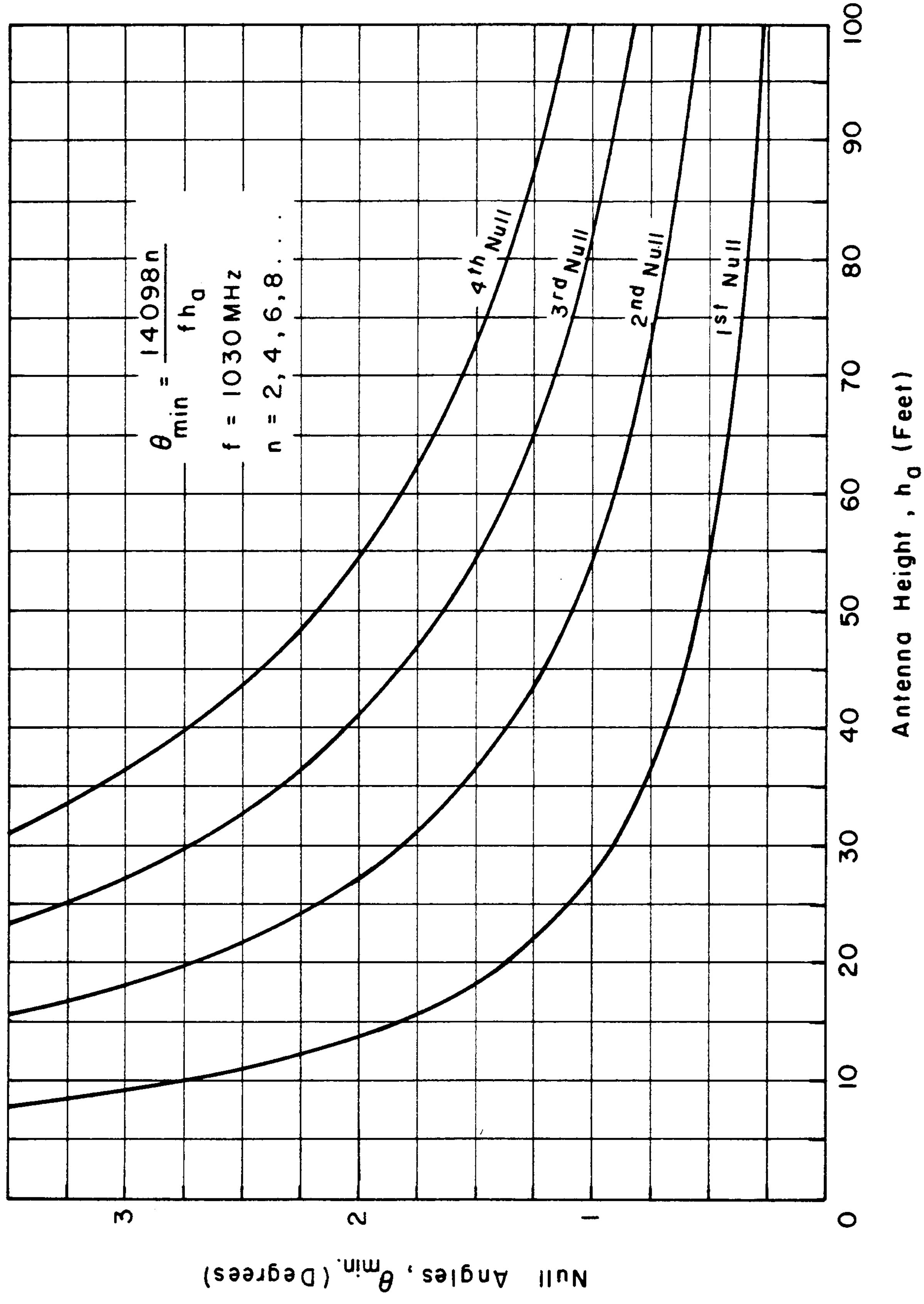


Figure 2-21. MINIMUM VALUE OF EARTH GAIN FACTOR (η)

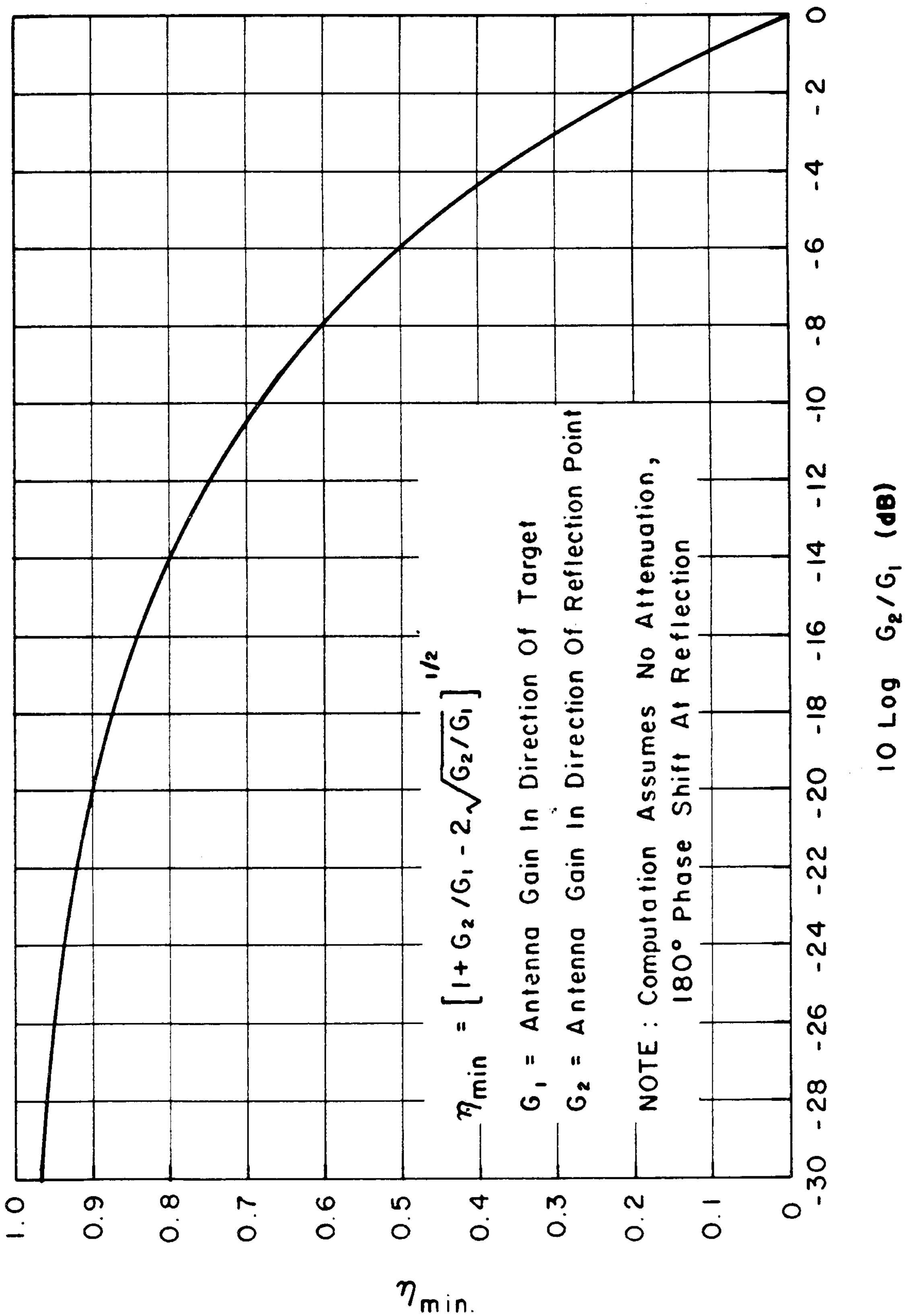
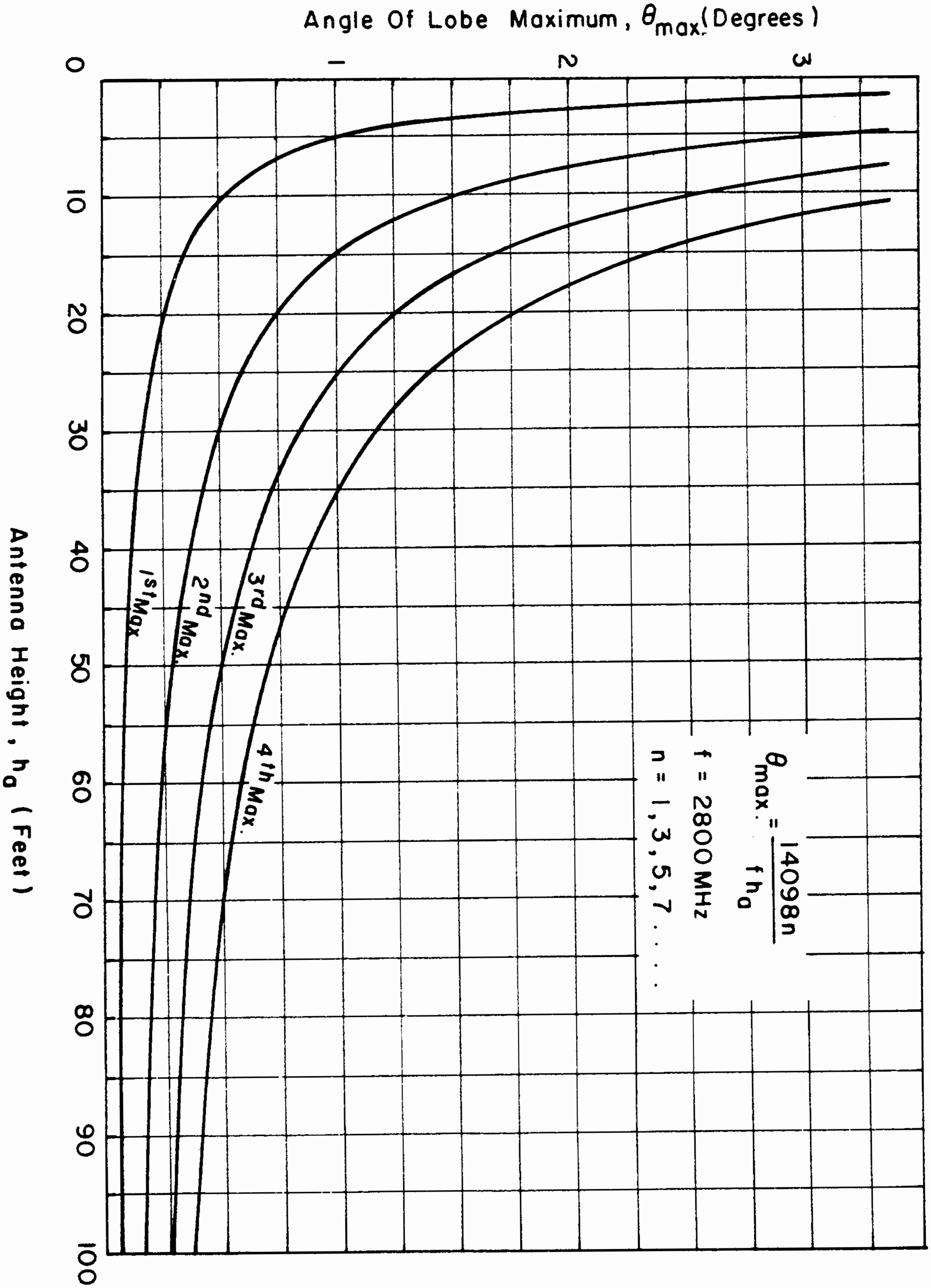


Figure 2-22. LOBE PEAK ANGLES AT 2800 MHz



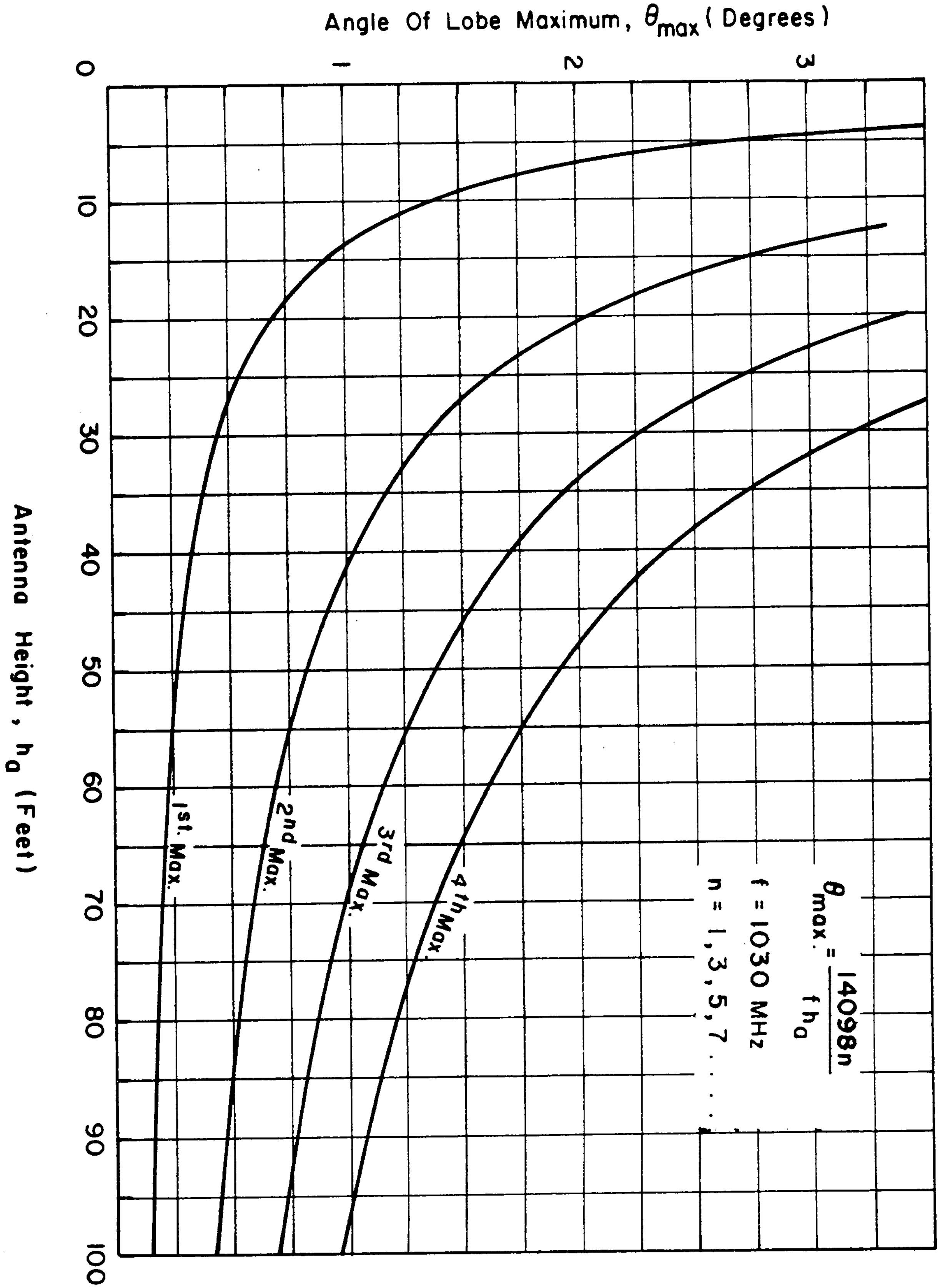
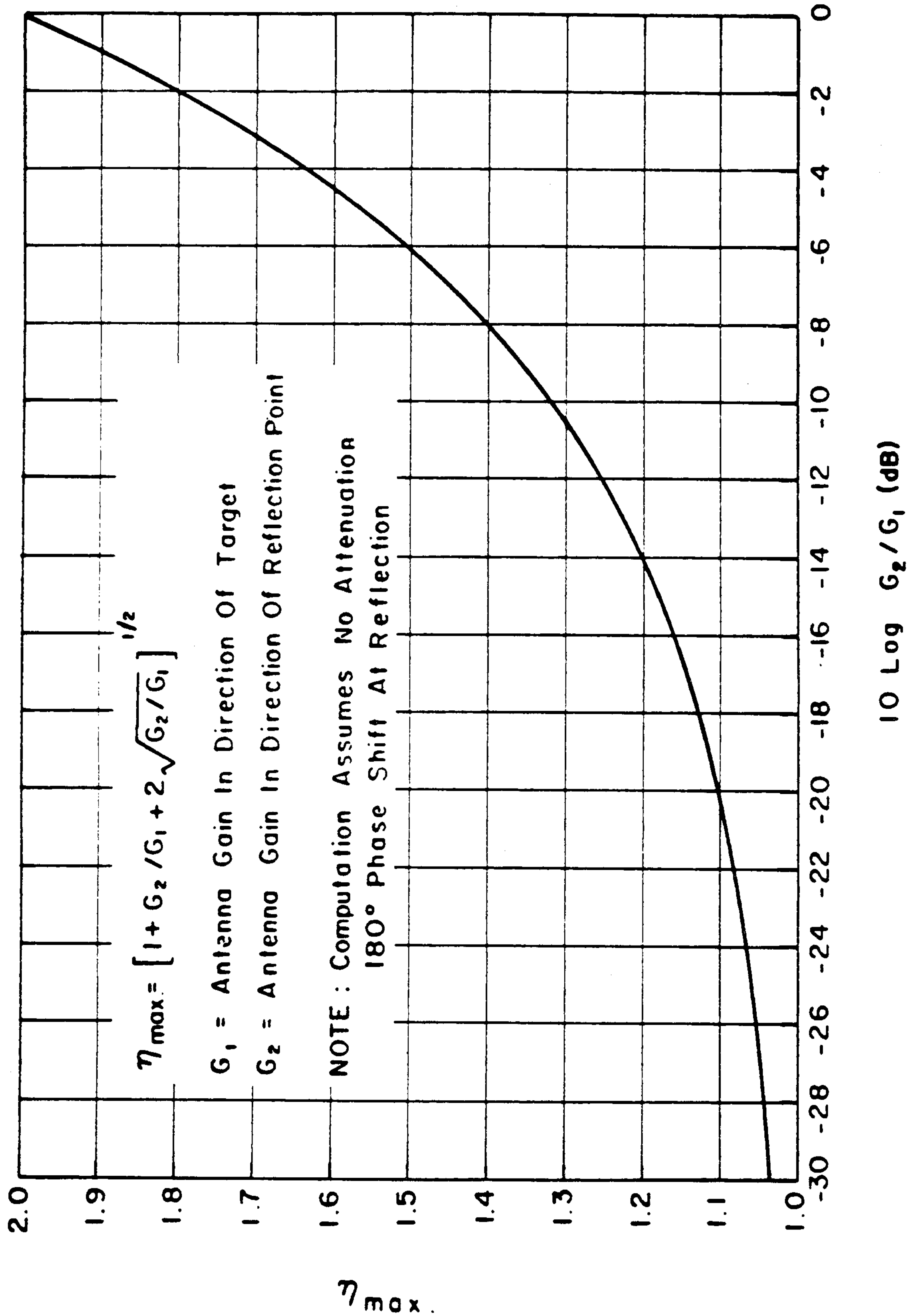


Figure 2-23. LOBE PEAK ANGLES AT 1030 MHz

Figure 2-24. MAXIMUM VALUE OF EARTH GAIN FACTOR (η)



Range coverage with reflections is thus simply η times the free-space range.

15. ASR Case. For ASR operation a two-way radar path is involved, and by reciprocity the same reflection effect occurs for both transmitted and echo signals. In this case, therefore, the ratio of radar return power with ground reflection to return power in free space is $\eta_t^2 \eta_e^2$, where the subscripts t and e refer to transmit and echo paths, respectively. For ASR-4B, 5, 6, and 7 which always use the same antenna for transmitting and receiving $\eta_t^2 = \eta_e^2 = \eta^2$ and the return power ratio is η^4.

16. Under this condition, the modification in coverage range for detection at the same power level is

$$R_r^4 = \eta^4 R_f^4$$

or

* $$\frac{R_r}{R_f} = \eta \quad \text{(ASR-4B, 5, 6, and 7, and ASR-5E, 6E, 7E and 8 with main antenna only)} \qquad (2\text{-}30)$$ *

(Free-space range, R_f, for ASR's can be determined from equation 2-1 (p. 64) and plotted in figures 2-1 through 2-6.)

* 17. In the case of the ASR-5E, 6E, 7E and 8, however, near-range operation will in all likelihood make use of the main antenna for transmission and the passive horn for signal reception. *

18. In this situation $\eta_t^2 \neq \eta_e^2$ due to the differing antenna patterns, and each must be determined separately. The range modification for this case is

* $$\frac{R_r}{R_f} = \sqrt{\eta_t \eta_e} \quad \text{(ASR-5E, 6E, 7E and 8 with dual beam antenna)} \qquad (2\text{-}31)$$ *

19. To summarize, the effects of vertical lobing may be examined by determining the angles of nulls and lobes from figures 2-19 and 2-20, or 2-22 and 2-23 for the particular radar antenna height and frequency. It should be noted that radar height here means height of the particular antenna above the smooth reflecting surface. This may differ considerably from the height above ground as illustrated

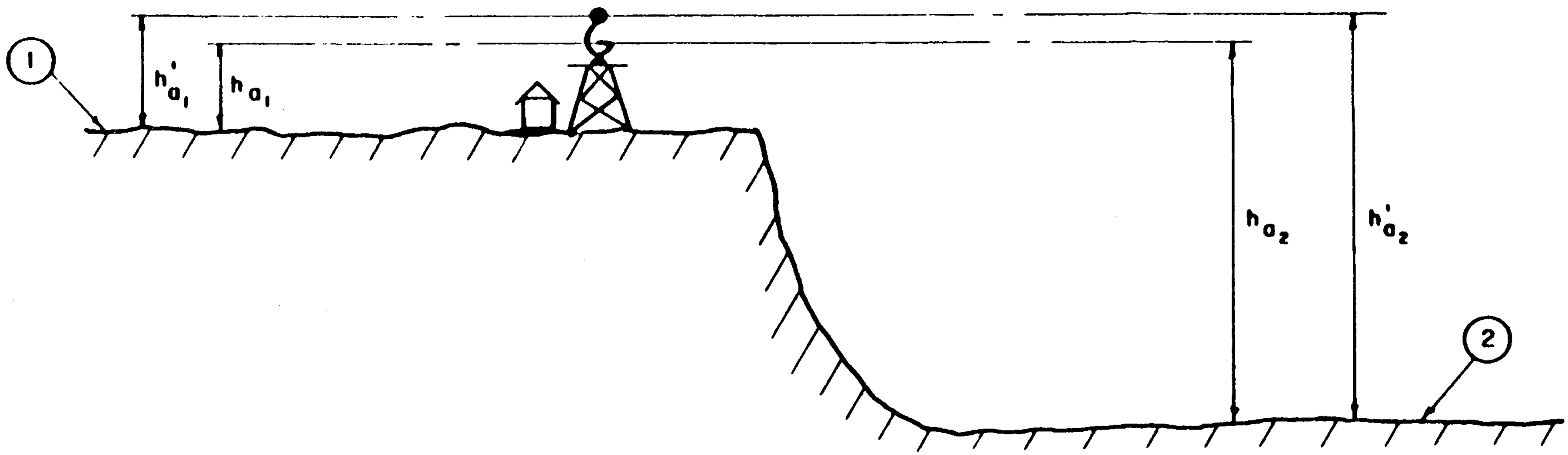
in figure 2-25. As mentioned above, the analysis given here assumes a flat earth. While this assumption generally produces little error in terminal ASR/ATCBI siting, a more accurate curved earth analysis should be used for values of h_a above 100 feet. For this case, null angles may be determined using techniques described in reference 7.

20. The first null (n = 2) is the one which will cause the greatest trouble with the second and third nulls being lesser in importance, for air route and fix coverage where aircraft are flying at a relatively constant altitude. However, the null angle becomes critical when it approaches the glide slope angle of aircraft arriving at airports in the coverage area. In this situation, higher order nulls may be detrimental to air traffic coverage. Higher order nulls can also affect high-altitude fix coverage. The plotted lobe null and maximum angles indicate that the ATCBI will experience fewer lobes below a altitude than will an ASR system.

21. Once the elevation angles of the lobe peaks and nulls are determined (with respect to horizontal), the corresponding earth gain factors, η, can be found. To do this the antenna power gains G_1 and G_2 at angles $\pm\ \theta_{min}$ and/or $\pm\ \theta_{max}$ are found. These may be determined from the appropriate antenna elevation pattern diagrams given in chapter 1. It should be noted, however, that the gain determinations must account for antenna tilt angle as this can alter computational results. The angular relationship is illustrated in figure 2-26. In like manner, any slope of the reflecting surface must be taken into account for proper determination of θ_{min} and θ_{max}.

22. With G_1 and G_2 determined, η_{min} and η_{max} are found directly from figures 2-21 and 2-24. For ATCBI and ASR-4B, 5, 6, and 7 systems, the range coverage at each critical null or maximum angle is then found by direct multiplication of free-space range, as determined for the plots in section 3, by the corresponding value of η. For
* ASR-5E, 6E, 7E, and 8 this is slightly more difficult *
since use of both antenna patters will produce two values of η_{max} and η_{min} for each critical angle. The approximate range multiplier in this case is the square root of the product of the η_{max}'s and η_{min}'s.

FIGURE 2-25. ANTENNA HEIGHT FOR LOBING CALCULATIONS

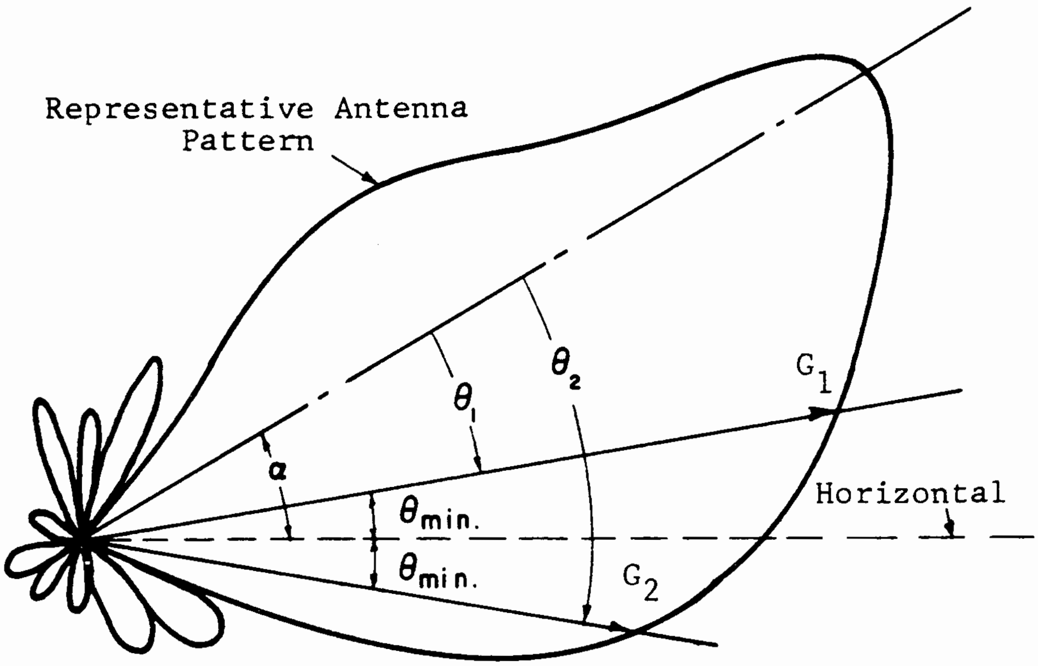


h_{a_1} = ASR Antenna Height Used in Lobing Calculations for Reflections from Surface (1)

h_{a_2} = ASR Antenna Height Used in Lobing Calculations for Reflections from Surface (2)

Primed Dimensions Indicate the Corresponding Heights for ATCBI Lobing Calculations

FIGURE 2-26. ANGULAR RELATIONSHIPS FOR NULL DEPTH DETERMINATION



α = Antenna Tilt Angle (to nose of beam)

θ_1 = Antenna Elevation Angle (below nose of beam) of Target

θ_2 = Antenna Elevation Angle (below nose of beam) of Reflection Point

23. The development shows that the values of the null angles are dependent only upon antenna height for a given radar or beacon. This is demonstrated by the curves in figures 2-19 and 2-20. The depth of null, however, is dependent upon antenna tilt angle as shown in figures 2-27 through 2-35. This is illustrated by the partial radar coverage diagrams sketched in figures 2-36 and 2-37.

24. It should be remembered that the development given here also assumes a smooth reflecting surface which provides no attenuation and 180° signal phase shift, and assumes small angles and distant targets such that $\theta = \psi$ in figure 2-18. The latter assumption provides little error when $h_a < 100$ feet; the effects of the other assumptions are discussed in the following subparagraphs.

(b) Terrain Roughness Effects.

1. Vertical lobing effects, as suggested above, are quite dependent upon the terrain surface. Reflection is greatest when the reflecting surface is smooth, such as a runway or calm sea. When the reflecting surface is uneven, such as is encountered on land or with a choppy sea, reflection is decreased. Uneven land areas, trees, grass, rough sea, etc., may in fact, absorb a large portion of the radiated energy or cause scattering of the energy, thus virtually nullifying any effect of reflected signals upon the direct wave.

2. As a criterion for the occurrence of lobing effects it is convenient to assume a surface to be smooth (and consequently a good reflector) if the height of surface irregularities, Δh, at the reflection point produces a net signal phase difference of less than 45°. This occurs when $\Delta h \leq \Delta h_c$ where

$$2 \Delta h_c \sin \psi = \lambda/8 \qquad (2\text{-}32)$$

and

ψ = grazing angle

3. For $\Delta h > \Delta h_c$ the surface may be considered rough, with no appreciable lobing effects. Δh_c may be conveniently determined from figure 2-38. It should be noted that as radar antenna height increases, the angle, θ, of the first null, and therefore the grazing angle, ψ, decreases ($\theta = \psi$). Since, from figure 2-38, critical height increases

Figure 2-27. TILT ANGLE EFFECT ON BEACON NULL DEPTH - FIRST NULL

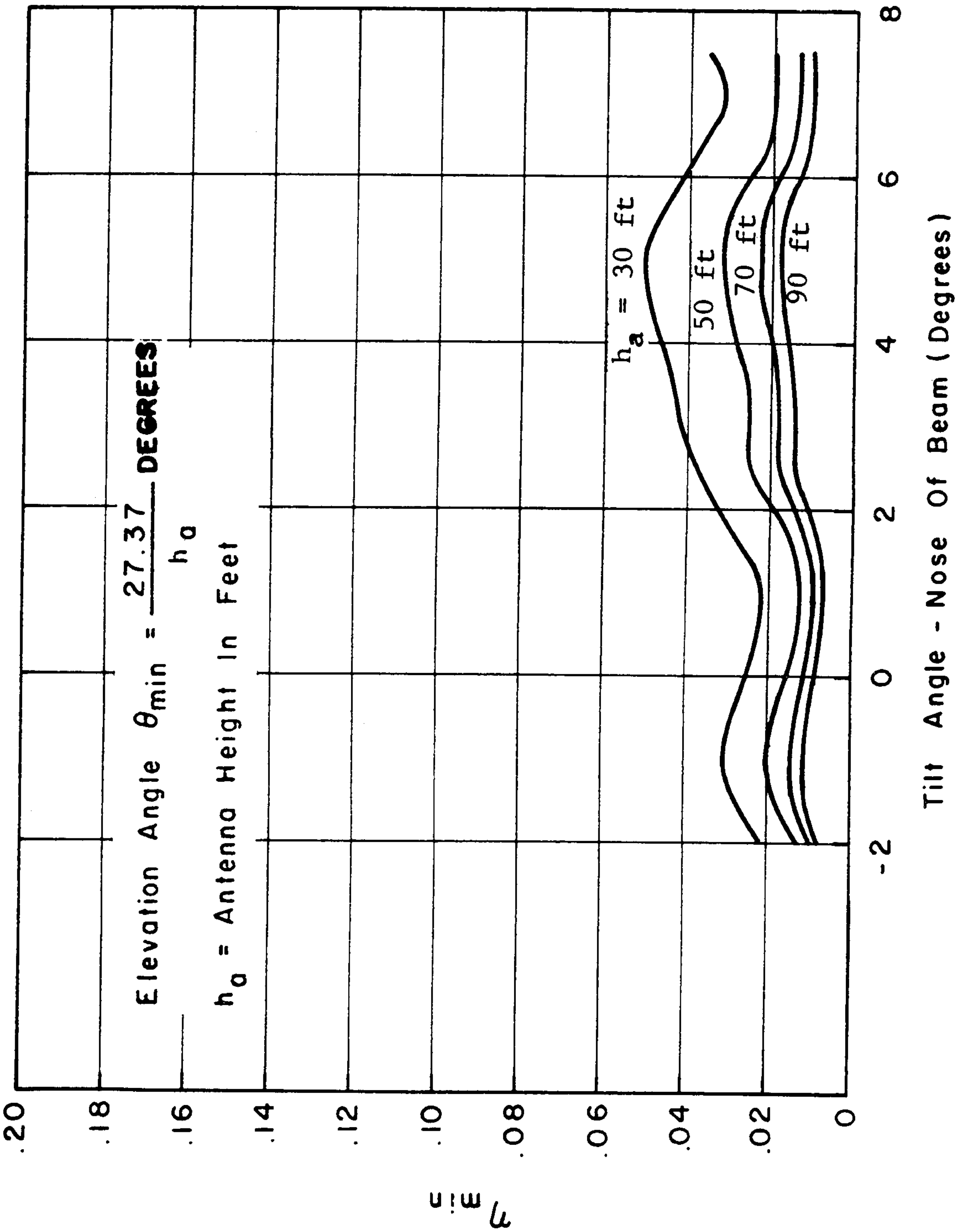


Figure 2-28. TILT ANGLE EFFECT ON BEACON NULL DEPTH - SECOND NULL

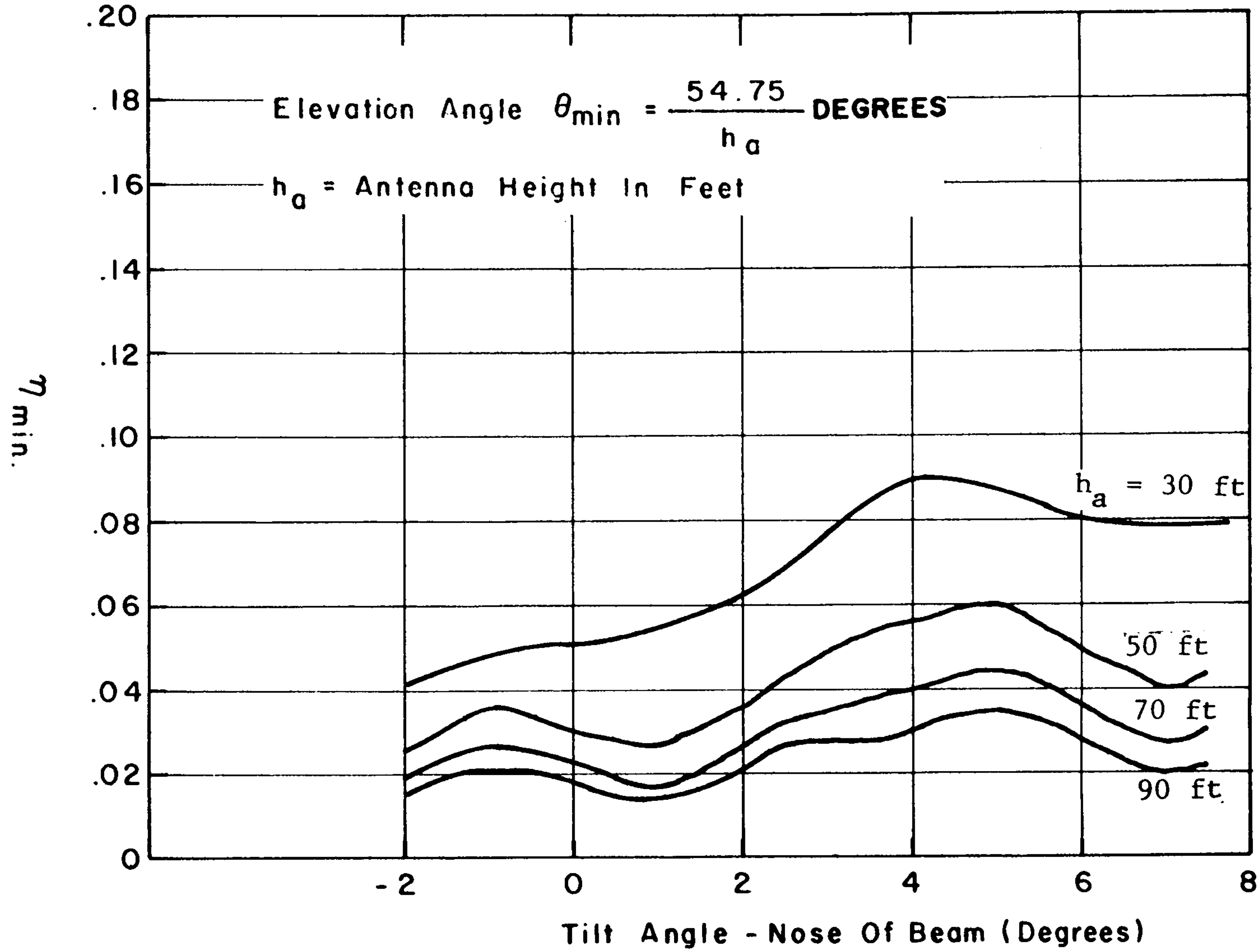


Figure 2-29. TILT ANGLE EFFECT ON BEACON NULL DEPTH - THIRD NULL

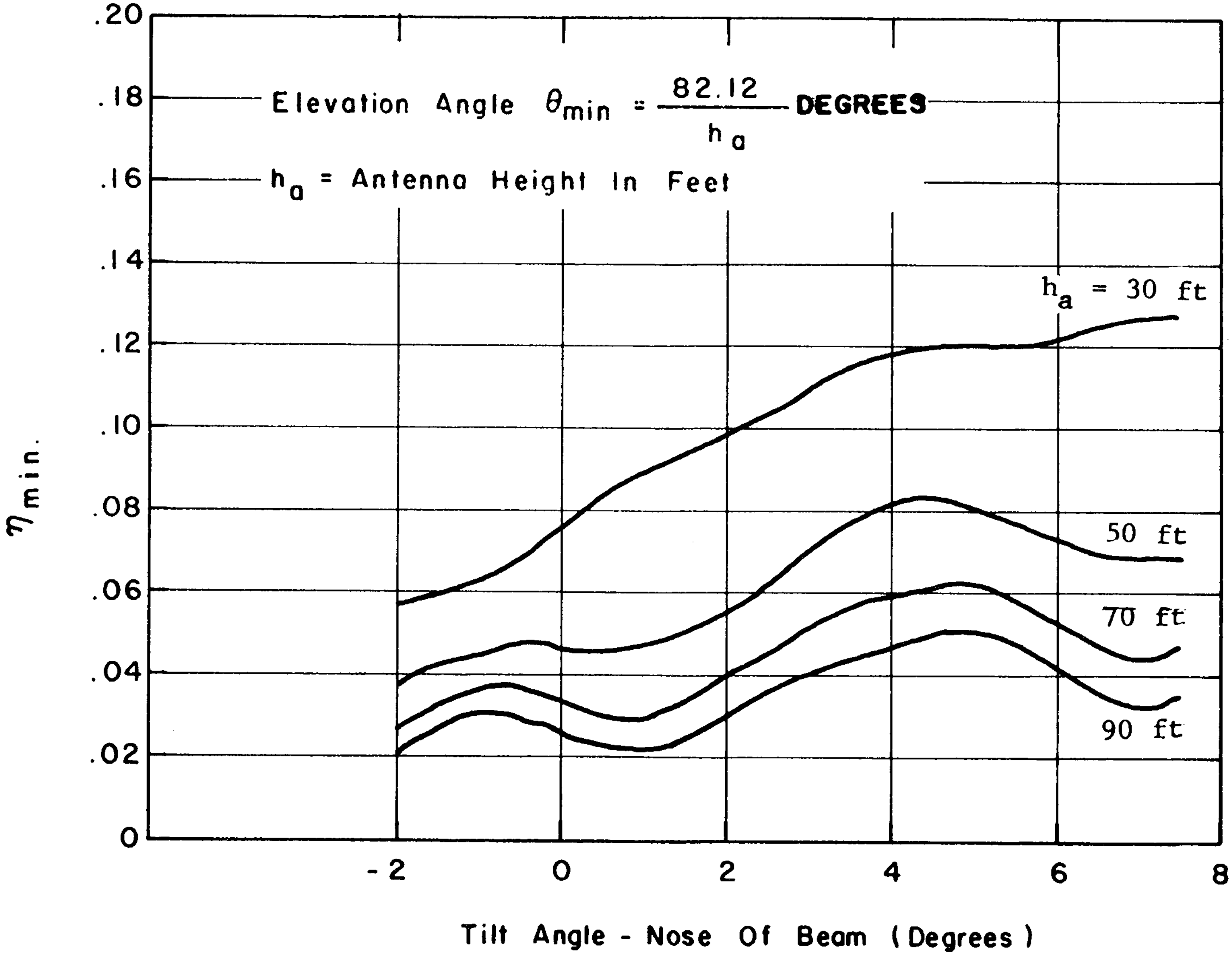


Figure 2-30. TILT ANGLE EFFECT ON ASR NULL DEPTH - FIRST NULL, ASR-4B, 5, 6, and 7 (AT 2800 MHz)

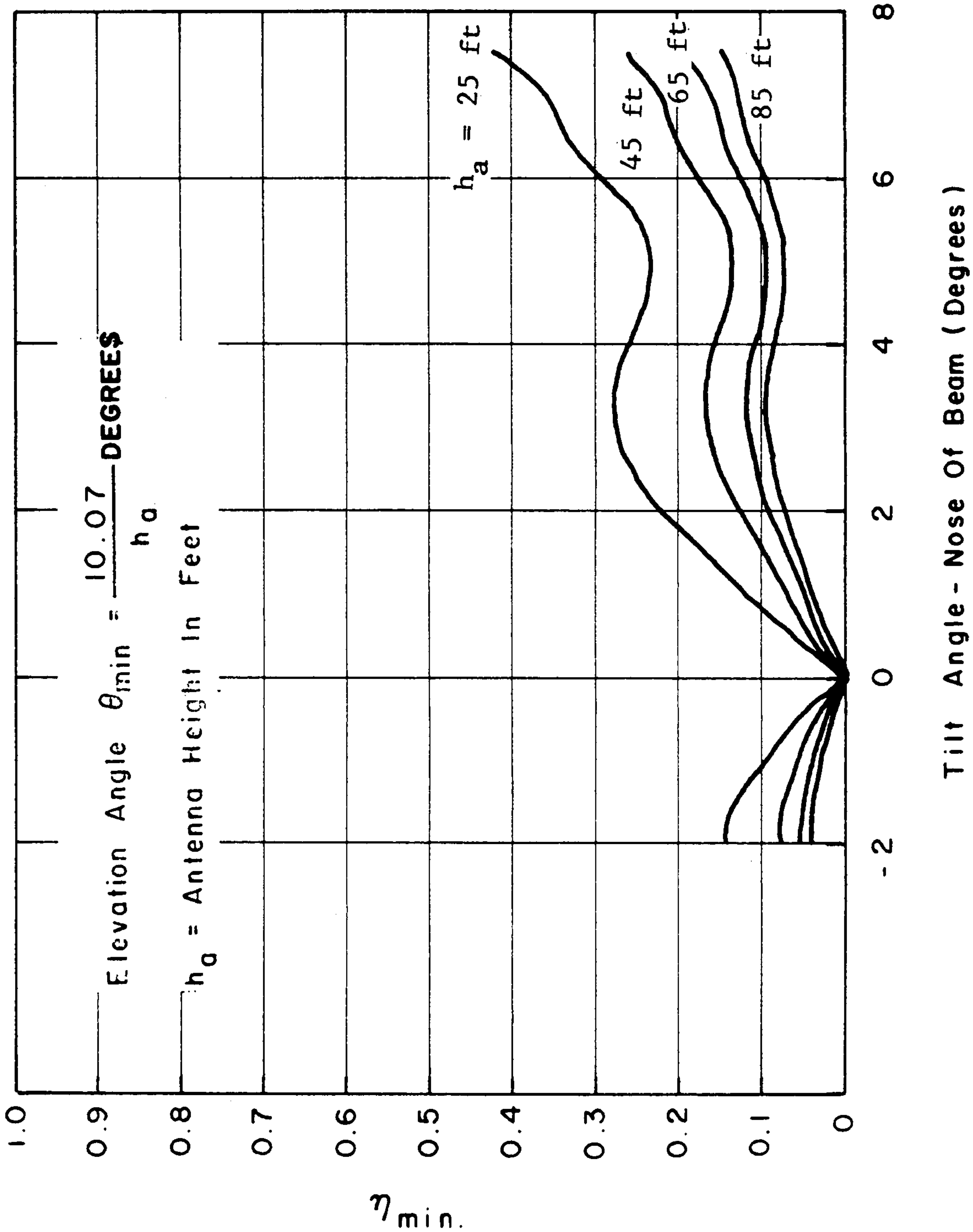


Figure 2-31. TILT ANGLE EFFECT ON ASR NULL DEPTH - SECOND NULL, ASR-4B, 5, 6, and 7 (AT 2800 MHz)

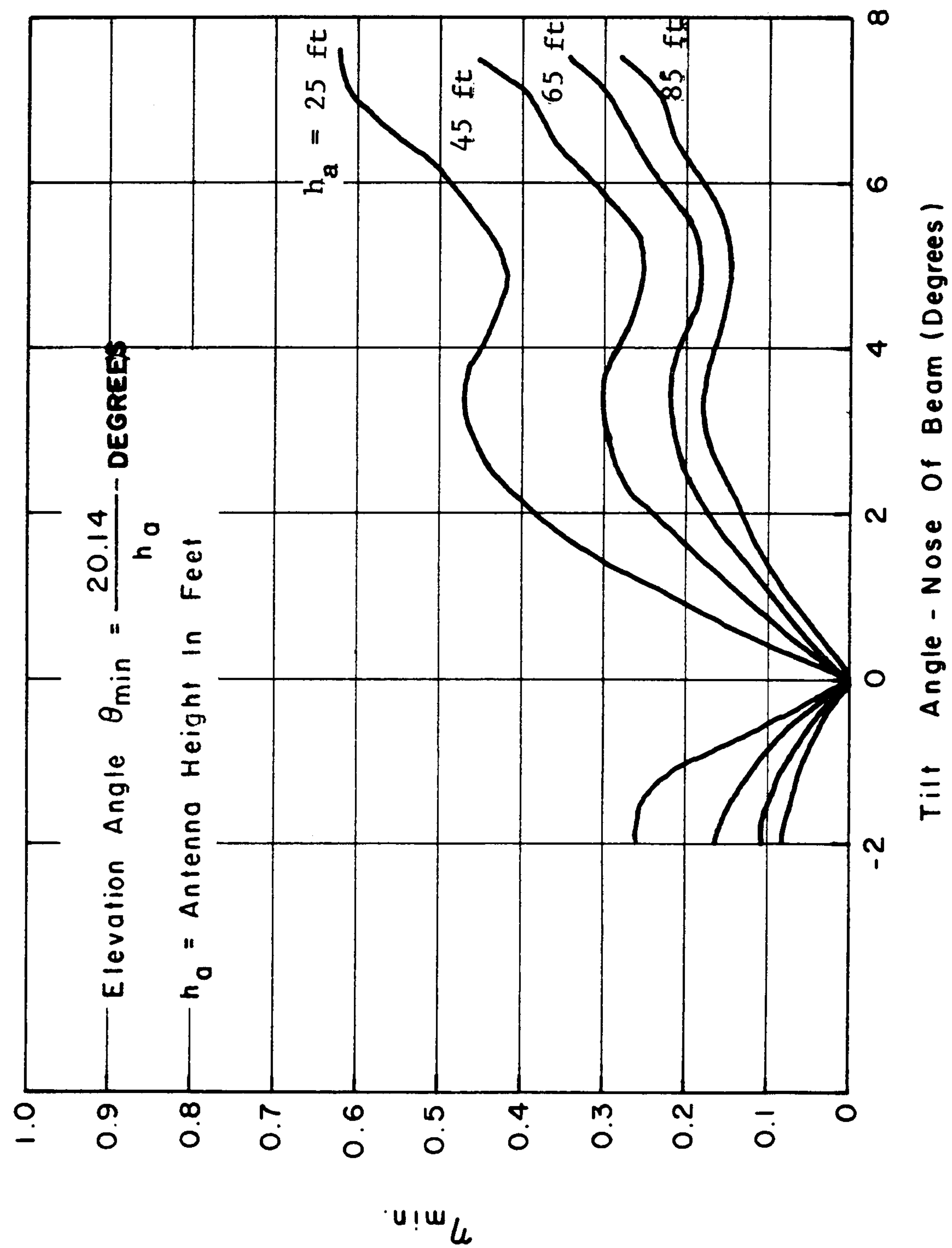


Figure 2-32. TILT ANGLE EFFECT ON ASR NULL DEPTH - THIRD NULL, ASR-4B, 5, 6, and 7 (AT 2800 MHz)

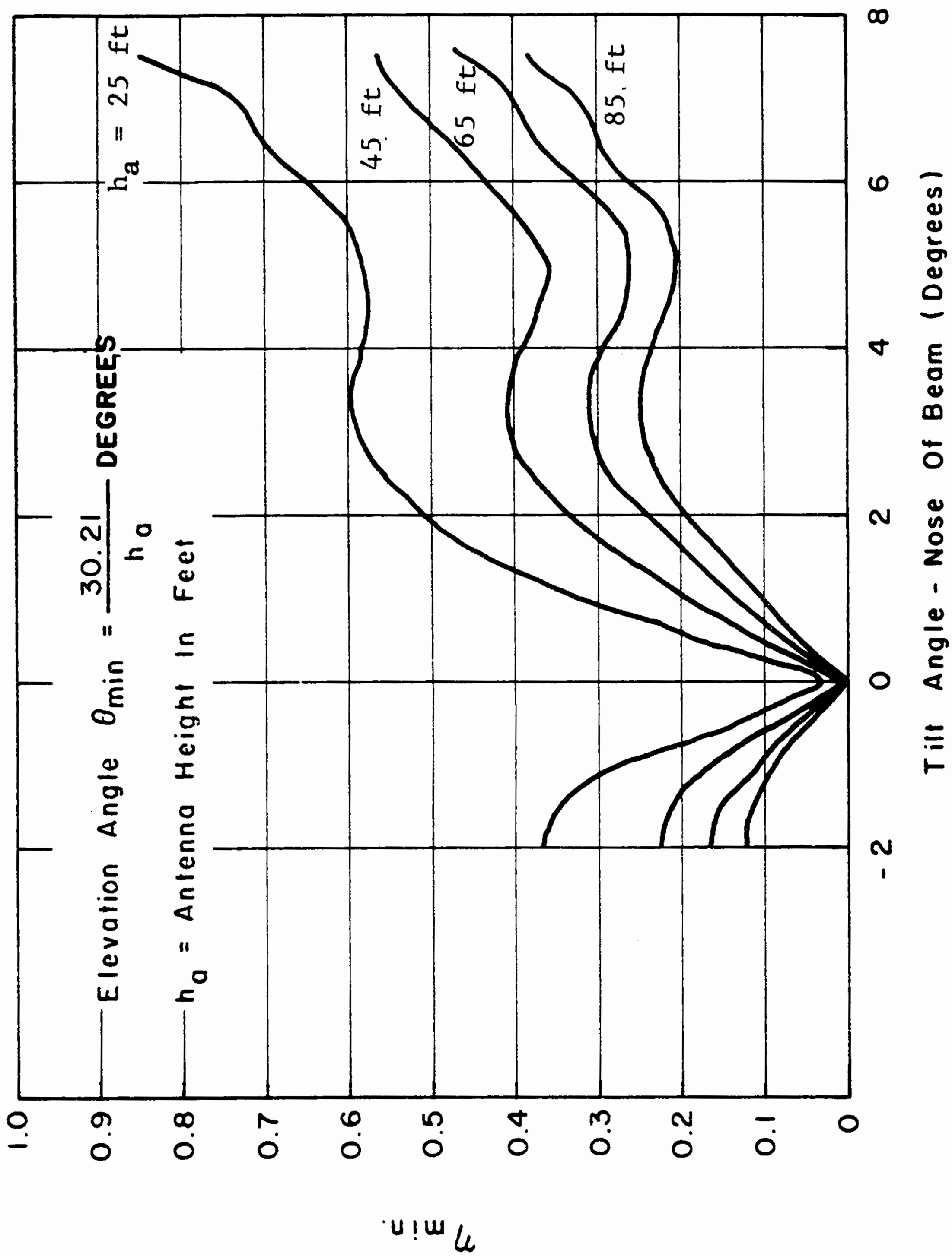


Figure 2-33.

TILT ANGLE EFFECT ON ASR NULL DEPTH - FIRST NULL, ASR - 8 (Using Passive Receive Horn, f = 2800 MHz)

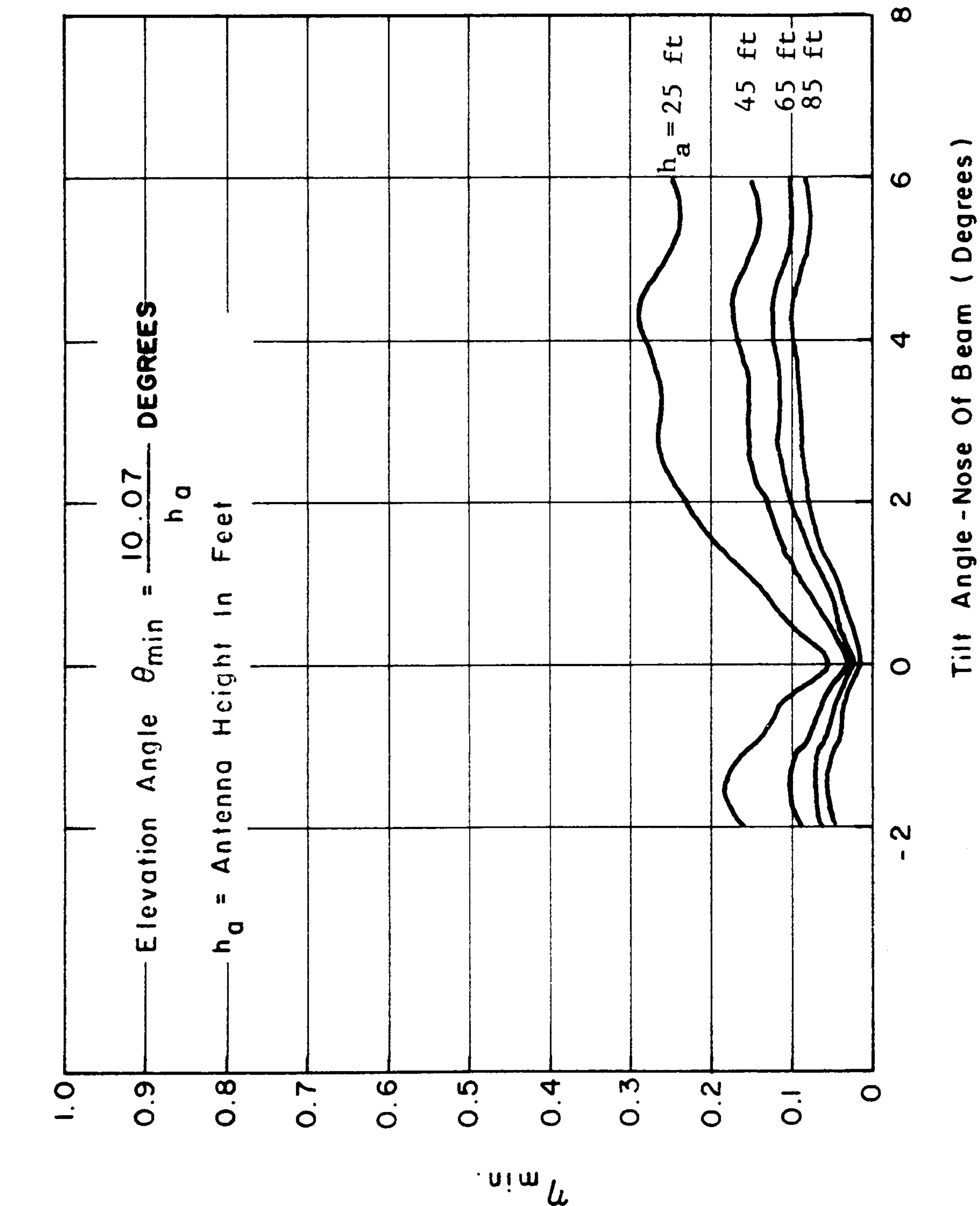


Figure 2-34.

TILT ANGLE EFFECT ON ASR NULL DEPTH - SECOND NULL, ASR-8 (Using Passive Receive Horn, f = 2800 MHz)

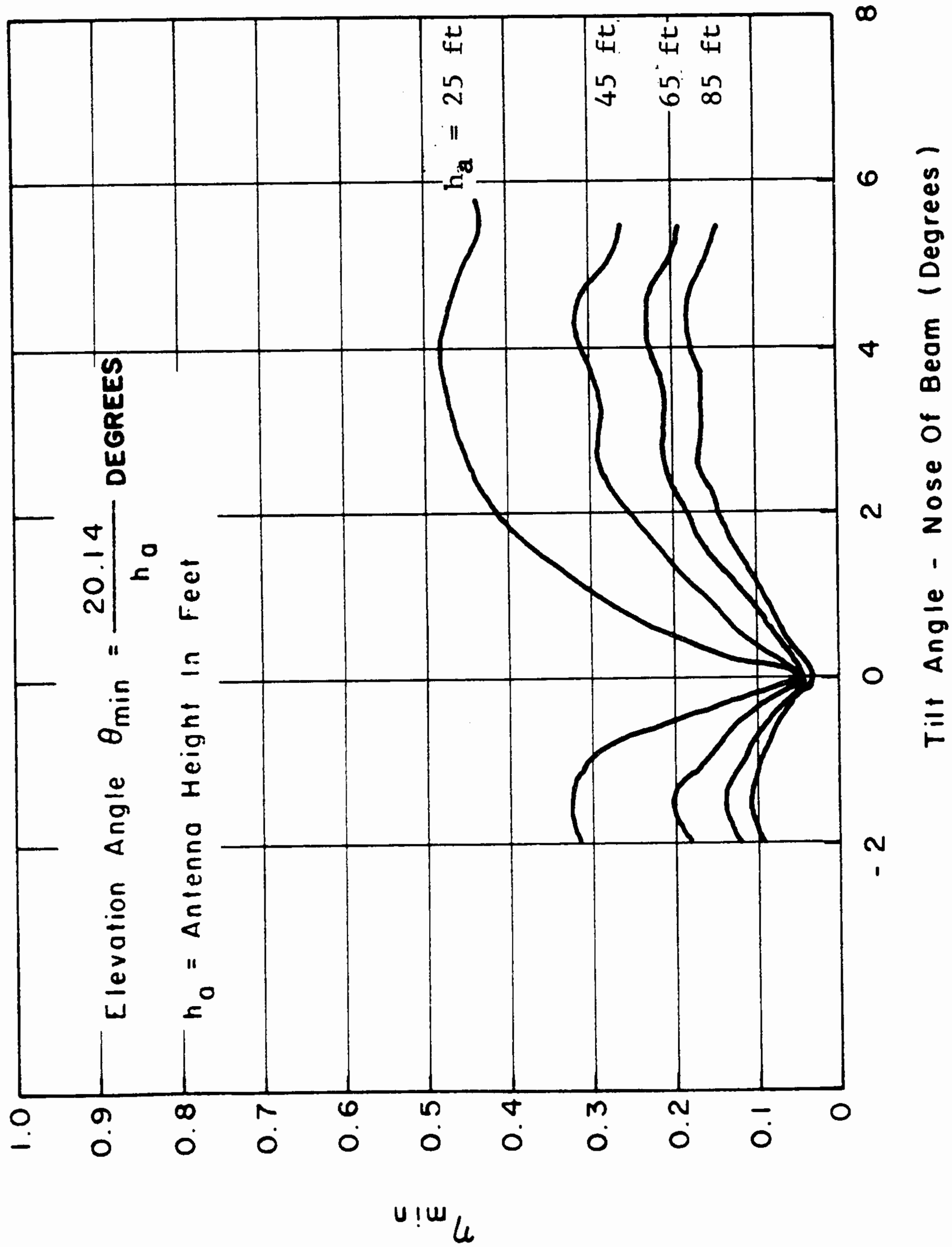


Figure 2-35.

TILT ANGLE EFFECT ON ASR NULL DEPTH - THIRD NULL, ASR-8 (Using Passive Receive Horn, f = 2800 MHz)

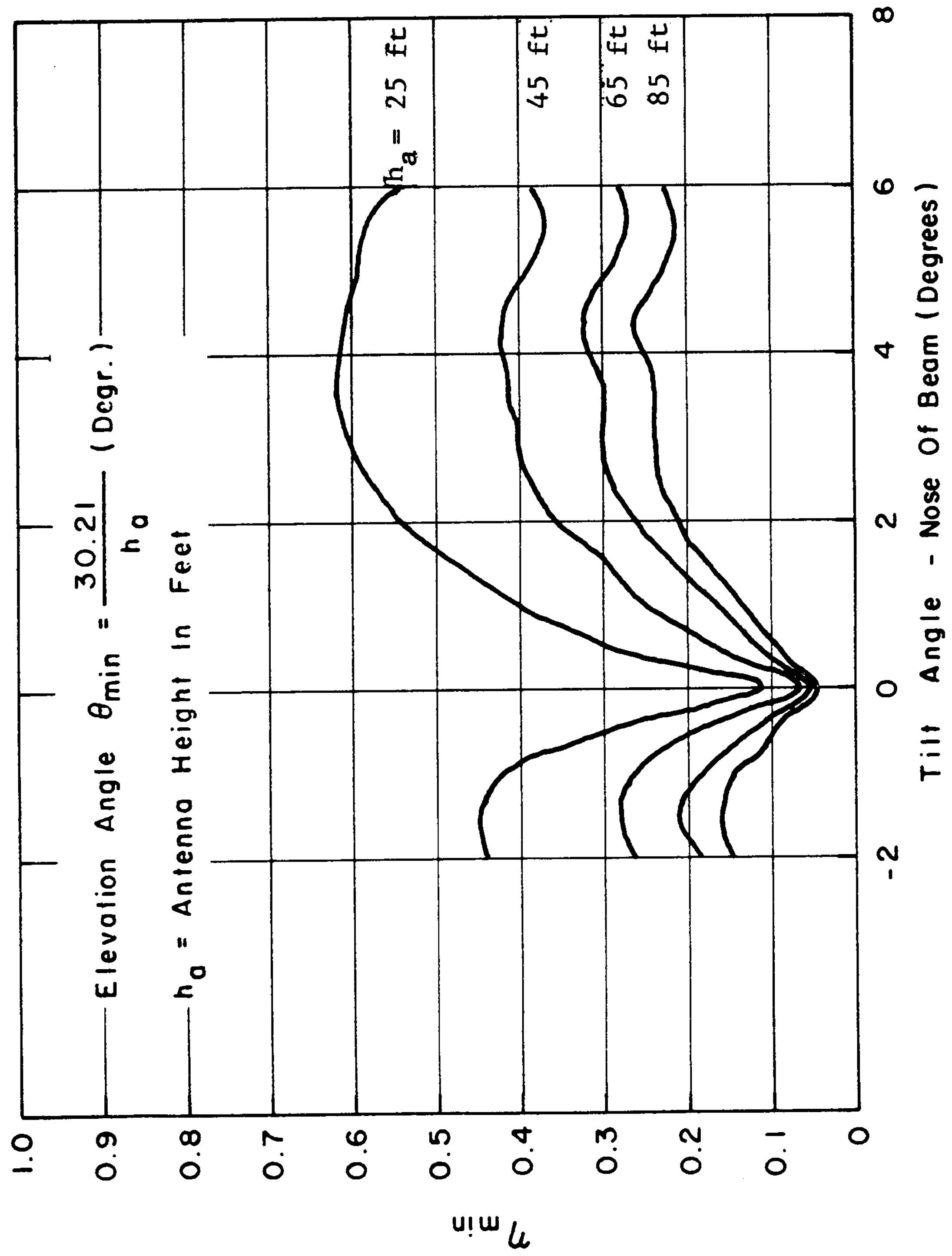


Figure 2-36. EFFECT ON THE LOBE PATTERN CAUSED BY VARIATION IN ANTENNA HEIGHT - ASR-4B, 5, 6, and 7

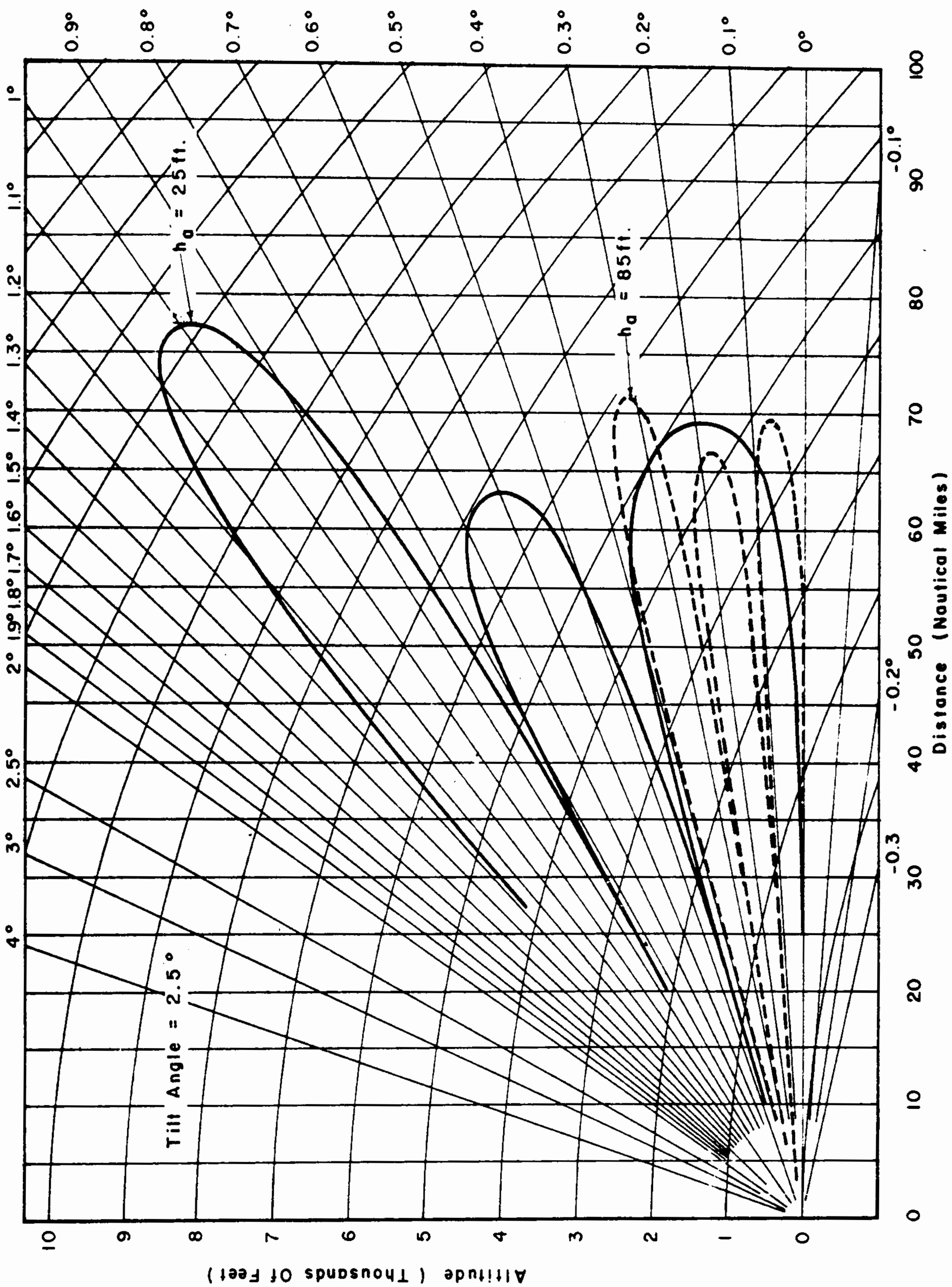


Figure 2-37. EFFECT ON THE LOBE PATTERN CAUSED BY VARIATIONS IN ANTENNA TILT ANGLE - ASR-4B, 5, 6, and 7

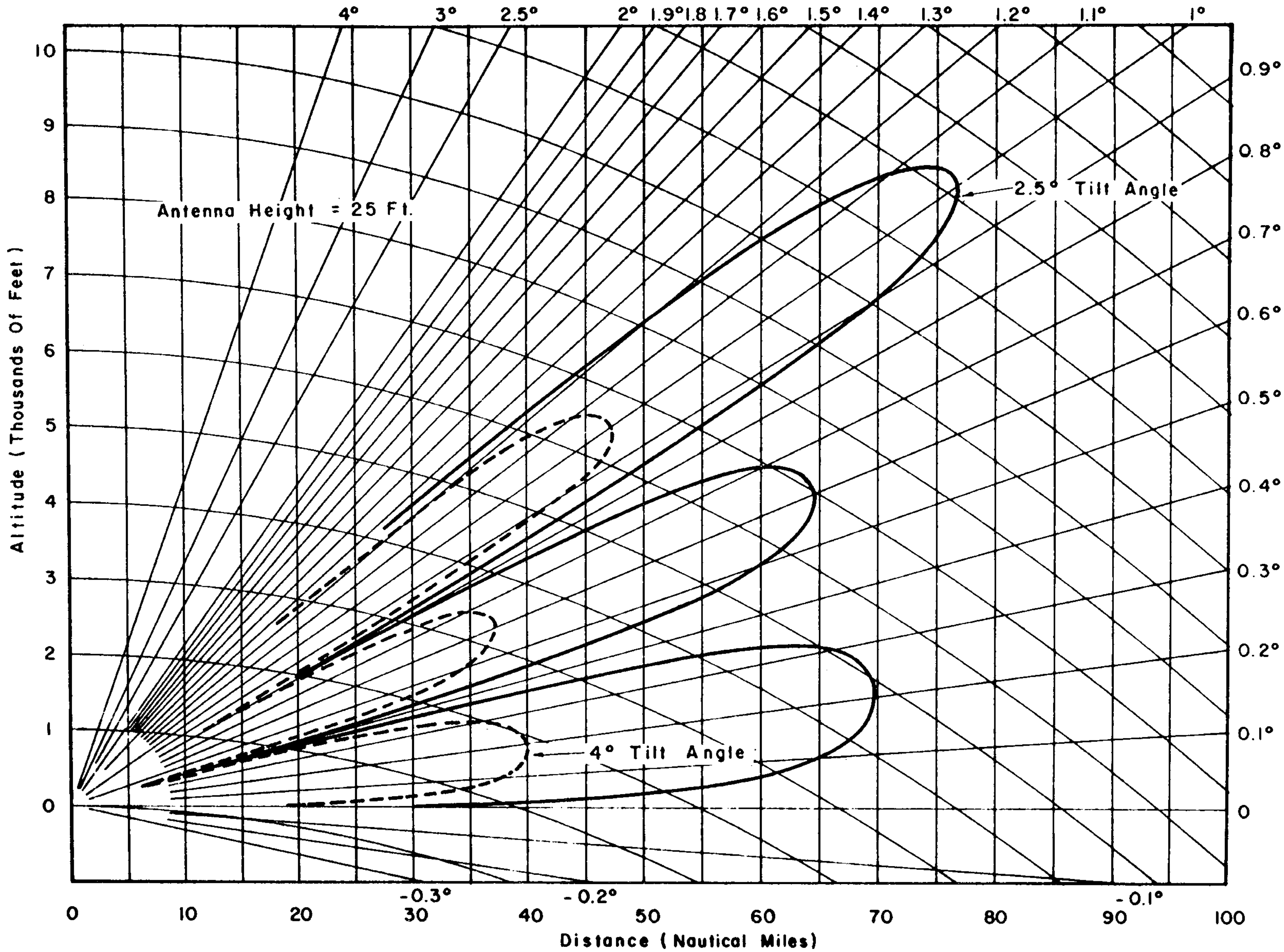
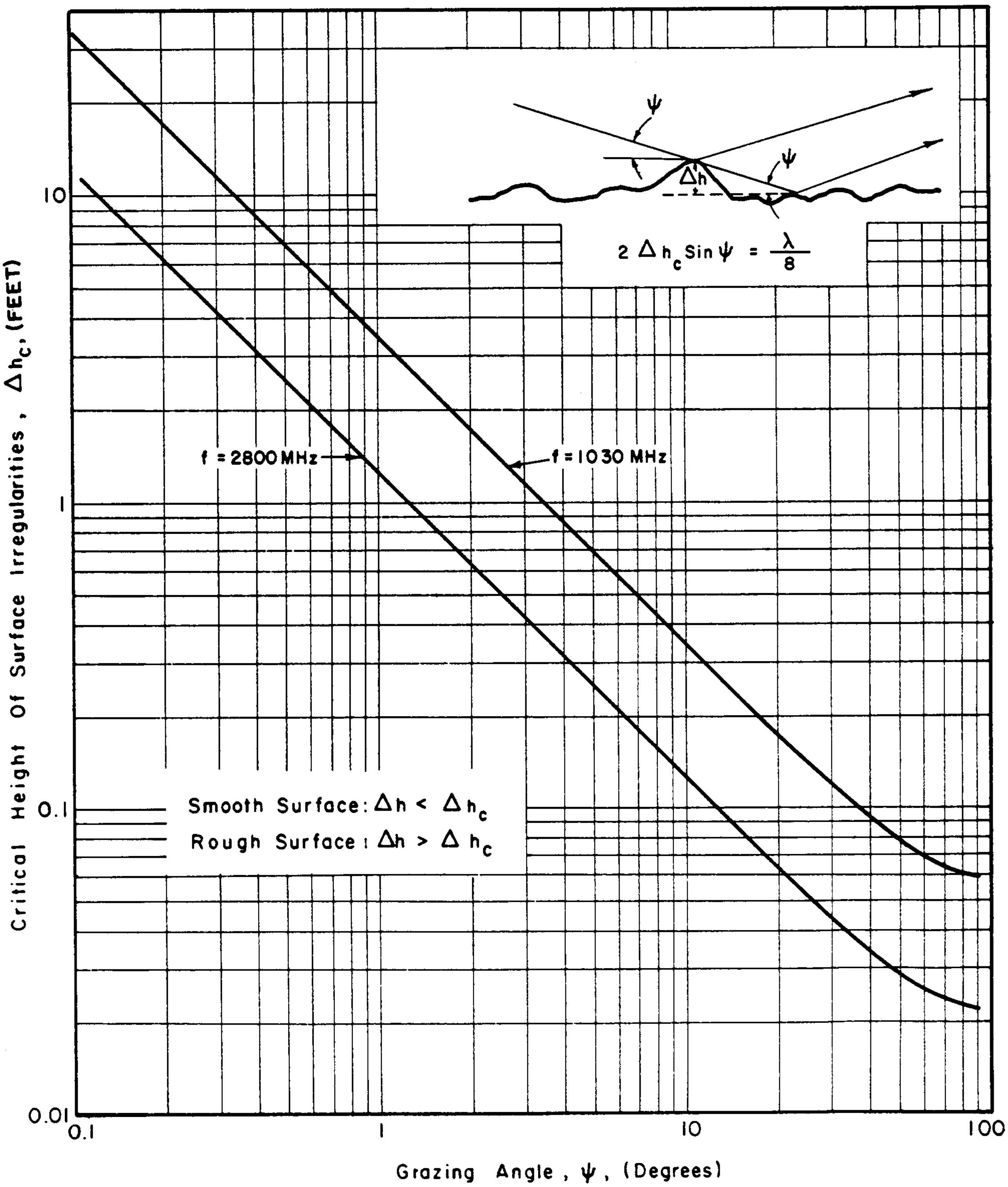


Figure 2-38. SURFACE ROUGHNESS CRITERION



with decreasing grazing angle, rougher terrain will be required to break up reflections using high antenna towers than is the case for low towers.

(c) Location of Reflection Point.

1. The distance, d_1, from the radar to the reflection point for each null in the vertical lobing pattern may be determined from the expression

$$d_1 = \frac{4\,h_a^2}{n\lambda} \qquad (2\text{-}33)$$

2. This location is determined from simple image theory, but is only rigorously correct for perfectly smooth reflectors. The reality of the "reflected" field at a given point in space is the sum of radiation from currents induced over a large surface region illuminated by the energy source. Vertical lobing will nevertheless occur approximately as presented above for imperfect reflectors, if the surface is relatively smooth (as defined in the previous subparagraph) over the first Fresnel diffraction zone. The range limits, d_ℓ, of this region are given by

* $$d_\ell = \left[\frac{1}{2n} + \frac{1}{n^2} \pm \frac{\sqrt{1+n}}{n^2}\right]\frac{8h_a^2}{\lambda} \qquad (2\text{-}34)$$ *

For the first null n = 2, and

$$d_\ell = \begin{cases} \dfrac{0.536\,h_a^2}{\lambda} & \text{(near point)} \\[2ex] \dfrac{7.464\,h_a^2}{\lambda} & \text{(far point)} \end{cases} \qquad (2\text{-}35)$$

These distances are plotted in figures 2-39 through 2-44 for the first three nulls at ASR and ATCBI frequencies.

3. The use of high towers introduces several considerations which make the elimination of the lobing condition more difficult. Rough and broken terrain in the general vicinity of the antenna site will tend to break up the reflecting surface and prevent the formation of lobes.

Figure 2-39. FIRST NULL REFLECTION POINT LOCATION - ASR EQUIPMENT.

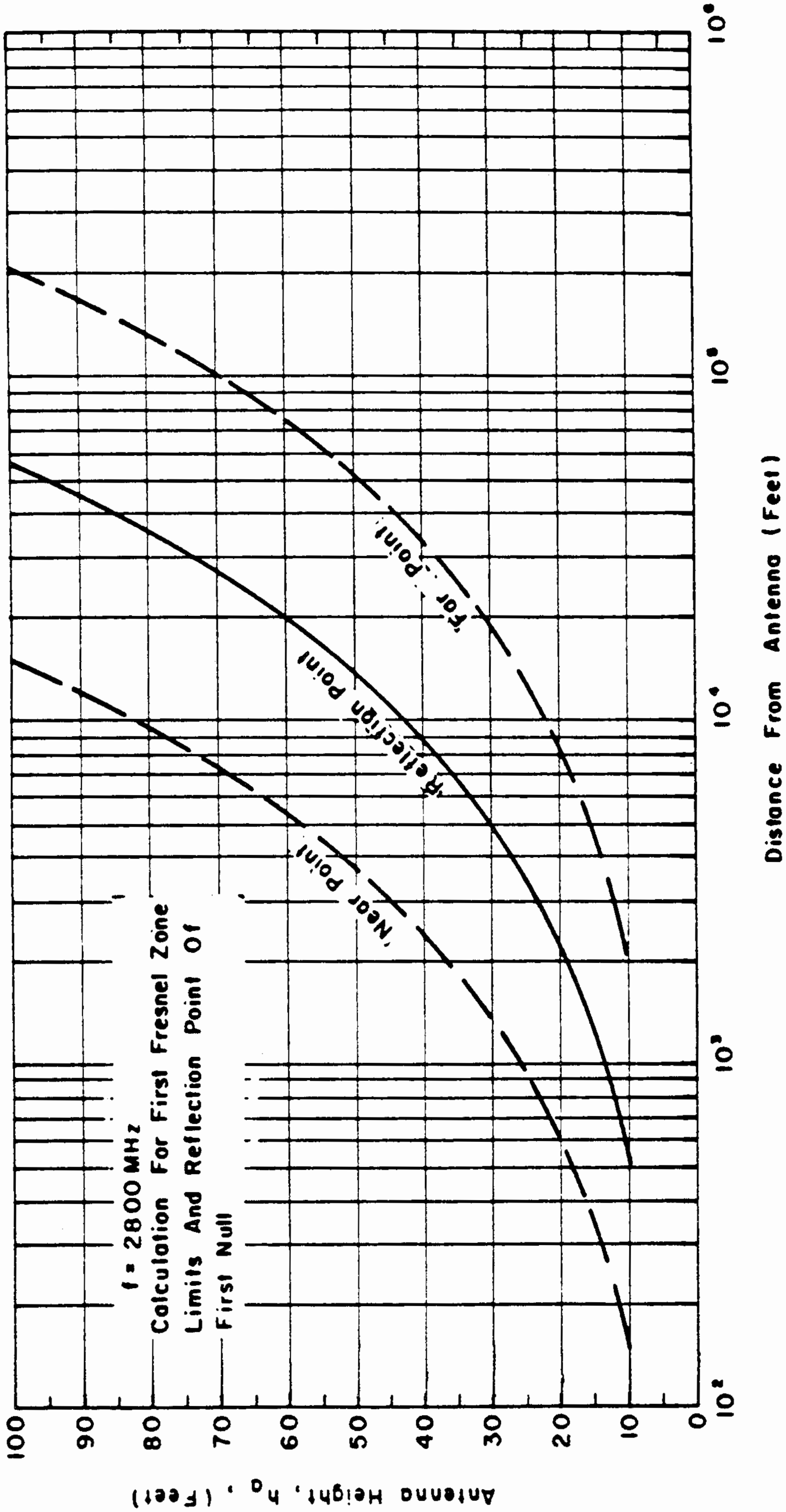


Figure 2-40 SECOND NULL REFLECTION POINT LOCATION - ASR EQUIPMENT.

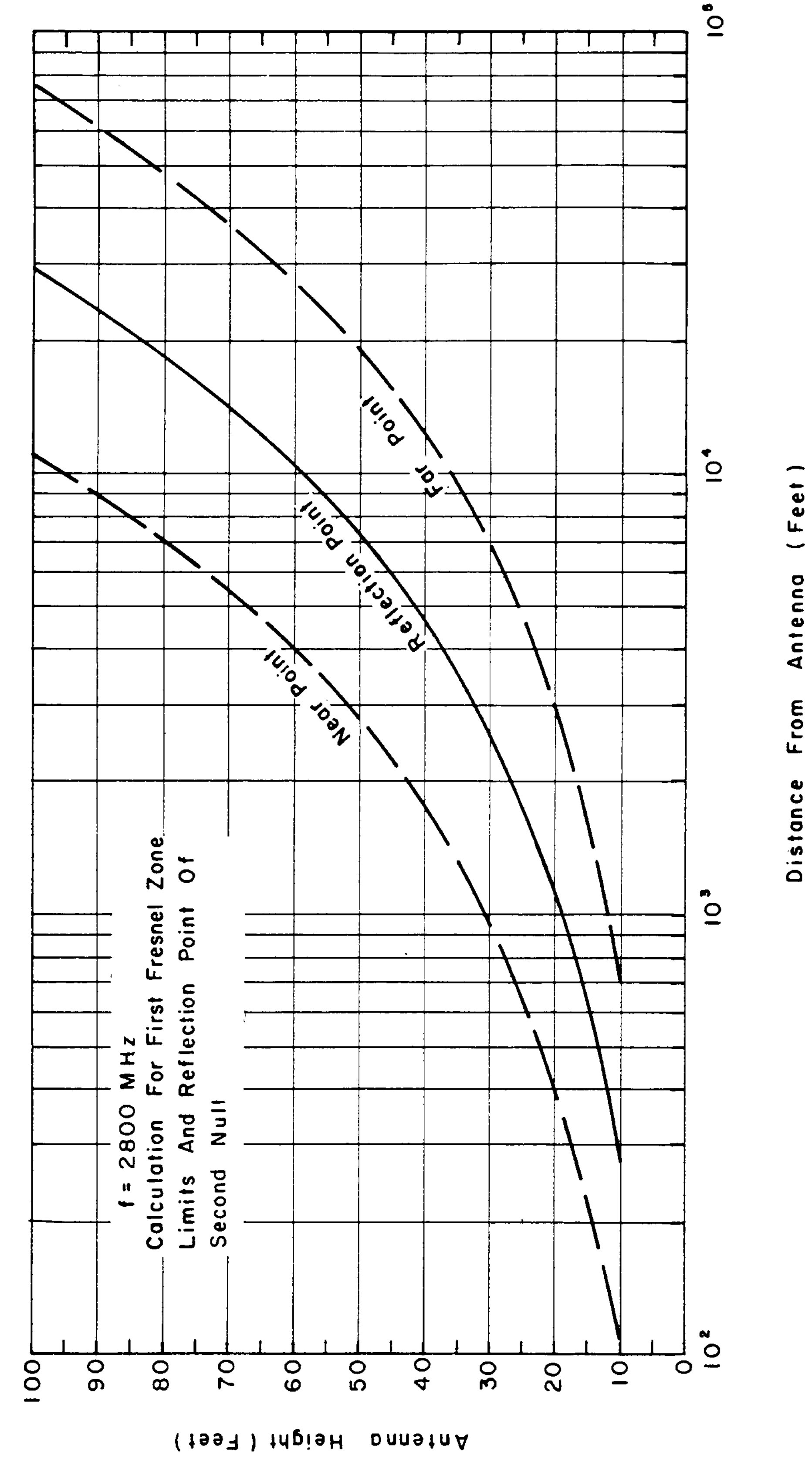


Figure 2-41 THIRD NULL REFLECTION POINT LOCATION - ASR EQUIPMENT

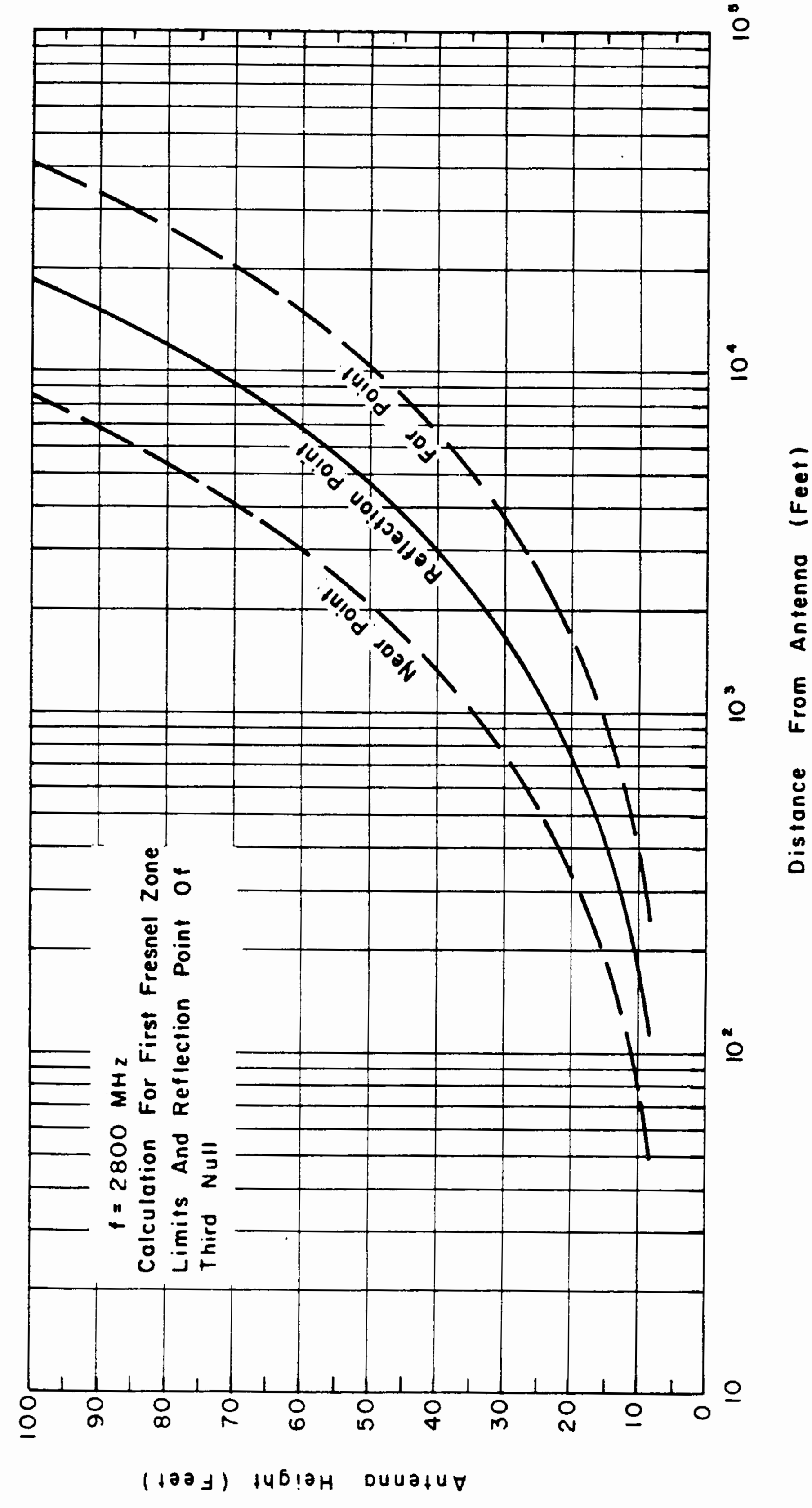


Figure 2-42.
FIRST NULL REFLECTION POINT LOCATION - ATCBI EQUIPMENT

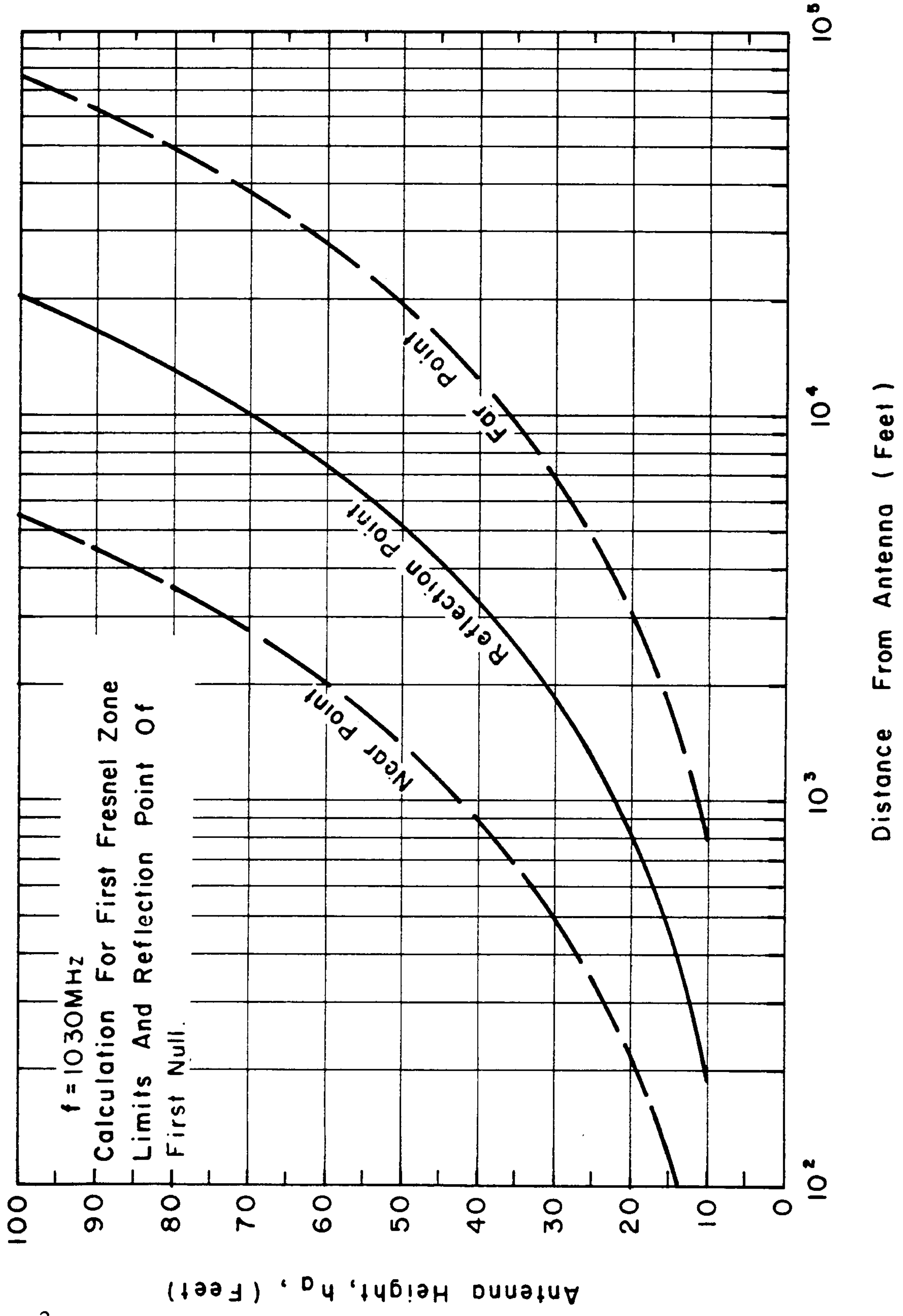


Figure 2-43. SECOND NULL REFLECTION POINT LOCATION - ATCBI EQUIPMENT

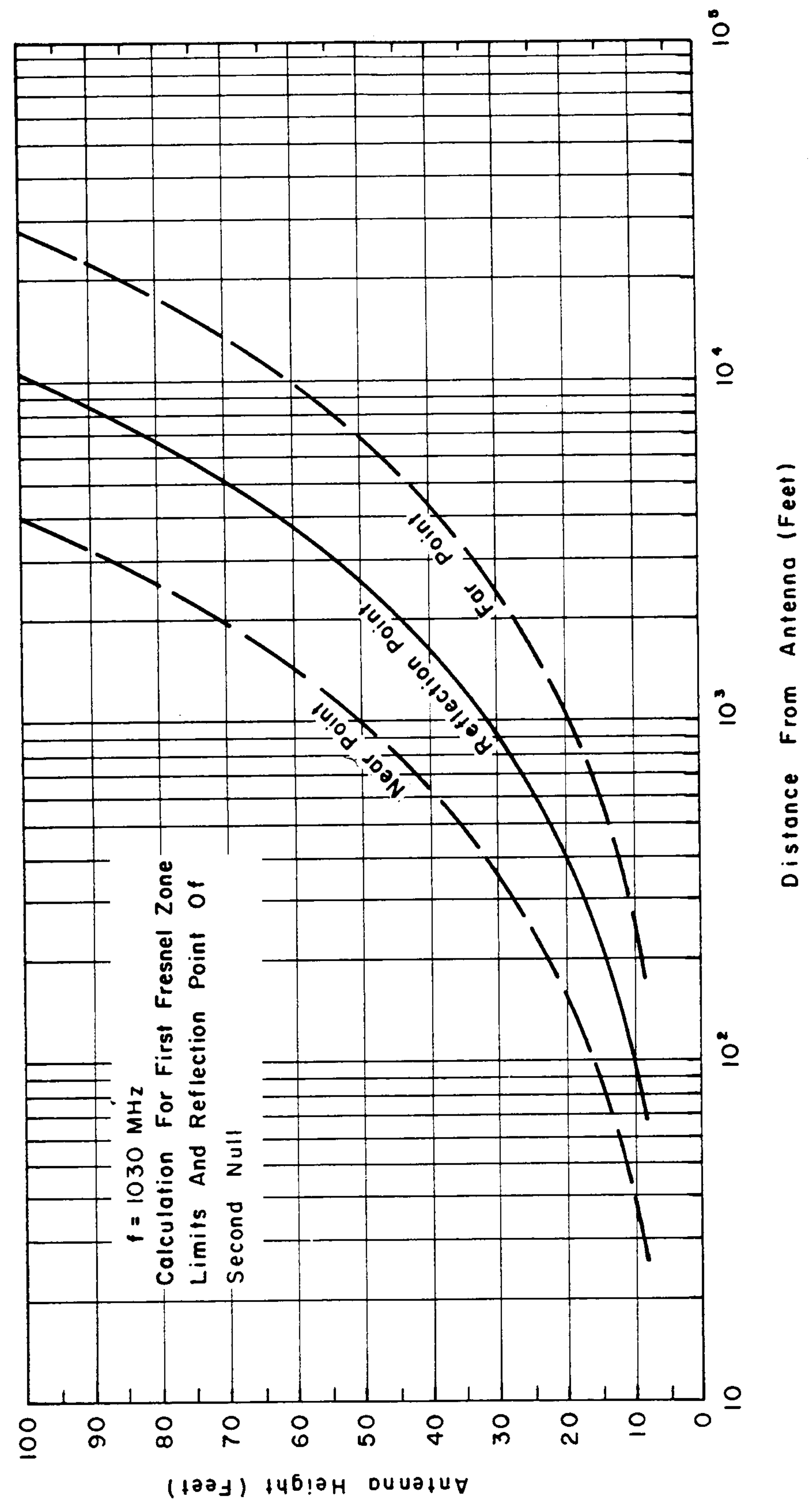
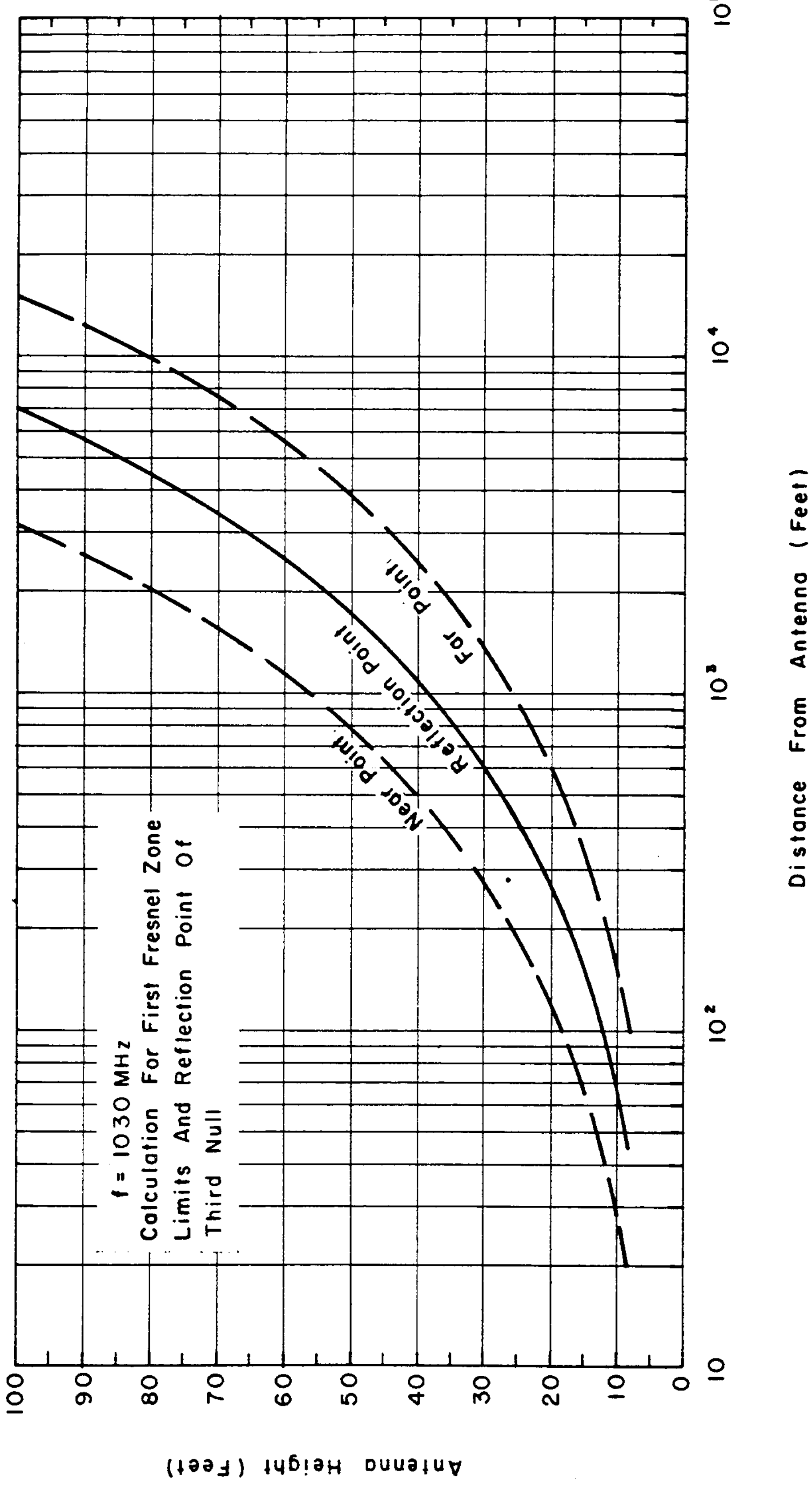


Figure 2-44. THIRD NULL REFLECTION POINT LOCATION - ATCBI EQUIPMENT



4. A review of figures 2-19, 2-20, and 2-38 indicates that high towers with their small grazing angles require much rougher terrain to break up reflections than the lower towers with their larger grazing angles. However, the higher towers extend the required reflecting area which must be considered to a much greater distance. This is shown in the curves of figures 2-39 and 2-42. As an example, consider a case where the surrounding terrain is relatively uniform with surface irregularities averaging 4 feet. Figure 2-38 indicates that at 2,800 MHz this would be considered relatively smooth terrain for grazing angles of 0.32° or less and rough terrain for higher angles. Reference to figure 2-19 indicates that for antenna heights less than about 30 feet all null angles are greater than 0.32°, so no vertical lobing should be expected when antennas are installed at effective heights below this value. If antennas are mounted higher than 30 feet, vertical lobing will occur PROVIDING the relatively smooth terrain condition exists over the first Fresnel zone. To illustrate this, consider an antenna height of 35 feet. Figure 2-39 shows that for this condition the first null reflection zone extends out to approximately 26,000 feet, or 4¼ nmi. Therefore, if the surface of relative smoothness extends out at least 4¼ nmi from the antenna, lobing will occur; if it does not, the presence of lobing is uncertain. Present theory does not cover the condition where the first Fresnel zone is only partially covered by "smooth" terrain. It would seem, however, that the severity of any lobing under this condition would depend upon the relative portion of the Fresnel zone covered by smooth terrain, with the region near the reflection point being more heavily weighted. It should also be noted that the presence of vertical surfaces near the Fresnel zone may act to screen or otherwise break up vertical lobing effects.

(d) Reflection Coefficient Effects.

1. As indicated above, the vertical lobing relationships developed here assume the reflected wave undergoes no attenuation and a 180° phase reversal at the reflecting surface. This is not the case in general, but serves as a conservatively useful assumption. If greater accuracy is desired, the magnitude, ρ, and phase, ϕ_r, of the actual surface reflection coefficient must be included in the analysis.

2. The calculated amplitude and phase of the reflection coefficient are plotted in figures 2-45 and 2-46 for a smooth sea and dry soil as a function of the angle of reflection ψ. Curves are given for horizontal and vertical polarization and frequencies between 100 MHz to 3,000 MHz. For dry soil, the reflection coefficient is not sensitive to frequency changes, and the 100 MHz curve may also be used for 3,000 MHz. It is seen that the reflection coefficient for vertical polarization is less than that for horizontal polarization.

3. The coefficient of reflection for vertical polarization varies rapidly with frequency and angle of reflection for sea water and more gradually for dry soil. The angle of reflection corresponding to the minimum point of the curves in figure 2-45 is known as the Brewster angle corresponding to a similar definition in optics. Cases of various other types of terrain not considered in figures 2-45 and 2-46 may be computed from the following equations:

4. For vertical polarization:

$$\rho \exp(-j\Phi) = \frac{\varepsilon_c \sin \psi - \sqrt{\varepsilon_c - \cos^2\psi}}{\varepsilon_c \sin \psi + \sqrt{\varepsilon_c - \cos^2\psi}} \qquad (2\text{-}36)$$

5. For horizontal polarization

$$\rho \exp(-j\Phi) = \frac{\sin\psi - \sqrt{\varepsilon_c - \cos^2\psi}}{\sin\psi + \sqrt{\varepsilon_c - \cos^2\psi}} \qquad (2\text{-}37)$$

where:

$\varepsilon_c = \varepsilon_r - j\ 60\sigma\lambda$

ε_r = dielectric constant of the reflector relative to air

σ = conductivity of the reflector mhos/meter

λ = wavelength, in meters

Φ = phase angle, lagging

Some typical ground constants are given in table 2-2.

FIGURE 2-45. MAGNITUDE OF REFLECTION COEFFICIENT

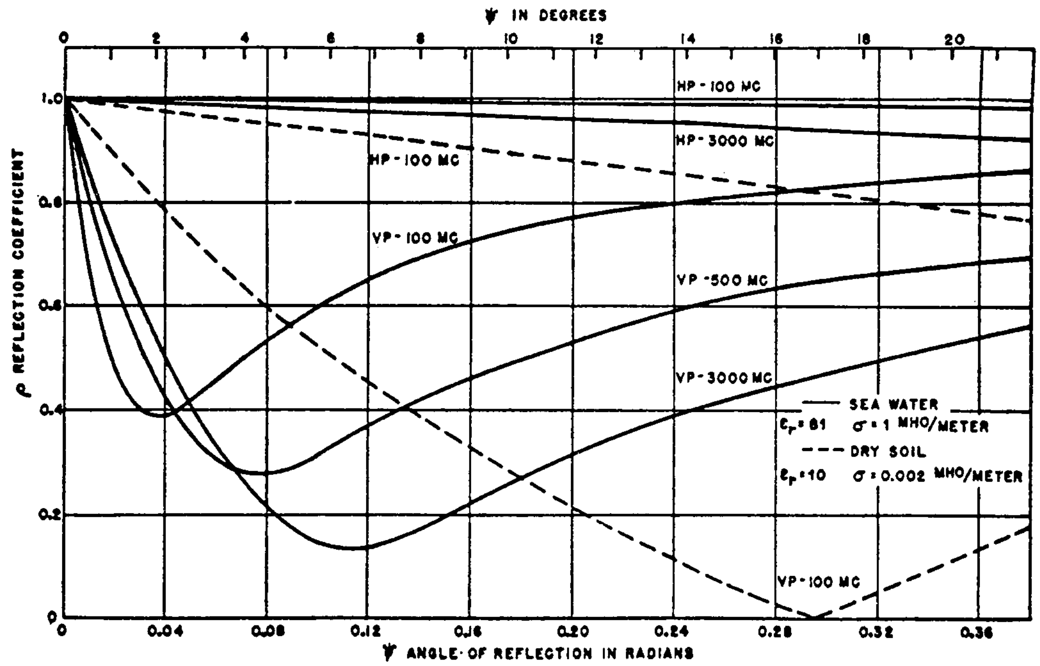
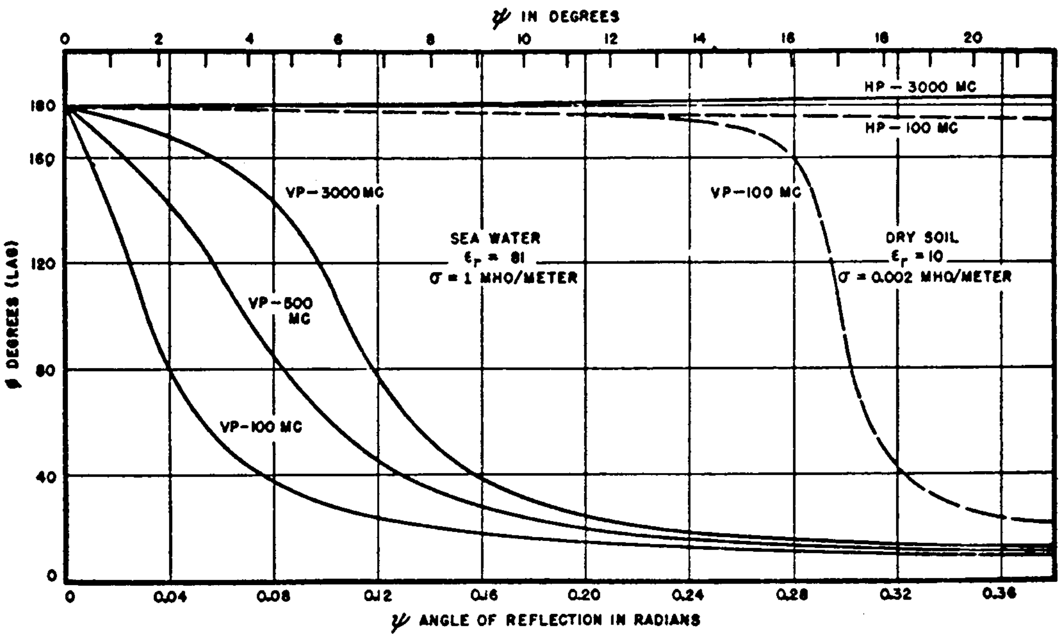


FIGURE 2-46. PHASE OF REFLECTION COEFFICIENT



NOTE: SOLID CURVE REPRESENTS SEAWATER.
DOTTED CURVE REPRESENTS DRY SOIL.

TABLE 2-2

TERRAIN REFLECTION CHARACTERISTICS [1]

Type of Terrain	Relative Dielectric Constant ε_r	Conductivity σ, mhos/meter
Rich soil	20	3×10^{-2}
Heavy clay	13	4×10^{-3}
Rocky soil	14	2×10^{-3}
Sandy dry soil	10	2×10^{-3}
City industrial area	5	10^{-3}
Fresh water	81	10^{-3}
Sea water	81	1

[1] Reference 7

c. Clutter.

(1) In the discussion of signal detectability given in section 3, it was assumed that only one echo signal is present within the range and angle sector being considered. If a few other targets are present within the total coverage volume of the radar, little or no harm is done. But if there are so many targets that they "run together" on the cathode-ray screen
* or other type of display, or if they overlap in time when *
time-gated automatic detection devices are employed, detection of a desired signal will be seriously affected. A profusion of echoes sufficient to produce this effect is called clutter or clutter echoes. Such echoes can be produced by the surface of the land or sea, by weather, and at times even by birds or insects.

(2) Clutter echoes from various types of terrain and from rain have many characteristics in common with receiver noise, in that they are randomly fluctuating in amplitude and phase, and in many cases they even have a probability density function like that of thermal noise. However, they differ in one imporatant respect--their fluctuation rate is much slower, which means that their frequency spectrum is narrower.

(3) When the clutter level is much higher than the receiver noise level, the detection problem is in terms of the signal-to-clutter ratio rather than signal-to-noise ratio. It has many properties in common with the problem of detecting a signal in thermal noise. But, because of the slower fluctuation rate, integration of pulses is relatively ineffective; the clutter is usually correlated for time separations which may be of the order of pulse periods. Also, some clutter may be spiky in character, which means that its statistics are different from those of the receiver noise. But the basic problem of detection is the same: the signal power must on the average be great enough to produce a probability of detection substantially greater than the false-alarm probability.

(4) Radar detection capability, therefore, is analyzed by considering how the target echo and the clutter echoes vary with the range, so as to determine at what ranges the target-to-clutter-signal ratio necessary for detection is reached. In the absence of specific information on the clutter statistics, a reasonable assumption to make for the required signal-to-clutter ratio is that, for given detection probability and false-alarm probability, it corresponds to the required signal-to-noise ratio for single-pulse detection (no integration). This value as determined from reference 6 for $P_{fa} = 10^{-6}$ is about 16.7 dB. This value must, of course, be modified by the mti improvement factor provided by radar

signal processing. Values of this improvement factor are tabulated in table 1-1 for the ASR systems.

(5) The signal-to-clutter (s/c) ratio is given by the ratio of the effective radar cross sections of the target and the clutter, σ_t and σ_c, if both target and clutter are subject to the same propagation factors. However, the propagation factors may be different, because of antenna pattern effects. The criterion of detectability of the target therefore becomes

$$s/c = \frac{\sigma_t G_t G_r}{\sigma_c G_{tc} G_{rc}} \qquad (2\text{-}38)$$

where

G_t = radar transmit antenna gain in direction of target

G_r = radar receive antenna gain in direction of target

G_{tc} = radar transmit antenna gain in direction of clutter

G_{rc} = radar receive antenna gain in direction of clutter

For ASR-4B, 5, 6, and 7

$$G_t = G_r = G, \; G_{tc} = G_{rc} = G_c$$

* For ASR-5E, 6E, 7E and 8 the gains are not equal due to employment of the dual beam antenna (see figure 1-6). *

(6) When the clutter is from a rough surface, σ_c is the product of the cross section per unit area, σ_o, and the area of the surface, A_c, illuminated by the radar pulse. For a radar of horizontal beamwidth, θ_a, radians and pulse length, τ, seconds * and viewing the surface at a grazing angle, ψ, this area is, for small values of ψ, *

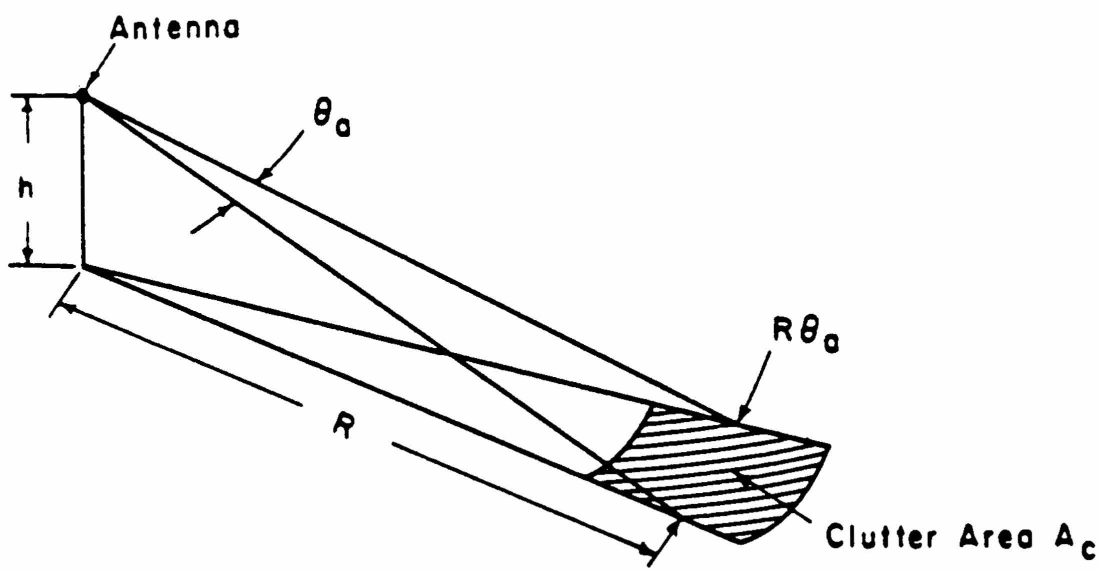
$$A_c = R\theta_a \frac{c\tau}{2} \sec \psi \qquad (2\text{-}39)$$

where R is the radar range to the surface and c is the velocity of propagation (3×10^8 m/sec). This is shown diagrammatically in figure 2-47. Thus,

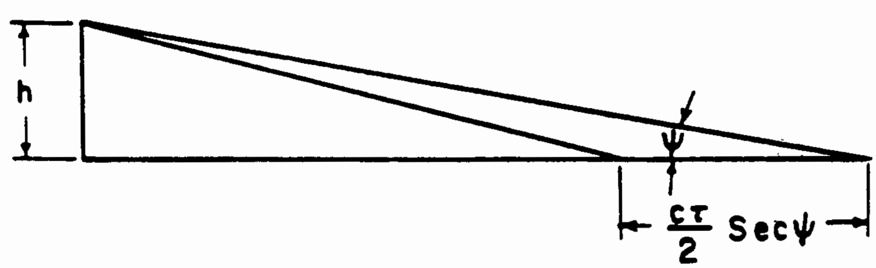
$$\sigma_c = A_c \sigma_o \qquad (2\text{-}40)$$

and once σ_o is known, both clutter cross section and s/c are readily determined for the target of interest

Figure 2-47. CLUTTER PATH GEOMETRY



a) Surface Area Illuminated By Radar Pulse - Pictorial



b) Surface Area Illuminated By Radar Pulse - Profile

(7) Expressing range, R, in nautical miles and using the radar parameters indicated in table 1-1 gives, for ASR-4B, 5, 6, and 7

* $A_c = 6060.4 \text{ R sec } \psi$ (sq. meters)

and hence

$\sigma_c = 6060.4 \text{ R } \sigma_o \text{ sec } \psi$ (sq. meters) (2-41) *

* For ASR-5E, 6E, and 7E

$A_c = 5858.4 \text{ R sec } \psi$ (sq. meters)

and

$\sigma_c = 5858.4 \text{ R } \sigma_o \text{ sec } \psi$ (sq. meters) (2-41A) *

* For ASR-8,

$A_c = 4218.2 \text{ R sec } \psi$ (sq. meters)

and

$\sigma_c = 4218.2 \text{ R } \sigma_o \text{ sec } \psi$ (sq. meters) (2-42) *

σ_o in these equations has the dimensions of (m^2/m^2). It should be noted here that clutter extends outward in range only as far as the radar horizon. This distance depends upon earth curvatures, screening, etc. It is discussed in some detail in section 2.

(8) The clutter cross section per unit area. σ_o, is a parameter which exhibits considerable variation with terrain type, terrain condition (e.g., moisture content, snow cover, seasonal foliage cover, wave patterns, etc.), and grazing angle. In addition, σ_o for any given clutter cell will vary in time due to the effects of wind/wave motion and of radar beam scanning. The variable nature of clutter makes prediction of σ_o difficult and subject to considerable error. This should be borne in mind when performing clutter analyses so as to avoid computational elaboration not justified by clutter data accuracy.

(9) Simple clutter analyses may be carried out based on mean values of σ_o derived from measurement or theoretical models. Some useful σ_o data is presented in tables 2-3 and 2-4 for land and sea clutter. If the tabulated σ_o data is used, the mean clutter cross section can be computed with the aid of equations 2-41, 2-41A, or 2-42 above. Use of equation 2-38 (p. 132) will then allow computation of the s/c ratio given target. It should be noted here that antenna gain values used in the calculation must account for any antenna tilt employed. To a first approximation it can be assumed that the target will be detected in the presence of clutter if the computed value of s/c is greater than 16.7 dB minus the radar mti improvement factor, I. This occurs when

TABLE 2-3

LAND CLUTTER REFLECTIVITY, 0-1° ANGLE OF INCIDENCE [1]

Reflectivity in db below 1 m^2/m^2,
Pulse width = 1 μs, $\theta_a = 2°$,
σ_o = median backscatter

Terrain	L-Band (1.2 Gc) σ_o	S-Band (3.0 Gc) σ_o	C-Band (5.6 Gc) σ_o
Desert	45	--	--
Cultivated Land	32 (V)	--	38
Open Woods	34 (H)	33	--
Wooded Hills	35 45	32 47	-- --
Small House Districts	--	35	35
Cities	30	--	--

[1] Reference 2

TABLE 2-4

NORMALIZED MEAN SEA BACKSCATTER COEFFICIENT, σ_o 1/

S-Band (3.0 Gc), 0.5-10 μs pulse,

		σ_o in dB below 1 m^2/m^2				
Sea State	Pol	Grazing Angle (degrees)				
		0.1	0.3	1.0	3.0	10.0
0 Calm	V	---	---	---	---	---
	H	90†	83†	73	68†	---
1 Smooth - < 1 ft Waves	V	---	62†	56	52	---
	H	80	74	65	59	---
2 Slight 1-3 ft Waves	V	72†	59†	53	49	38
	H	75†	66	55	53	51
3 Moderate 3-5 ft Waves	V	---	55†	48	43	34
	H	68	58†	48	46	46
4 Rough - 5-8 ft Waves	V	---	54†	42	38	31†
	H	38	50†	42	41	---
5 Very Rough 8-12 ft Waves	V	---	50†	38†	35	28†
	H	53	44	42	38	38†

1/ Reference 2

† 5 dB error not unlikely

* $$10 \log s/c \geq \begin{cases} -14.3 \text{ dB (ASR-4B, 5, 5E, 6, 6E, 7, 7E)} \\ -17.3 \text{ dB (ASR-8)} \end{cases} \quad (2\text{-}43)$$ *

(10) If clutter data is obtained via direct measurement of clutter power, C, through use of a mobile radar unit, it should be compared with the signal power, S, from an otherwise detectable aircraft. Measured values of C must, of course, be corrected to account for differences in antenna gains between the test radar and the radar being sited. S may be determined from the standard radar equation:

$$S = \frac{P_t G_t G_r \lambda^2 \sigma_t}{(4\pi)^3 R^4} \quad (2\text{-}44)$$

where

P_t = transmitter peak power (in watts)

G_t = transmitting antenna gain in target direction

G_r = receiving antenna gain in target direction

λ = wavelength (in meters)

σ_t = target radar cross section (in sq. meters)

R = range to target (in meters)

and values of the parameters are listed in table 1-1 (p. 3 and 4). Target detection in clutter can then be determined from equation 2-38 (p. 132) providing $S > S_{min}$, the radar mti sensitivity.

(11) It should be recalled that the computational methods discussed here assume clutter power to be much greater than system noise. If this is not the case, achievement of the requisite s/c ratio will not insure target detection since this may be limited by receiver noise.

(12) In addition to the diffuse scattering considered above, considerable radar clutter may also be generated by large buildings, water towers, power lines and other stationary objects, and by vehicular traffic, birds and other slow moving objects. Clutter return from these objects are usually treated separately, in much the same manner as targets. Where the resulting clutter is intolerably severe, attempts should be made to provide either (a) natural shielding of the clutter

source, or (b) manmade shielding in the form of properly designed fences. The latter may be accomplished using the methods described in references 8 or 9.

d. Angels.

(1) Clutter that is nonstationary and elusive is most commonly called "angels". Angel echoes can be obtained from regions of the atmosphere where no reflecting objects apparently exist. They take many different forms and have been attributed to various causes, including birds, insects, and meteorological effects.

(2) Probably the most important source of angels is birds, especially for ground-based radars looking over the sea. Although the radar cross section of a single bird is small compared with that of an ordinary aircraft, bird echoes can be relatively strong, especially at the shorter ranges because of the inverse-fourth-power variation with range. For example, the radar cross section of a bird the size of a sea gull might be of the order of 0.01 m^2. A bird with this cross section at a range of 10 nmi will return an echo signal as large as that from a 100 m^2 radar cross section target at 100 nautical miles. When birds travel in flocks, the total cross section can be significantly greater than that of a single bird. Because the radar display collapses a relatively large volume of space into a small radar screen, the display can appear cluttered with bird echoes even though only a few birds can be seen by visual examination of the surrounding area. Birds can fly at speeds up to 50 knots (or higher if carried by the wind). This is probably too high a speed to be rejected by most mti radars. The small echoing area of birds means that they are primarily seen at relatively short ranges, 20 to 25 miles or less, for medium-power search radars.

(3) Insects, even though small, may also be readily detected by radar. A direct correlation has been shown between nighttime angel echoes detected by radar and observations of insects within a searchlight beam illuminating the same volume as the radar. Insects are usually carried by the wind; therefore angels due to insects might be expected to have the velocity of the wind. Both insect and bird echoes are more likely to be found at the lower altitudes, near dawn and twilight. Since the majority of insects are incapable of flight at temperatures below 40° or above 90°F, large concentrations of insect angel echoes would not be expected outside this temperature range.

(4) Still another source of angel echoes may be attributed to anomalous propagation. Radar waves directed at low angles can be reflected or refracted to the ground by (a) an atmospheric layer of considerable refractivity, (b) sharp refractive

gradients over a local terrain feature such as intense moisture gradient over a river or lake, or (c) wind-carried refractive inhomogeneities. The echoes return to the radar by the same path. In essence, the radar "sees" the ground or some object on the ground as a target. For example, a very realistic target might be tracked by the radar operator if the deflected radar beam happened to be illuminating a moving train. An "apparent" moving target might also be indicated even when the beam observes a stationary object on the ground provided the reflecting portion of the atmosphere is itself in motion. At a range of 50 miles, a horizontal reflecting layer rising 3 m/sec can cause an apparent echo to move at 300 mph.

(5) Many angel echoes are not attributable to these sources, however, but are believed to be caused by such meteorological effects as: sharp gradients in the refractive index of the atmosphere, invisible bubbles of buoyant air, thermal columns below cumulus clouds, atmospheric moisture gradients, and others.

(6) In general, angels caused solely by meteorological effects are beyond the control of radar siting engineers and do not require unusual consideration when selecting a particular radar location within a limited region. Angels due to birds and insects, however, do merit some consideration insofar as their severity can be controlled by the radar stc characteristics.

e. False Targets.

(1) Beacon False Targets.

(a) As discussed in chapter 1, reflecting surfaces can constitute a severe problem to ATCRBS operation due to the generation of false targets. These most commonly occur when the main beam of the ATCRBS directional antenna successfully interrogates an airborne transponder via a reflected signal path. This will produce an apparent target at the azimuth of the reflector and at a range corresponding to that of the reflected path, which is always greater than the direct path range. This range difference is generally imperceptible on a normal display, however. The reflector and path geometry are illustrated in figure 1-23. The range and azimuth region over which false target effects may be observed are limited by (1) interrogation link power and sensitivity, and (2) reflector dimensions and aspect angle. This assumes that the ATCRBS interrogation link limits system performance. (The assumption is justified in appendix 2.) As discussed in chapter 1, sls is also employed in ATCRBS equipment to reduce the incidence of beacon false targets.

(b) In order to determine the amount of energy reflected by the reflecting object, its bistatic radar cross section, σ_b, may be determined from (reference 10):

$$\sigma_b = \frac{4\pi A_{eff}^2}{\lambda^2} \qquad (2\text{-}45)$$

where

A_{eff} = effective area of the reflector

λ = wavelength

(c) The effective area of a reflector is its cross sectional area, A, multiplied by the sine of the angle of incidence, α.

$$A_{eff} = A \sin \alpha \qquad (2\text{-}46)$$

(d) For a flat rectangular reflector

$$A_{eff} = hw \sin \alpha \qquad (2\text{-}47)$$

where

h = reflector height

w = reflector width

(e) These relationships may be used except where the reflector width exceeds that of the ATCBI antenna beamwidth. In that case

$$w = \frac{\pi}{180} R_2 \, \theta_{ai} \qquad (2\text{-}48)$$

where

R_2 = range between antenna and reflector

θ_{ai} = interrogation antenna azimuth beamwidth (degrees)

and w and R_2 are measured in the same units. For a flat, lossless, reflector A_{eff} may be determined using the nomograph in figure 2-48a. The nomograph construction assumes $\theta_{ai} = 2^\circ$.

(f) With A_{eff} known, the maximum range over which targets can be falsely interrogated can be determined from the bistatic radar equation

Figure 2-48a. BEACON REFLECTION NOMOGRAPH - EFFECTIVE AREA DETERMINATION

Equation: $A_{eff.} = hw \sin^{n} \alpha$

SOLUTION.

1. DETERMINE WIDTH OF REFLECTOR AND RANGE FROM TRANSMITTER SITE. IF ACTUAL WIDTH OF REFLECTOR IS GREATER THAN INCIDENT BEAMWIDTH AT THAT RANGE AS DETERMINED FROM THE "A" SCALE USE RANGE SIDE OF SCALE, OTHERWISE USE WIDTH SIDE.
2. PLACE STRAIGHT EDGE BETWEEN ABOVE POINT ON "A" SCALE AND POINT ON "B" SCALE EQUAL TO HEIGHT OF REFLECTOR AND OBTAIN ACTUAL AREA ON "C" SCALE.
3. FROM THAT POINT ON THE "C" SCALE LAY THE STRAIGHT EDGE TO A POINT ON THE "D" SCALE CORRESPONDING TO ANGLE OF INCIDENCE. THE INTERSECTION ON THE "E" SCALE YIELDS THE EFFECTIVE AREA IN FT.^{2}
4. IF WIDTH OF REFLECTOR IS GREATER THAN ANTENNA BEAMWIDTH AS PER STEP NO. 1, OMIT STEP NO. 3 AND USE ACTUAL AREA OBTAINED IN STEP NO. 2 TO COMPLETE THE SOLUTION.

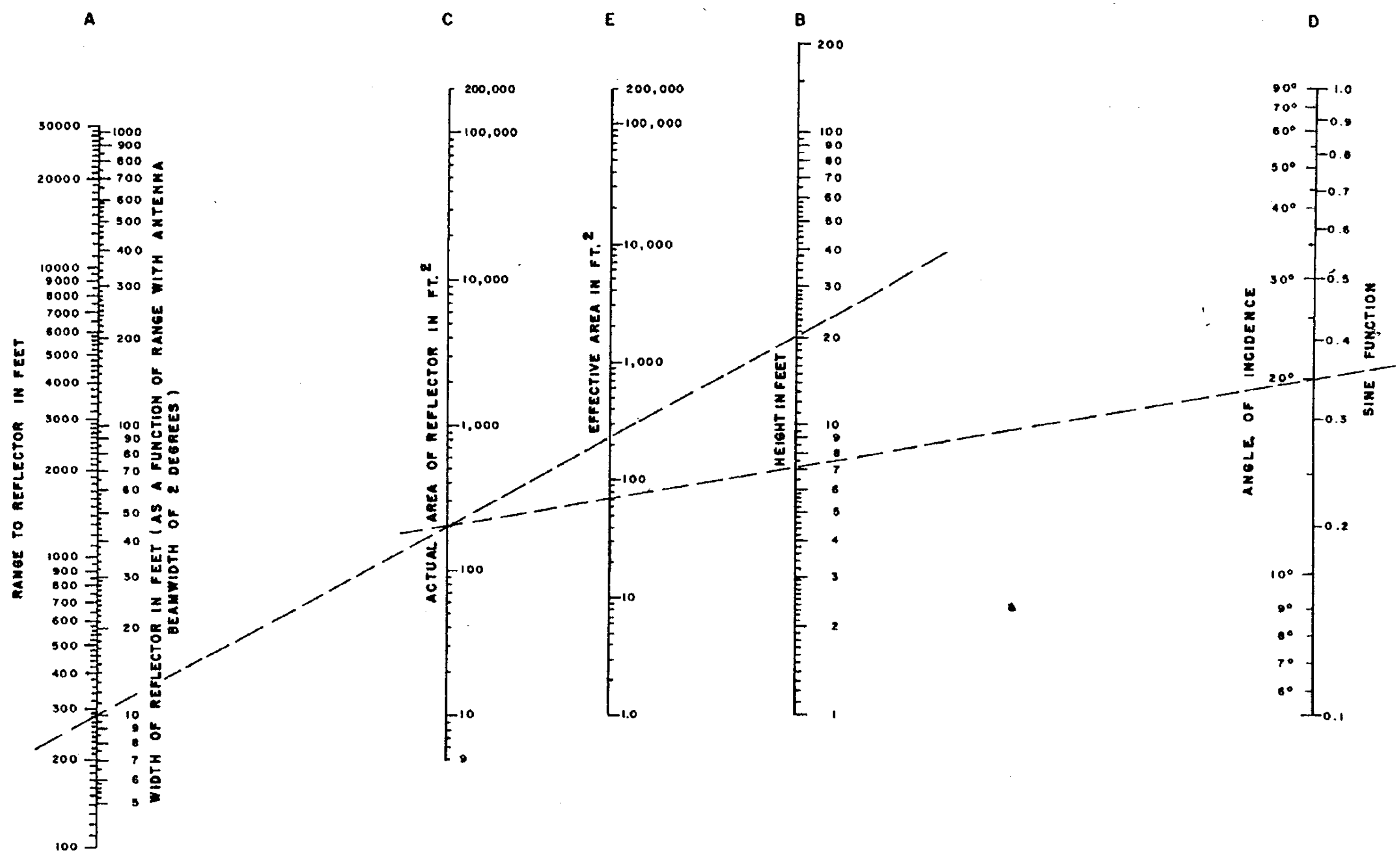


Figure 2-48b. BEACON REFLECTION NOMOGRAPH - MAXIMUM RANGE DETERMINATION

Equation : $R_2 = \sqrt{\dfrac{P_d G_i G_t A_{eff}^2}{(4\pi)^2 R_1^2 S_{min} L_s}}$

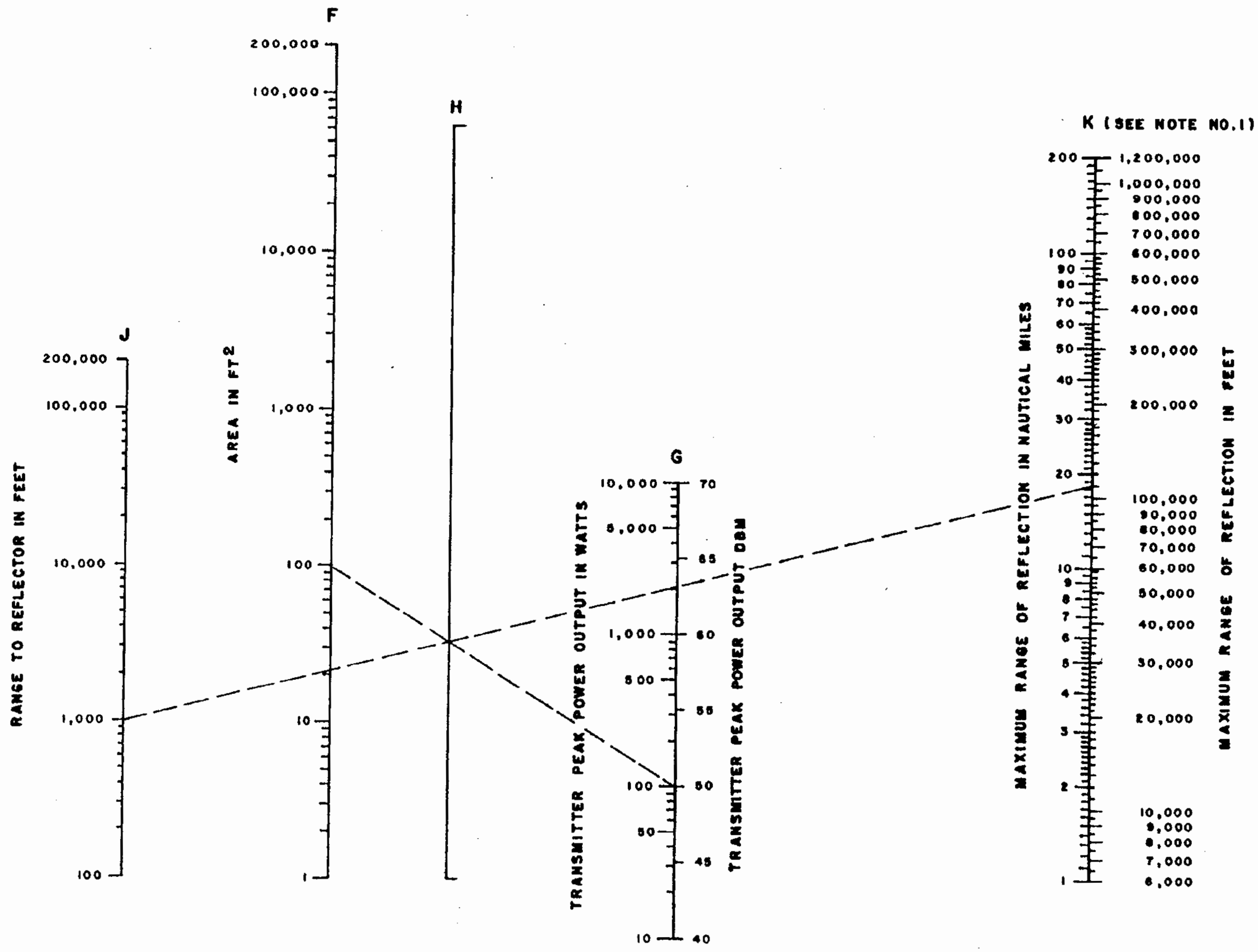
SOLUTION :

1. LAY STRAIGHT EDGE BETWEEN POINT ON "F" SCALE EQUAL TO RESULT OF STEP NO.2 OR NO.3 OF FIG.2-48A, AND A POINT ON THE "G" SCALE RELATING TO TRANSMITTER PEAK POWER, THUS LOCATING AN INTERSECTING POINT ON THE DIMENSIONLESS "H" SCALE.
2. PIVOT THE STRAIGHT EDGE AROUND THAT POINT ON THE "H" SCALE TO INTERSECT A POINT ON THE "J" SCALE CORRESPONDING TO RANGE FROM THE TRANSMITTER TO THE REFLECTOR. THE RESULTING INTERSECTION WITH THE "K" SCALE YIELDS THE MAXIMUM RANGE OF THE REFLECTION.

NOTES

1. MAXIMUM RANGE OF REFLECTION FOR AIRCRAFT TRANSPONDER WITH A MINIMUM TRIGGERING LEVEL OF - 74 dBm
2. ASSUMED VALUES FOR ANTENNA GAINS AND SYSTEM LOSSES ARE :

G_i = 22.5 dbir
G_t = 2 db
L_s = 5.5 db (Transmission Line Losses)



$$S_{min} = \frac{P_d \; G_i \; G_t \; A_{eff}^2}{(4\pi R_1 R_2)^2 \; L_s} \qquad (2\text{-}49)$$

where

P_d = ATCBI peak power output

G_i = interrogator antenna gain

G_t = transponder antenna gain

R_1 = range between reflector and target

R_2 = range between antenna and reflector

L_s = system losses, and

S_{min} = transponder minimum sensitivity

in consistent units. Rearranging gives

$$R_1 = \sqrt{\frac{P_d \; G_i \; G_t \; A_{eff}^2}{(4\pi \; R_2)^2 \; S_{min} L_s}} \qquad (2\text{-}50)$$

(g) Equation 2-50 may be conveniently solved for R_1 under the conditions

S_{min} = -74 dBm

L_s = 5.5 dB (see reference 8)

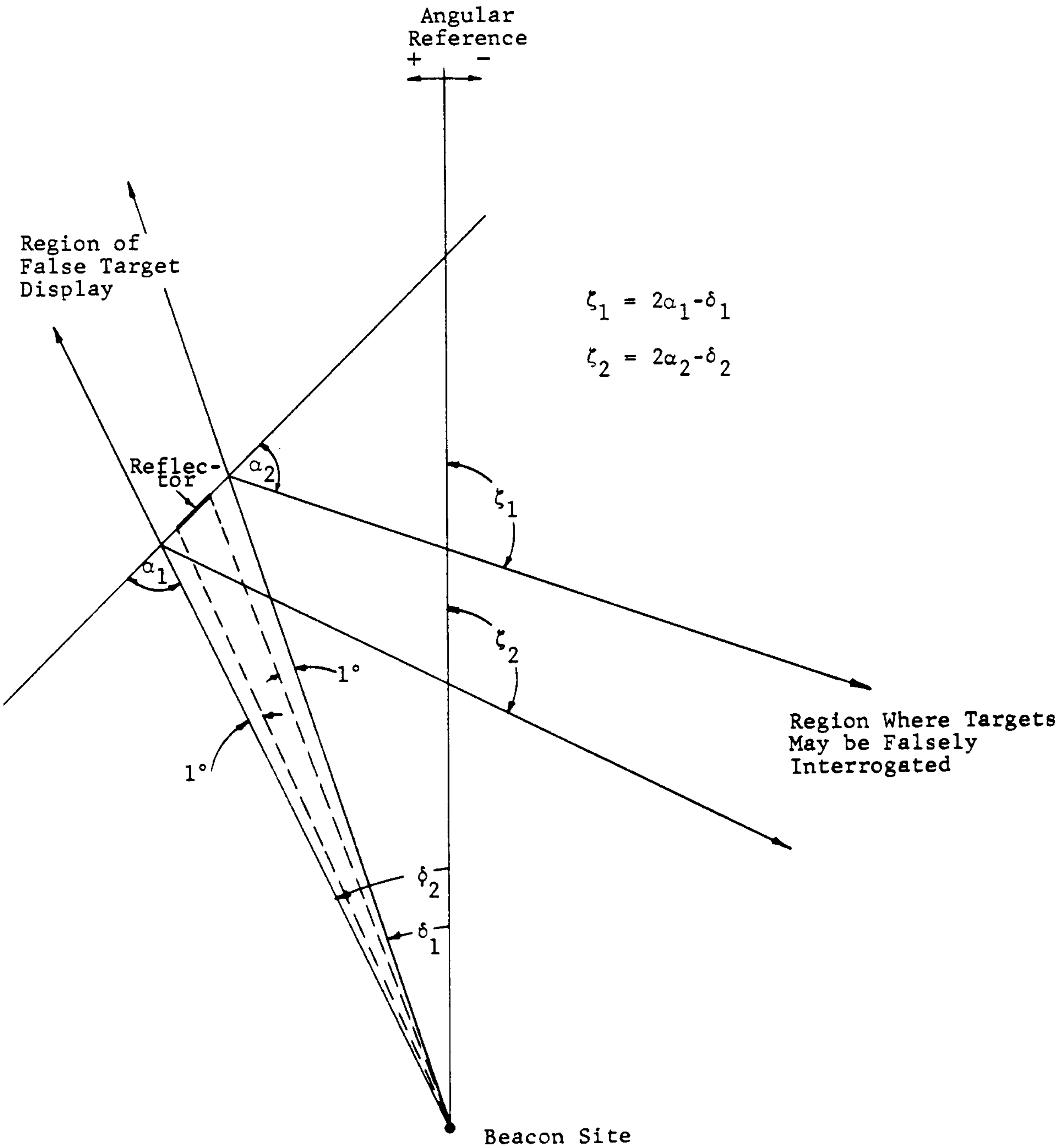
G_i = 22.5 dBir

G_t = 2 dBir

with the aid of the nomograph in figure 2-48b. A brief examination of the nomograph indicates that for transmitter power on the order of 200 watts, reflectors of 300 square feet effective area within 1,000 feet of the interrogator can cause false targets to appear at any range within the 60 nmi region of interest to a terminal ATCBI installation. With a transmitter power of only 50 watts, the same reflector can cause false targets to appear at any range out to 30 nmi.

(h) The angular extent of the sectors affected by false targets is defined in figure 2-49. The incident rays

FIGURE 2-49. BEACON FALSE-TARGET ANGULAR GEOMETRY



are set 1° beyond the edges of the reflectors to account for scanning of the antenna beam across the reflecting surface. False targets are displayed at azimuth angles between δ_2 and δ_1. These occur due to targets in the angular sector between ζ_2 and ζ_1. The false targets are displayed at ranges corresponding to $R_1 + R_2$.

(i) Some of the characteristics of beacon false targets which are important in differentiating them from second-time-around returns, near synchronous fruit, etc., are:

1. The false target and the normal replies will generally appear in pairs. There is an exception to this, however, if the aircraft is in a screened region for direct interrogation, but can be interrogated via a reflected path.

2. The range of the reflection will, at all times, be greater than the ranges of the normal reply. If the range of the normal reply is increasing or decreasing, the same change in range will apply to the reflection.

3. The rotational direction of the normal and reflected replies are reversed. If the normal reply is received from an aircraft that is flying a clockwise orbital course, the reflected replies from the same reflection would follow a counterclockwise orbital course.

(j) Because of the importance to air traffic control operations, all terminal siting analyses should include an assessment of the locations where beacon false targets may be expected to determine the impact of overall ATC operations. Metal buildings or building roofs, water towers, fences, parked aircraft, etc., within 1 mile of the radar site should be considered as primary potential sources of reflected false targets. Large reflecting surfaces at even greater distances may also cause difficulties as can be seen from figures 2-48a and b.

(2) Radar False and Unwanted Targets.

(a) False targets may be generated in ASR equipment by much the same reflection mechanism as described above. These will occur in the same areas as beacon false targets, but will generally be less severe in effect. As a consequence, it is usually acceptable to ignore reflected radar false target effects in favor of a careful consideration of beacon false targets.

(b) Of more serious concern are unwanted radar targets caused by the detection of moving targets other than aircraft. These include automobiles, railroad trains, birds, etc. This occurs since the undesired targets are of sufficient size that they can be detected, and since their velocity is outside the radar's mti rejection region. Some reduction in the detection of unwanted echoes may be achieved through the proper use of radar's stc or css capabilities, but efforts should be made to minimize this problem at the time of site selection. To do this, sites should be selected which provide natural shielding of the nearby highways and railroad lines. Where this is impossible, landscaping or other artificial means to provide the necessary screening should be considered. In addition, selection of sites where visible vehicular or rail traffic travels along a radar tangential path will minimize the false targets produced.

f. Tangential Course Problems.

(1) The ASR mti receiver operates to reduce the appearance of stationary targets (clutter) on the radar ppi display. This is commonly done, as described in chapter 1, by using canceler networks with response characteristics dependent upon the observed target Doppler frequency. These networks are arranged to have near-zero response for Doppler frequencies approaching zero.

(2) Doppler frequency is related to target velocity by the expression:

$$f_d = \frac{2v_r}{\lambda} \tag{2-51}$$

where

v_r = target radial velocity component with respect to radar

λ = wavelength

(3) From equation 2-51 above, it can be seen that even moving targets may be invisible to an mti radar if their direction of flight causes the radial component of their velocity to approach zero. This occurs as the target flight path becomes tangential to circles drawn about the ASR site.

(4) As a consequence, ASR site selection should include careful examination of airways which carry traffic on tangential flight paths for the potential loss of radar coverage. Loss

of coverage is said to occur whenever signal dropout causes missed detection for a period of three (or more) consecutive radar scans. Remembering that coverage loss due to tangential courses is a problem which affects only the radar's mti receiver, consideration can probably be limited in most cases to a region within 10 or 15 nmi of the radar site. Beyond this range, clutter is usually not a factor and the normal or log radar receiver is employed. Exceptions occur where mountains or other terrain features cause clutter, and hence mti usage, to extend to greater ranges.

(5) Using the above criterion, the critical dropout time may be taken as

$$T_D = \frac{120}{w_r} \tag{2-52}$$

where

T_D = critical dropout time (sec)

w_r = radar scan rate (rpm)

(6) Using the parameters given in table 1-1,

$$T_D = 8 \text{ sec} \quad \text{(ASR-4B, 5, 6)} \tag{2-52a}$$

$$T_D = 9.4 \text{ sec (ASR-7)} \tag{2-52b}$$

$$T_D = 9.6 \text{ sec (ASR-8)} \tag{2-52c}$$

(7) Considering now the tangential path geometry of figure 2-50, the maximum length, L_{dm}, of the dropout region (centered on tangency point) is

$$L_{dm} = 2d \operatorname{Tan} \alpha$$

and

$$\sin \alpha = \frac{v_{rm}}{v_g}$$

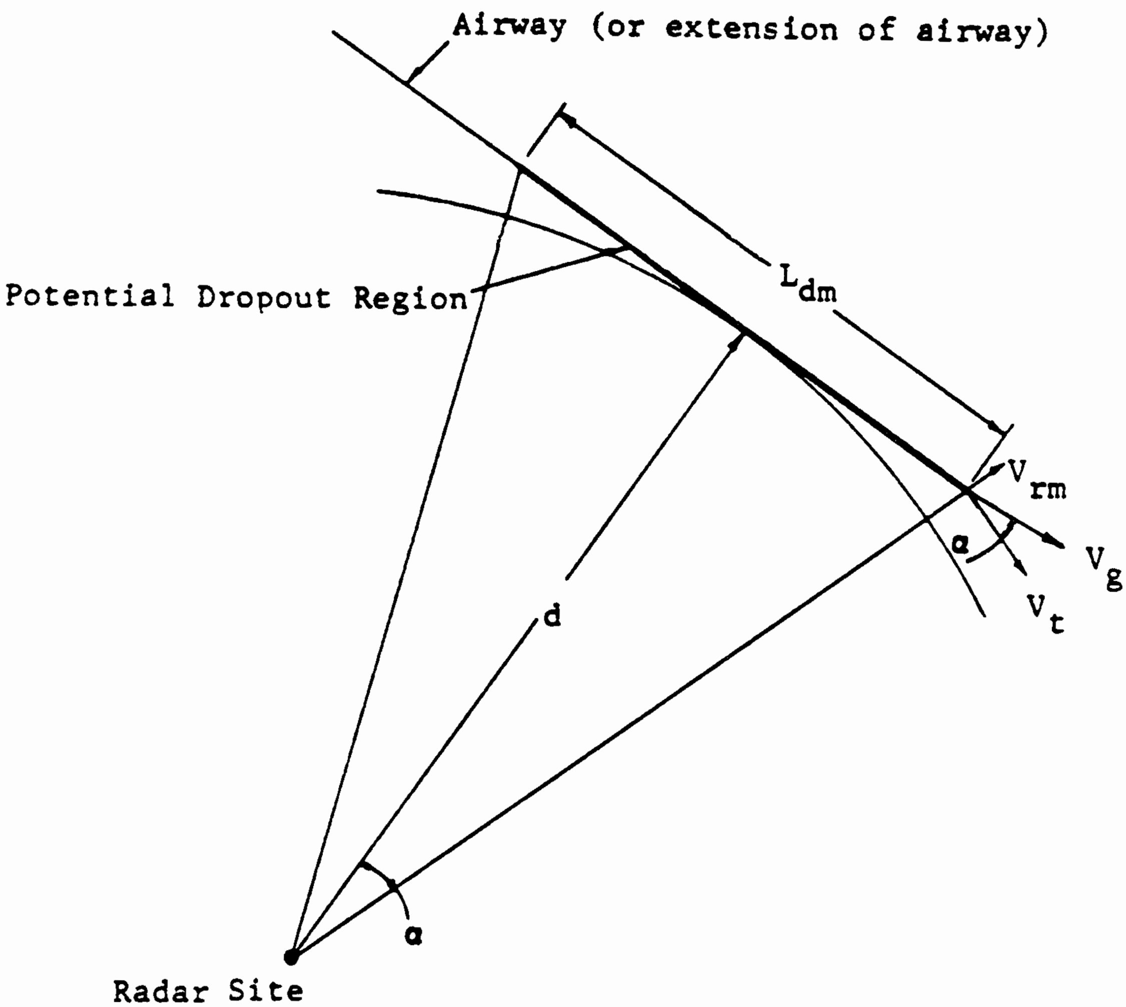
(8) This gives

$$L_{dm} = 2d \operatorname{Tan} \left[\sin^{-1} \left(\frac{v_{rm}}{v_g} \right) \right] \tag{2-53}$$

where

d = distance from site to airway (or its extension) at the point of tangency

FIGURE 2-50. TANGENTIAL PATH GEOMETRY



d = Distance from Site to Airway at Tangent Point

L_{dm} = Maximum Distance of Coverage Dropout

V_{rm} = Minimum Radial Velocity Detectable by MTI

V_g = Target Ground Speed

V_t = Target Tangential Velocity

* α = One-Half the Maximum Angular Extent of Dropout Region *

v_{rm} = minimum radial velocity detectable by mti

v_g = target ground speed

(9) Of the parameters in the above equations, only v_{rm} is not dependent upon the path geometry. This minimum detectable radial velocity is dependent upon several factors including: (a) the basic mti canceler response, (b) the particular form of velocity shaping employed, and (c) the radar prf jitter characteristics, and hence is not readily specified with accuracy at the time of siting. It is probably sufficient, however, for preliminary analyses, to assume a minimum detectable radial velocity of 20 knots. (This is based on assuming target visibility begins where response is better than -6 dB with respect to the maximum response of a double delay-line mti canceler, with the first blind speed at 120 knots.) Using this value, and the values of d and v_g for the particular airway being examined, L_{dm} can be readily determined from equation 2-53. This is solved graphically in figure 2-51.

(10) As may be seen from figure 2-50, L_{dm} is centered on the point of tangency between the airway, or its extension, and a circle about the ASR site. The distance, L_d, of ACTUAL dropout corresponds to the region of overlap between the airway plan, and L_{dm}. This is illustrated in figure 2-52. As is readily apparent, L_d may be considerably less than L_{dm}.

(11) For each airway where coverage dropout is possible, the distance L_{dm} can be determined from figure 2-51. Map study of the local air routes will then allow the actual dropout region, and L_d, to be determined. Once known, L_d may be used together with the aircraft velocity to determine the duration, T_d, of coverage dropout. This is given by

$$T_d = 3600 \frac{L_d}{v_g} \qquad (2\text{-}54)$$

where

T_d is in seconds

L_d is in nautical miles

v_g is in knots

(12) This is plotted in figure 2-53. Tolerable coverage dropout will be experienced where the value of T_d so determined is less than T_D as derived from equation 2-52 (p. 149). Further

Figure 2-51. MAXIMUM COVERAGE DROPOUT CAUSED BY TANGENTIAL TARGETS

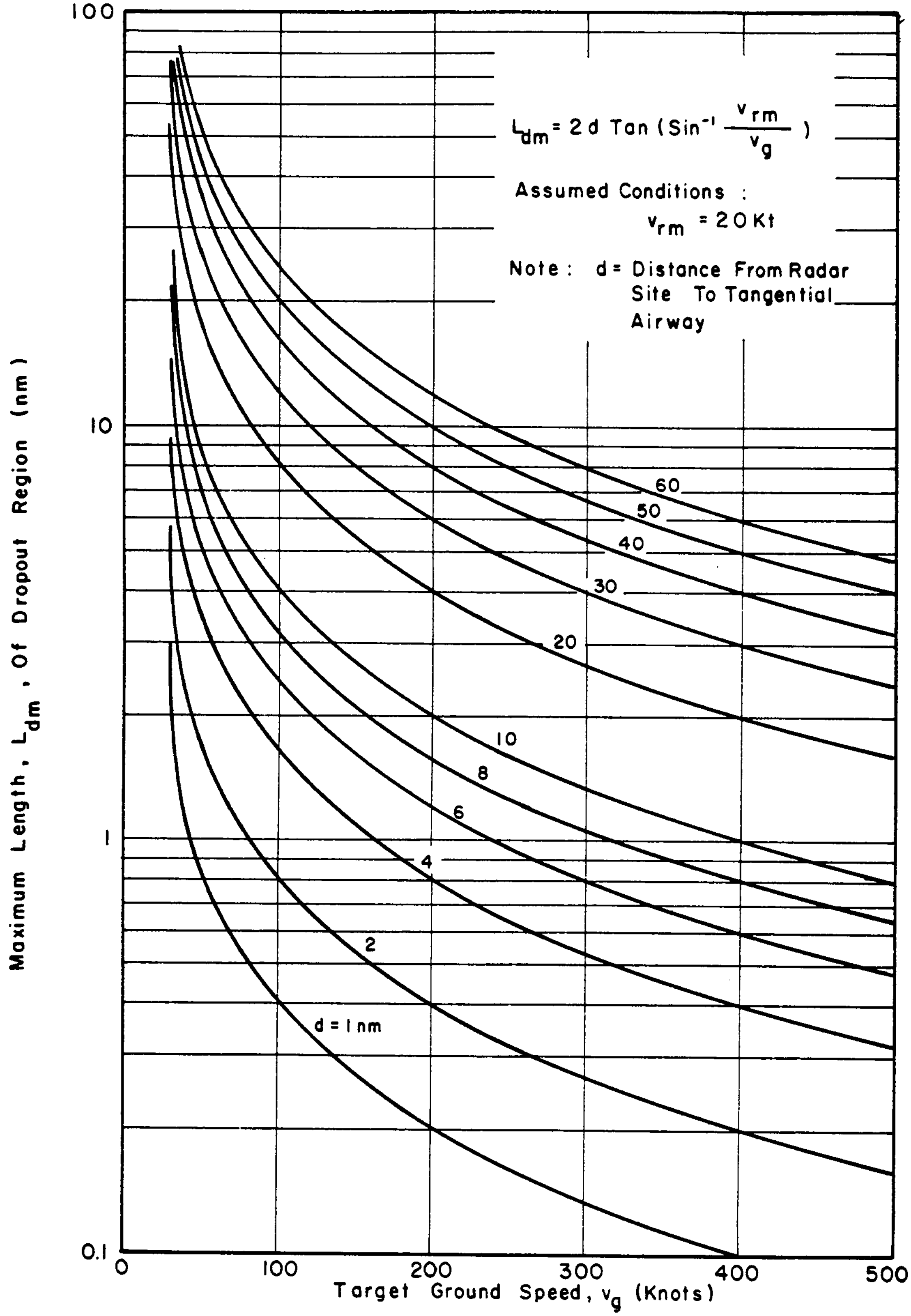
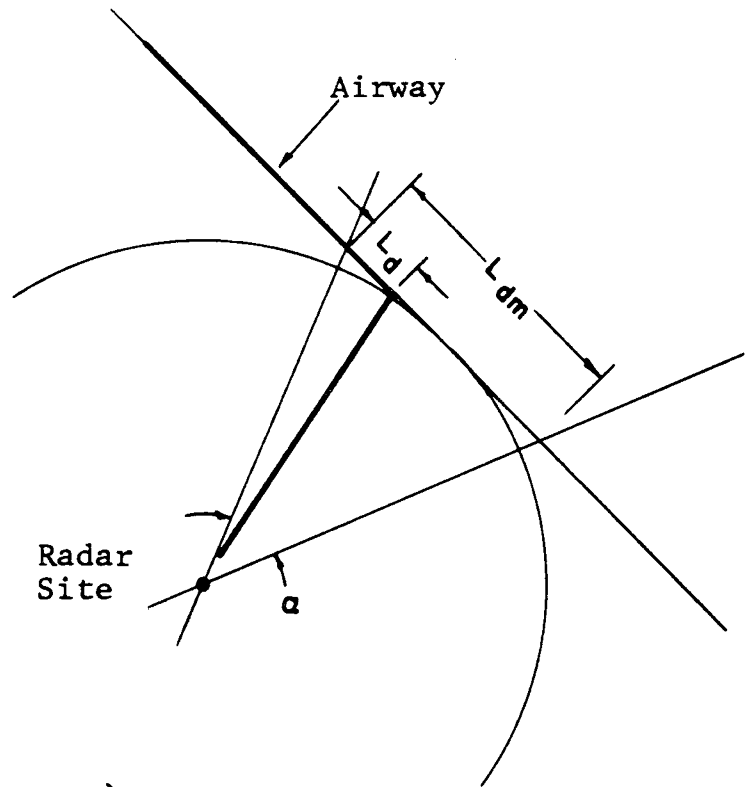
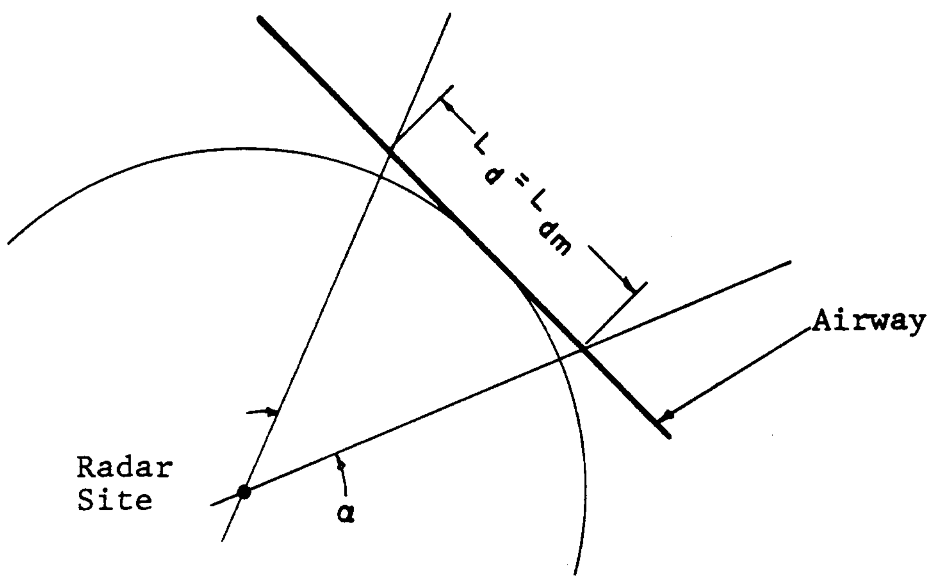


FIGURE 2-52. COVERAGE DROPOUT REGION

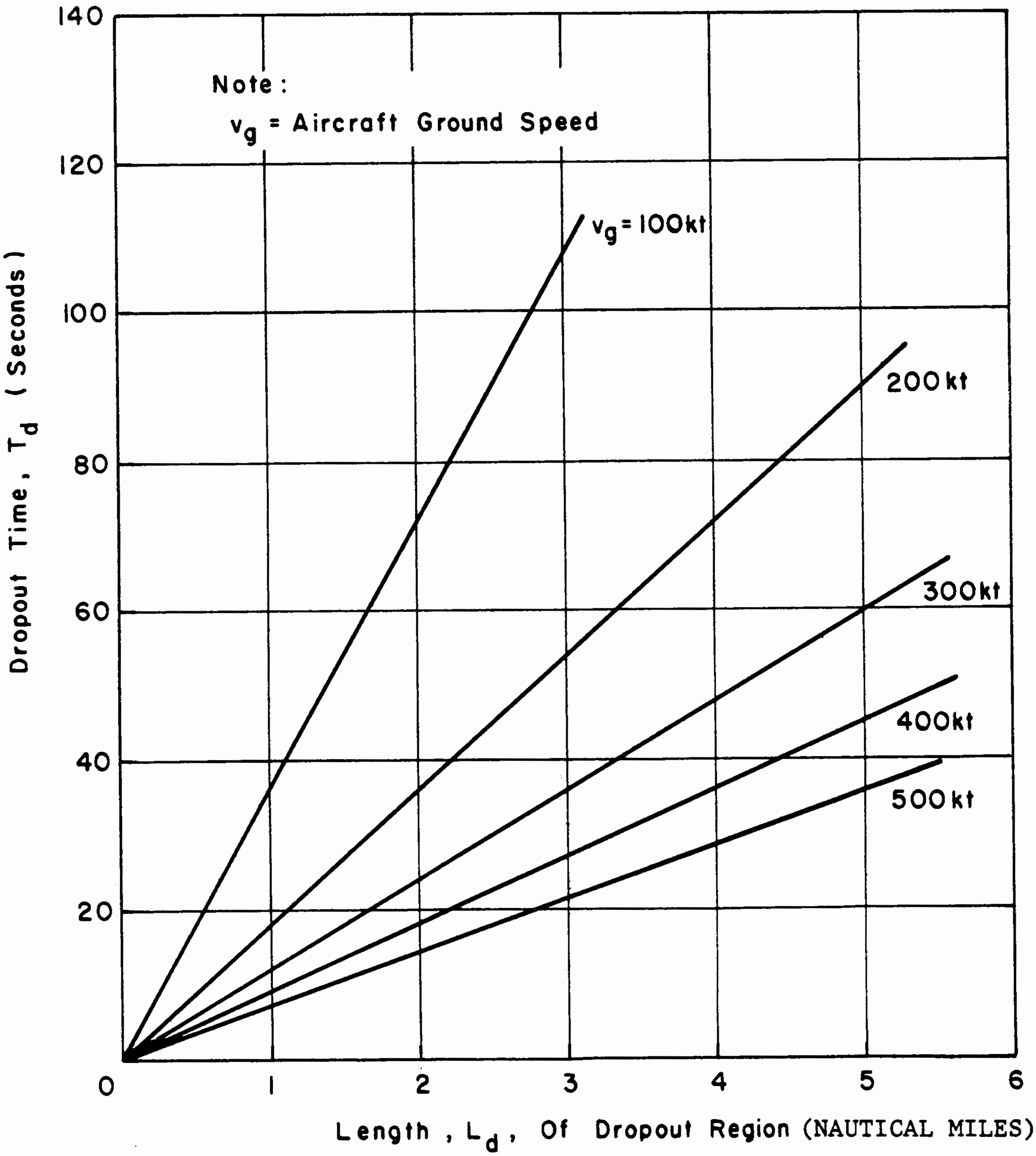


a) $L_d < L_{dm}$



b) $L_d = L_{dm}$

Figure 2-53. TIME VS. DISTANCE FOR COVERAGE DROPOUT



consideration of a site where $T_d \geq T_D$, for any airway within the (usually 10 or 15 nmi) range region of mti receiver usage, should be given only after coordination with Air Traffic and Flight Standards Division representatives.

23. SOURCES/CAUSES OF DEGRADED PERFORMANCE.

a. Introduction. Radar performance is materially affected by the environment, and therefore the geographic location, in which it operates. The two most important factors which influence radar/beacon coverage are the earth's surface and its atmosphere.

(1) The earth's surface or terrain in the vicinity of the radar/beacon antenna can alter the free-space radiation pattern as well as produce unwanted signal returns. The extent of these earth-surface effects depend on the effective antenna height, surface roughness, terrain features, and the presence of natural or manmade obstacles about the site. The specific character of these surface related parameters determines the radar/beacon coverage obtainable by virtue of the screening, lobing, false targets, and/or clutter they produce.

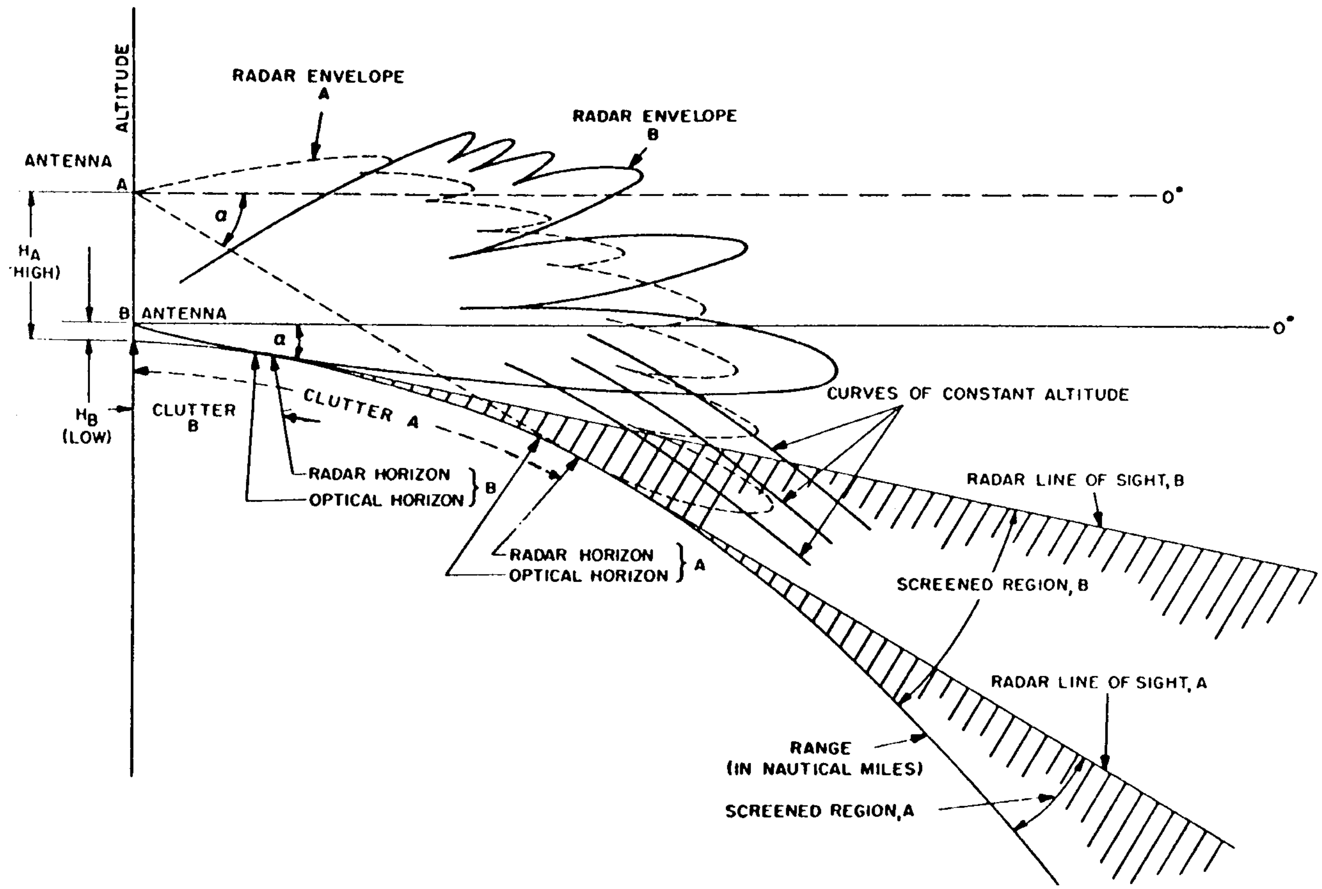
(2) The earth's atmosphere within the geographical region of the site can also affect radar/beacon performance by (1) refraction caused by an inhomogeneous atmosphere, (2) attenuation due to severe weather conditions, and/or (3) chemical damage to the components of the radar/beacon system from corrosive agents (or contaminants) in the atmosphere. These sources of system performance degradation are discussed below.

b. Site Elevation and Surface Roughness.

(1) The effect of site elevation on the radiation pattern and coverage of the radar/beacon antenna may be seen in figure 2-54. A comparison of radiation patterns between the high-sited and low-sited antenna in the figure shows that the high-sited antenna has the greater low-angle coverage. However, the extent of clutter (signal return from nearby land and sea surfaces) is increased for high-sited radars and the high-altitude coverage is correspondingly decreased.

(2) The effective height of an antenna is a significant factor in calculating the effect of the earth on the radiation pattern. It may or may not correspond to the site elevation. The effective height of an antenna--with the earth regarded as a smooth reflector--is its height above the local terrain or reflecting surface. Effective height can vary as the antenna rotates. This is especially true of a coastal cliff-sited antenna; its effective height is equal to its elevation on an over-water azimuth, but is much less when the antenna looks inland.

FIGURE 2-54. COMPARISON BETWEEN HIGH-SITED, LOW-SITED RADAR/BEACON



(3) The factor of effective antenna height has added significance where reflections from the earth's surface materially affect the structure of the radiation pattern. Where the earth is smooth, relative to radar wavelength, ground reflections of the radar beam occur. Where the earth is rough, diffuse reflection (scattering) of the radar beam results, the radiation pattern is much less affected by ground reflection, and the factor of effective antenna height has reduced significance.

(4) Ground reflection occurs when the beam radiated from the antenna strikes the surface of the earth and bounces upward. The vertical coverage of a radar can vary greatly because of ground reflections, as the reflected wave may arrive at the target in a manner that will either aid or oppose the direct wave. This effect of subtraction and addition between the reflected wave and the direct wave creates a vertical pattern of nulls and lobes as illustrated in figure 2-54. Lobing effects are discussed quantitatively in detail in paragraph 22b. With low-sited antennas in smooth terrain terminal areas, beacon lobing null angles frequently occur which approach the glide slope angles for descending aircraft and may seriously compromise ATCBI coverage.

(5) In general, the selection of high versus low antenna elevations requires a tradeoff between the various performance degrading effects to achieve optimum coverage. An ideal antenna height will keep lobing null angles below glide slope paths while minimizing the clutter area and permitting adequate high and low altitude coverage.

c. Terrain Types. In general, radar sites are divided into three geographic categories: coastal, flat-earth, and mountainous. Since the terrain varies considerably with locality, a discussion of each category is included as background information for guidance in specific site selection.

(1) Coastal Sites.

(a) When the area of primary search overlooks the sea, the site should be located to obtain a wide, unobstructed panorama of the sea. Low-angle, long-range coverage is best obtained with the antenna site at the highest practical elevation.

(b) Lowering the height of the antenna raises the radar los and results in a reduction in range coverage at the lower altitudes. Therefore, if the detection of target aircraft at low angles is a criterion in meeting operational requirements, the sacrifice in low-angle coverage that results from decreasing the antenna height must be carefully considered.

(c) The extent of sea clutter can be expected to diminish with decreased radar horizon distance as the elevation of the antenna is decreased. For the case of a radar sited relatively low over the sea, the problem is one of intensity of clutter rather than of extent of clutter relative to the maximum range of the radar.

(d) The radiation pattern for a lower antenna height (see paragraph 22b), is characterized by fewer lobes at higher elevation angles and greater spacing between the lobes. The consequent reduction in low-angle coverage is in addition to that imposed by changing the radar los. The reduction of low-angle coverage and the greater gaps in vertical coverage are perhaps the most important characteristics of the low-sited coastal radar.

(e) Radar range, as well as the extent of sea clutter, varies somewhat with the condition of the sea. When the sea is smooth, clutter is reduced and the vertical radiation pattern is characterized, in general, by a large number of closely spaced lobes in the pattern. As an approximation, the number of lobes will be equal to the number of half wavelengths contained in the height of the antenna above the sea. Some extension of the radar range can be expected as a result of lobing. This may be offset, however, by loss of tracking ability associated with the gaps of the interference pattern. Under conditions of a disturbed sea, it may be expected that the clutter will increase in extent and intensity, and that the radiation pattern will tend toward the free-space condition because of the effect of scattering. As a result, radar coverage or tracking beyond the range of clutter may be expected to be more "solid"; however, because of the great intensity of the sea return, tracking within the range of clutter may be greatly diminished.

(f) An estimate of the extent of the sea return can be made by assuming various antenna elevations and by calculating the corresponding distances to the radar horizon. Under conditions of a disturbed sea, the sea return will tend to extend to the radar horizon. Tracking at ranges less than the horizon distance may be largely handicapped by sea clutter.

(g) If there is a choice between a site overlooking the open sea and one overlooking a large expanse of relatively protected water of comparable azimuth extent, the latter is to be preferred. This is because of the reduced sea clutter and, to some extent, the more nearly stable effect on the radiation pattern. The guiding factors, in any case, should be: (a) maximum unobstructed azimuthal coverage, and (b) sufficient antenna height for operational coverage of low altitude fixes.

(2) Overland Sites.

(a) In overland azimuth sectors of search, particularly over rough terrain, ground clutter can be extensive up to the radar horizon.

(b) In addition, permanent echo returns from terrain features located beyond the radar horizon may be visible on the radar indicator because of their height and large reflecting areas. The primary difference, then, between a site overlooking the sea and one overlooking land, is the extent and intensity of the clutter. Land search imposes more severe clutter limitations on a given radar. Again, the height of the antenna above the ground will have to be a compromise between the maximum useful range of a radar, for a given target aircraft, at medium or low altitudes and the amount of ground clutter that can reasonably be tolerated.

(c) Flat Earth Sites.

1. In situations where the terrain in a general locality of a proposed radar site is relatively flat, particular regard should be given to: (1) the distant horizon should be visible from the antenna location over as great an azimuth sector as possible, particularly in the azimuth sector of interest for minimum screening; and (2) the ground in the vicinity of the antenna should be thoroughly rough, with trees, undergrowth, small buildings, and such obstructions that will break up reflections of the radar beam. (Care should be taken that this roughness does not increase clutter or permanent echoes unduly.)

2. In heavily forested regions, or in the presence of natural/manmade obstructions to visibility, the radar antenna should be tower-mounted at a height sufficient to clear the obstructions and permit visibility of the distant horizon.

3. Clutter may be reduced to some extent by adjusting the antenna tilt, by using mti devices, or by incorporating an allowable amount of local screening.

4. The first two clutter control measures are associated with the radar equipment. In the latter method, the screening obstacle may be a ridge, a succession of ridges, or a series of hills in the vicinity of the site.

5. The location of the antenna, with respect to the screening obstacle, should be such that the clutter is reduced to allowable limits and that the elevation of the line-of-sight does not exceed operational limits. In an idealized case, the location of a radar antenna would be at the center of a large, shallow, saucer-shaped depression. The clutter would then be limited largely to the periphery of the depression. However, such depressions are not commonly found. The same effect can be created by trees or other types of vegetation completely surrounding the site. Nonreflective manmade objects may serve a similar purpose.

(d) Mountain Sites.

1. In mountainous regions the location of a search-radar antenna is determined, as a general rule, by the amount of screening that may be tolerated from adjacent mountain ranges or ridges, the extent and intensity of the clutter and permanent echo return, the accessibility of the site, and the economic limitations and special problems imposed by the topography of a locality. With the relatively high elevation of an antenna site located on a mountain top, the problem of clutter is correspondingly greater.

2. The principal factors to be considered in selecting a mountain location are: (1) the elevation of the tentative site in relation to that of adjacent screening terrain, (2) the distance between the site and the screening terrain, and (3) the range of performance capability of the radar compared with the clutter.

3. The first two factors combine to determine the angular elevation of the los or screening angle. They should be such as to yield a maximum depression of the los in the azimuth sectors of

primary operational interest. The second, screen distance, affords an estimate of the extent of clutter to be expected--clutter generally extends to the visible sky line. The choice of a mountain-top location as a radar site thus involves a compromise between screening and clutter limitations and radar performance capability.

4. Mountain-top sites often introduce special problems of access, installation, operation, and maintenance. These concern access road construction; protection against wind, snow, and ice; and the availability of water and local fuel. These are items of particular interest to the construction engineers in a siting party. They are items, too, whose costs may rule out the use of otherwise desirable sites.

(e) Urban Sites.

1. Urban areas present widely varying conditions which can affect radar and beacon performance. Such sites are typified by variable skyline and surface conditions, and increased problems due to structures, vehicular traffic, rfi, and atmospheric contaminants. Frequently, cost related factors are decisive in selecting site locations in urban areas. Land availability and the cost thereof, will in many cases severely limit the number of potentially acceptable site locations.

2. Once potential site locations are determined, selection should give special attention to screening and reflections due to structures, interference, potentially corrosive atmospheric pollutants, and clutter. Screening, clutter, and reflection problems can be examined with the aid of techniques presented in paragraphs 22a, c, and e. Interference and corrosion considerations are discussed in subsequent subparagraphs.

3. For typical housing developments and established urban communities, the compact arrangement of homes usually presents a surface of closely spaced rooftops interspersed with tree foliage. This type of reflecting surface, being highly irregular, will in general "break up" the impinging ASR and beacon radiation to the extent that little lobing can be expected. However,

ASR clutter will increase in the azimuth sector and range over which this surface extends. Nevertheless, with use of mti and stc clutter reduction techniques, antenna heights and tilt angles can usually be found which afford an effective compromise between this type of clutter and the low-altitude coverage desired.

4. Highways, streets, or roads located near a site under consideration should be noted particularly when the road surface will be directly illuminated by the ASR and beacon. If the course of the thoroughfare is along a radial of the scanning ASR or beacon interrogator, localized vertical lobing can be expected. Furthermore, moving vehicular traffic along a highway, road, or railroad will generate moving target indications on the ppi.

5. Because of the constant construction and renewal activities in and around urban areas, it is advisable to contact municipal officials to identify any planned construction in the vicinity of the site being considered which could degrade and/or compromise radar and/or beacon performance.

d. Anomalous Propagation.

(1) Electromagnetic waves propagating through the earth's atmosphere do not travel in straight lines, but are curved. This curvature is caused by the variation with altitude of the velocity of propagation, or the index of refraction, defined as the ratio of velocity of propagation in free space to that in the medium in question. For a standard atmosphere, the index of refraction decreases with altitude, causing the radar waves to bend downward. At times, however, changes in the standard conditions of the atmosphere brought about by moving air masses, rain, fog, temperature inversions, etc., can cause changes in the nominal index of refraction. When this occurs, abnormal propagation results where radar waves are bent either further downward, or in some cases, upward. This departure from the normal bending of the radar wave is called anomalous propagation.

(2) The term anomalous progagation includes both superrefraction and subrefraction. Superrefraction results in an extreme downward bending of the radar waves and permits ground and near surface targets to be seen considerably beyond the normal radar horizon. The energy is propagated in a region called a duct which usually

lies at or near the earth's surface. A duct is produced when the index of refraction decreases with altitude at a rapid rate.

(3) Upward curvature of the radar waves occur when the refraction index increases with increasing altitude. This is called subrefraction and leads to a decrease in radar range as compared with standard conditions. At ASR and beacon frequencies, the index of refraction, n, for air which contains water vapor is (from reference 11)

$$n = 1 + \frac{77.6p \times 10^{-6}}{T} + \frac{0.373e}{T^2} \qquad (2\text{-}55)$$

where

p = barometric pressure in millibars (1 mm Hg = 1.3332 millibars)

e = partial pressure of water vapor in millibars

T = absolute temperature, °K.

(4) The barometric pressure, p, and the water vapor content, e, decrease rapidly with altitude, while the temperature, T, decreases slowly. Hence, the index of refraction normally decreases with increasing altitude. A typical value of the index of refraction near the surface of the earth is 1.0003, and in a standard atmosphere it decreases at the rate of about 13.1×10^{-8} per foot of altitude.

(5) The atmospheric conditions that can produce anomalous propagation are those where the pressure, temperature, and water vapor content gradients depart drastically from that of a standard atmosphere. As stated earlier, to produce a duct, the index of refraction must decrease with altitude at a rapid rate (i.e., faster than normal). This can occur when (1) the temperature increases, and/or (2) the humidity (water vapor content) decreases abnormally with altitude. An increase of temperature with altitude is called a temperature inversion and occurs when the temperature of the sea or land surface is appreciably less than that of the air. A temperature inversion, by itself, must be very pronounced to produce ducting. Water-vapor gradients are more effective than temperature gradients alone. Thus, superrefraction is usually more prominent over oceans, especially in warm climates.

(6) In general, superrefraction will occur when the air is exceptionally warm and dry in comparison with the air at the surface. Some of the more familiar causes of these conditions are as follows:

(a) Over land masses, superrefraction is most noticeable on clear summer nights, especially when the ground is warm and moist. This leads to a temperature inversion at the ground and a sharp decrease in humidity with altitude. Such ducting will usually disappear during the warmest part of the day.

(b) Movement of large masses of warm dry air, from land, over cooler bodies of water produces temperature inversion. At the same time, moisture is added from the water to produce a moisture gradient. The resulting ducting tends to be more prominent on the leeward side of land masses and can last for long periods of time.

(c) Ground ducts can be produced by the diverging downdraft under a thunderstorm that causes a temperature inversion and a decreasing moisture gradient over the lowest few thousand feet of altitude.

(7) In temperate climates, superrefraction is more common in summer than in winter. It does not occur when the atmosphere is well mixed, a condition generally accompanying poor weather. When it is cold, rough, stormy, rainy, or cloudy, the lower atmosphere is well stirred up and propagation is likely to be normal. Both rough terrain and high wind tend to increase the atmospheric mixing, consequently reducing the occurrence of ducting.

(8) Atmospheric ducts are generally of the order of several tens of feet high, never more than perhaps 500 or 600 feet. They are primarily limited to low angles of elevation, rarely affecting radar/beacon coverage at angles above 1.0 to 1.5°. In general, low-sited radars are more susceptible to ducting than high-sited ones.

(9) The chief effect of ducting is to extend the surface coverage of the radar/beacon, while at the same time creating a large hole of poor coverage in the airspace above the extended surface coverage. In the case of the ASR, this can be troublesome. Most of the long-range, low-altitude coverage will include clutter, making detection of aircraft more difficult. Also, the extended ranges within the duct may result in ambiguities and confusion because of interference of second-time-around echoes.

(10) Furthermore, superrefraction is a phenomenon that cannot be depended upon. Its presence and magnitude are determined by meteorological conditions over which there is no control.

(11) Subrefraction phenomena occur less frequently than ducting. In certain cases, fog can lead to substandard propagation or subrefraction. Fog forms when the water in the air changes from the gaseous to the liquid state, but the total water content remains unchanged. The effect of water in the liquid form on the index of refraction is negligible compared to the water vapor content (see equation 2-55, p. 163). Therefore, the formation of fog near the surface results in a reduction in the water vapor contributing to the index of refraction at the surface. All other factors being equal, the net result is that the water vapor content increases with altitude causing the index of refraction to increase with altitude. It should be pointed out that although fog can cause subrefraction, the presence of fog is neither a necessary nor a sufficient condition for its occurrence.

(12) Since the meteorological conditions that support anomalous propagation will in general extend throughout and beyond the terminal airspace of interest, the options for reducing its effect by selective siting are limited. As stated earlier, low-sited radar/beacon systems are more susceptible to the effects of ducting than high-sited ones. This can sometimes be beneficial against potential ducting at coastal sites where the effective antenna height above the sea is 500 feet or more. Shielding or screening is another option. However, this is limited by the amount of low-altitude coverage that can be sacrificed within the airspace.

(13) Although the siting options with respect to anomalous propagation are limited, it is nevertheless important that the siting engineer understand and recognize the causes and effects of anomalous propagation. Efforts should be made to collect the climatological data necessary to predict its occurrence and estimate its effect on ASR/beacon performance, so that when the condition occurs it will be recognized and the radar/beacon output properly interpreted.

e. Weather.

(1) Although one of radar's specific benefits is the ability to penetrate fog, rain, snow, etc., these weather conditions do have degrading effects upon system performance. Of these effects, the most important are

(1) reduction in radar sensitivity due to absorption and/or scattering of energy, and (2) masking or confusion of legitimate targets due to the display of echoes from the weather itself. Overall performance degradation is generally more pronounced for rain than for other possible weather conditions, and is frequency dependent. It may be neglected at ATCRBS frequencies, but must be taken into account when evaluating ASR system coverage capability. At the S-band frequency of ASR equipment, rain attenuation and rain backscatter may be determined from data in reference 10. This is summarized here for convenience in figure 2-55 and table 2-5.

* (2) If rain is widespread in the area, it may fill a radar resolution cell. Since the volume, v_r, of a cell is given by *

$$v_r = R^2 \theta_a \theta_e \frac{c\tau}{2} \quad (2\text{-}56)$$

where

R = range

θ_a = antenna azimuth beamwidth

θ_e = antenna elevation beamwidth

τ = pulse duration

c = velocity of light

(3) The resolution cell volume at R = 50 nmi is given by

$v_r = 2.48 \times 10^9$ meters^3 (ASR-4B, 5, 6, and 7)

$v_r = 1.76 \times 10^9$ meters^3 (ASR-8)

(4) Referring to table 2-5, it can be seen that for very heavy rain, precipitation echo cross sections up to 546 square meters can develop for the ASR-4B, 5, 6, and 7. This is much larger than that of any competing target aircraft.

(5) Successful detection of desired targets under severe rain conditions therefore requires rejection of precipitation echoes. This is done in ASR systems primarily by a switch to cp operation. There are two types of cp, distinguished by the direction of rotation of the electric vector as viewed by an observer looking in the

Figure 2-55 RAIN ATTENUATION

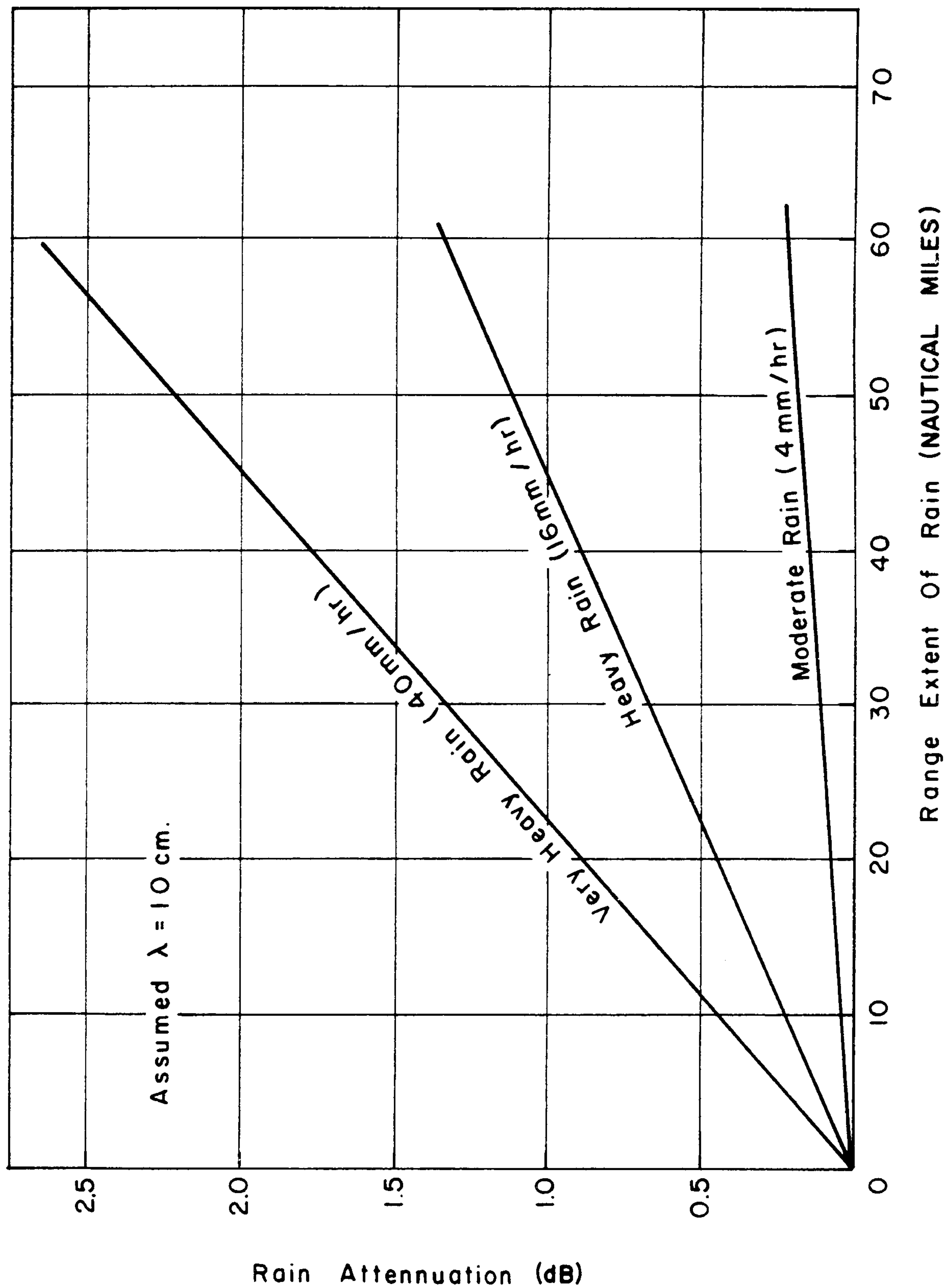


TABLE 2-5

RAIN BACKSCATTER [1]

Weather Condition	Rain Backscatter Cross Section Per Unit Vol. m^2/m^3
Light Rain (1 mm/hr)	6×10^{-10}
Moderate Rain (4 mm/hr)	6×10^{-9}
Heavy Rain (16 mm/hr)	5×10^{-8}
Very Heavy Rain (40 mm/hr)	2.2×10^{-7}

[1] Data derived from reference 11

direction of propagation. A clockwise rotating electric field vector is known as right-hand cp, while a counter-clockwise rotation is known as left-hand cp. If the radar radiates one sense of circular polarized energy, it cannot accept the backscattered echo signal from a target such as a sphere since the sense of polarization is reversed on reflection. That is, if right-hand cp is transmitted, spherical raindrops reflect the energy as left-hand cp, just as the mirror-reflected image of a right-hand screw thread appears to be left-hand. Since the same antenna is used for both transmitting and receiving, and the radar antenna is not responsive to the opposite sense of rotation, the receiver does not receive echo energy from the spherical reflector.

(6) An aircraft target will return some energy with the correct polarization as well as energy with the incorrect polarization. Energy incident on the aircraft may be returned after one bounce, as from a plane sheet or a spherical surface; or it might make two or more bounces between various portions of the aircraft before being returned to the radar. On each bounce the sense of polarization is reversed. Signals which make single reflections (or any odd number) will be rejected by the cp antenna, but those signals which make two reflections (or any even number) will be accepted.

(7) The radar cross section of aircraft targets is, in general, less with circularly polarized radiation than with linear polarization. The difference in echo signal level with cp and lp will depend upon aspect angle, but it has been reported (reference 2) that on the average cross section with cp is about 5 dB less than with lp for the ASR frequency region.

(8) If it can be assumed that the combined effects of cp operation and mti improvement will allow a target to be detected against a rain clutter echo background, it is useful to determine the range of such detection, relative to free space operation. This is determined through a combination of the loss in signal strength due to cp (5 dB), and that due to rain attenuation. A convenient worst-case assumption for this factor is 2 dB (from figure 2-55) giving a total signal loss of 7 dB. This corresponds to a range coverage which is roughly 67% of the free-space range.

f. Corrosion, Sand, and Dust.

(1) Chemical constituents and/or sand and dust in the atmosphere are potential sources of corrosion or damage to

radar/beacon equipment or components. Protection against natural concentrations of these agents within a geographical region is best accomplished by specific design of the ASR/ATCRBS systems. However, within a given region certain locales (centered about chemical processing plants, sewage disposal facilities, ocean shorelines, mining operations, or industrial parks) may exhibit unusually high concentrations of such contaminants. In siting, these areas should be avoided.

(2) Some of the most important atmospheric constituents with respect to corrosion include chlorides, sulphates, nitrates, hydrogen ions, sand, and dust. Along ocean or sea coasts, salt spray is a corrosive factor for installations located less than 1,000 feet inland. This minimum distance should even be greater in coastal areas where unusual high wind conditions are known to prevail. Ozone at the earth's surface created by photochemical reduction of organic pollutants (smog) will deteriorate rubber materials. Sand and dust from storms in desert regions, or in and around stone quarries or mining operations, can have serious effects on moving parts (i.e., bearings, gears) of the radar/beacon antenna systems. Areas of high sand and dust concentration should be avoided, if possible.

(3) As a guide to identifying potential corrosive atmosphere about industrial areas, processing plants, or mining operations, table 2-6 shows the concentration, source, and locations of some of the more important of these atmospheric contaminants.

g. Structures. Structures such as buildings, metallic fences, towers, etc., in the vicinity of an ASR/beacon site can result in unsatisfactory radar/beacon coverage by virtue of the reflections they produce. This situation is most serious with respect to beacon operation where such reflections cause the radar beacon reply from an aircraft to appear at false azimuth and range positions (see paragraph 22e). In the case of the ASR, similar type false targets are possible in theory. However, because of the two-way propagation path involved, ASR false targets of this type are not considered a significant problem. The more important effect of structures upon ASR performance are the permanent echo returns they produce. This, however, is a potential problem for very large structures located 1/2 mile or more from the radar because of the recovery time limitations of the ASR. Such radar returns are generally considered as falling within the general clutter environment of the radar (see paragraph 22c) and may be treated as such in selecting the ASR/beacon site.

TABLE 2-6

ATMOSPHERIC CONTAMINANTS

Concentration (in rain water), Source, and Location of the Most Important Constituents with Respect to Corrosion/Wear [1]

Contaminant	Source	Location	Concentration in Rain Water, mg/liter
Chloride (Cl^-)	Sea Spray	Over sea or near the coast	2-20 average. In extreme winds up to 100
Sulphate (SO_4^{--})	Industrial Areas	Large cities, industrial areas	10-50 average. Higher under extreme conditions (e.g., smog)
Nitrate (NO_3^-)		Over land	1-5
Hydrogen ions		Over land, near industrial areas	Avg. 5
Sand/Dust	Mining operations. Desert wind storms	Over land. Desert areas.	

[1] Reference 13

Hence, from a siting standpoint, the more significant concern with structures within the immediate site vicinity (i.e., less than 1/2 mile) is their effect in producing beacon false targets.

(1) Fences.

(a) Among the most prominent sources of beacon false targets are chain-link fences. Reflections from such fences can cause beacon false targets over a large azimuth sector due to the variable angle of reflection that develops as the beacon interrogator beam sweeps along the fence. Fences as far as 6 miles from the transmitter site have been found to cause false target replies. The nomograph of figures 2-48a and b may be used to predict the range extent of beacon false targets for a given fence within view of the ASR/beacon site.

(b) If a site cannot be located which is free of possible false target reflections due to fences, consideration should be given to a site which is directly adjacent to the fence, thereby greatly reducing the effective reflecting area. Other alternatives, such as substituting wood fencing or tilting the fence to produce Brewster angle reflections should also be considered.

(2) Buildings.

(a) Large buildings within the vicinity of a site can produce beacon false targets and/or permanent radar echoes at the ASR display depending on their size, distance, and orientation relative to the direction of illumination, surface roughness, and material. Buildings with metal framework or metal siding or roofing are especially troublesome and should be avoided in the siting of the ATCRBS antennas. The site should be free from such reflectors out to a minimum of 1,500 feet from the antenna, preferably to a distance of 1 mile.

(b) Where no site is available with sufficient separation from nearby buildings to reduce the occurrence of false target reflections, an attempt should be made to locate a site for which the radar energy angle of incidence upon the reflector is as small as possible, thereby minimizing the effective reflecting area. Other alternatives include shield fencing or architectural treatment of the buildings for minimum reflections.

(3) Towers/Backup ASR/Beacon Facilities.

(a) Towers within the immediate vicinity of the ASR/ATCRBS site to support RML transmitters or backup radar/beacon systems will in all likelihood produce beacon false targets, and/or beacon splitting.

(b) Beacon false targets are frequently produced by reflections from the steel framework of towers. In the case of backup radar/beacon facilities located nearby, the antenna of the backup system presents an excellent reflecting surface for beacon false target replies to the primary system. Furthermore, any slightly different rotation rate of an operative backup dish relative to the primary system rotation can cause false target replies from almost all azimuths about the site.

(c) Towers erected near the ATCRBS site are also believed to produce splitting of beacon replies, and hence the reporting of false targets on automated display equipment. Studies of this phenomenon (references 13 and 14) have indicated that no radar/beacon site should be established within 1,200 feet of RML or other towers, in order to minimize beam split effects.

(4) Siting Guidelines with Respect to Structures. (See reference 8 for more detailed discussions.)

(a) In the selection of a site for an ASR/ATCRBS installation, the area should be free from potential reflectors out to a minimum of 1,500 feet from the antenna, preferably to 1 mile. Potential reflectors such as metal buildings (metal frame, siding, or roofing), chain link fences, metal towers, etc., that are not removed should be either shielded from direct illumination by the radar beacon or modified to minimize their effects. Exact predictions as to the severity of reflections from particular structure(s) are not possible since few reflecting surfaces are ideal lossless flat-plate surfaces, and the amount of reflection varies from object to object. Worst-case estimates can be made, however, with the aid of figures 2-48a and b. In so doing, consideration should also be given to second-bounce reflection paths.

(b) Tilting of a reflecting fence, or other flat reflectors, can be an effective means of reducing the intensity of reflected signals, and, therefore of eliminating false beacon replies.

(c) Application of a smoothly curved surface over a flat reflector results in divergent scattering and, therefore, elimination of false beacon replies.

(d) When screening or other techniques are not practical means of reducing false targets, an attempt should be made to locate the site in such a manner that the resulting false targets will fall in the least critical coverage area.

h. Interference Sources.

(1) The problems of mutual interference which might exist between an ASR/ATCRBS facility and various other types of electronic equipment operating in the general area of the proposed site should not be overlooked when considering a particular site location. Data should be gathered regarding the location and types of nearby radiation sources. An evaluation can then be made, if considered necessary to determine the extent of interference prevailing. This may influence the selection of a site location.

(2) Commercial installations that may cause interference include television stations, fm broadcast stations, and microwave links. The latter are frequently used by railroads, and by pipeline, power, and utility companies. A complete listing of all commercial, as well as FAA installations and their operating frequencies, may be obtained from the nearest regional office of the Federal Communications Commission (FCC). In addition to these sources, arc-welding equipment and improperly grounded or shielded industrial and/or diathermy equipment operated by industrial concerns or by local medical facilities will frequently radiate sufficient rf energy to cause objectionable interference.

(3) The proximity of the ASR/ATCRBS site to electrical power installations of all types should also be investigated as a likely source of interference. The presence of nearby power lines, telephone and telegraph lines, electric fences, electric railways, and the like may represent sources which conduct and reradiate rf interference that has been transmitted to the lines from a noise source by direct radiation, conduction, or induction. Strong interference levels may thus be conducted over long distances by power or telephone and telegraph lines, which in turn may radiate throughout their entire length. For this reason, isolation, noise suppression, or attenuation by means of natural or fabricated shielding must be considered where such conditions are likely to exist.

(4) Interference due to meteorological distrubances may include heavy rain, snow storms, deep snow on the ground, thunderstorms, etc.. From a siting standpoint, very little can be done about such sources of interference. However, information regarding weather conditions at the site should be obtained so as to recognize the conditions and limitations imposed on ASR/ATCRBS operation at a specific site.

i. ASR/ATCRBS Generated Interference.

(1) ASR and ATCRBS outputs generally have some degree of harmonic and spurious signal output. The FAA has agreed to take steps to minimize these unwanted portions of the output, and also to cooperate with microwave common carrier companies in an effort to reduce interference in the siting of radar/beacon systems. Interference has been experienced in a commercial microwave link that was traced to an en-route radar 70 miles away. The ASR/ATCRBS should be sited at least 10° off the microwave path, and shielding of the radar or link using existing obstructions or obstacles should be attempted.

(2) The spurious output from the ASR/ATCRBS may cause interference to television reception in the immediate vicinity of the site. Although a built-up area is generally an excellent site to break up lobing of the ASR/ATCRBS radiation patterns, residential and other areas where there are likely to be many tv receivers should be avoided if possible. If radar sites are established near residential areas, every consideration and effort should be made to minimize if not eliminate interference to the tv receivers in the vicinity.

SECTION 5. SITE REQUIREMENTS/LIMITATIONS

24. INTRODUCTION. A basic prerequisite prior to consideration of any property for use as an ASR/ATCRBS site is that the land is available and can be acquired through purchase or long-term lease. In addition, the land or parcel of property must be adequate to the extent that the construction, installation, and operational requirements of the ASR/ATCRBS facility can be met with reasonable cost and without undue environmental impact.

25. ENVIRONMENTAL IMPACT ASSESSMENT. Any location considered as a terminal radar site must receive a careful assessment of the overall environmental impact which will be produced by establishment and operation of an ASR/ATCBI site at the location. This assessment is to be carried out in accordance with FAA Order 1050.1A, Procedures for Considering Environmental Impacts of Proposed FAA Actions.

26. COMPONENTS OF AVERAGE FACILITY. A site would be considered adequate and reasonable in cost if the construction, installation, and logistics requirements approximate those of an average ASR/ATCRBS facility. The principal components of an average facility are:

a. A 120' x 120' plot of land including a 6-foot chain-link security fence surrounding the property where considered necessary.

b. Easements to preclude construction of any structure which would project above antenna platform level or which would be built of reflective materials within a 1,500-foot radius of the site property.

c. An access road not more than 1/4 mile long.

d. A standard transmitter/receiver building including air conditioning and engine generator units.

e. ASR/ATCRBS antenna on a 17-foot antenna tower.

f. A standard transformer substation.

g. Utility lines (power, water, telephone) or installations no more than 1/4 mile long.

h. Cable installation, with cable, between the transmitter/receiver building and TRACON building of about 6,000 feet in length.

27. LAND ACQUISITION.

a. The process of land acquisition, especially off-airport property, must be accomplished by the cognizant FAA offices. Once the particular parcel of land has been selected as an acceptable site location, action should be taken by these offices together with members of the siting team to:

(1) Reaffirm that the land is available and that no municipal or local government restrictions, zoning laws, or other legal restrictions exist on the property that would prohibit its use as an ASR/ATCRBS site.

(2) Provide or secure competent legal representation with respect to the legal aspects of property surveys, buying or leasing of land, and easements for access roads and utilities.

(3) Obtain permission for right of entry to private lands by survey personnel, and arrange for reasonable compensation to property owners for damage to property resulting from survey operations.

(4) Secure deed descriptions and copies of filed plans or maps covering the property and initiating title searches to determine the validity of title or easements.

(5) Provide or secure the services of personnel licensed to practice land surveys in the territory of jurisdiction.

(6) Review environmental impact factors.

b. Throughout the period of siting investigations and negotiations, and until such time as a real estate directive is issued for procurement of land, all negotiations with the owner and/or agent must be handled by the proper authorities of FAA, and all information must remain confidential to prevent the possible increase of property acquisition costs.

c. In the acquisition of land for an ASR/ATCRBS facility on airport property, being a definite benefit to the local airport, full cooperation of the local airport and city officials can be expected. These officials will be required to furnish the necessary land for the transmitter/receiver building, tower, cable runs, and access roads when located on the airport and to make available all existing power facilities and ducts which are adaptable to the system. Permission to install, operate, and maintain equipment within the boundaries of the airport is to be obtained through the use of license Form FAA-1334.

28. ACCESS ROAD. If an ASR/ATCRBS site is to be located on airport property, the access roads in use are usually adequate. However, it may be expected that the ASR/ATCRBS facility will be located at a site remote from existing roadways. Where existing roads provide all or part of the access necessary to the proposed site, a survey should be made to determine their adequacy for the vehicular traffic expected to utilize such roadways. Some of the important factors to be considered in the evaluation of existing access roads are (a) maximum load limit of roads, bridges, culverts, etc., (b) maximum clearance height of underpasses, (c) maximum grade, road, and shoulder width and minimum turn radius of road, (d) road surfaces--weather and seasonal considerations, (e) volume and class of traffic handled, and (f) adequacy of and responsibility for road maintenance (including snow removal). Useful data of this type can often be obtained by contacting state, county, or local highway department officials or, in the case of airport roads, cognizant airport officials.

29. ROAD CONSTRUCTION.

a. When the construction of a new access road is required, a study of the construction cost, annual maintenance, traffic handling capacity, and the salvage value at time of replacement must be considered in determining the relative economic merit of different surfaces for a given geographic area. It should be remembered that no FAA improvements can be made to roads on which the FAA does not have a lease, easement, or similar legal arrangement. Some of the important factors to be considered when new construction is required are as follows:

(1) The length of road required from the point of entry to the site.

(2) The climatic and geological variables having an effect on snow depth, rain, frost heavings, load bearing capacity, and sub-grade soil.

(3) The requirements for grading and filling.

(4) Need for the construction of bridges, culverts, etc.

(5) Availability of labor and materials locally.

b. The detailed design standard for new road construction will vary because of the diversity of available materials, and various climates and geographic locations. In the reconstruction of existing roads it is often economical and advantageous to utilize the existing roadbed as a base for the new construction. In this manner, advantage can be taken not only of the old paving materials, but also of the compaction afforded by previous traffic loadings.

30. CLEARING/GRADING/LANDSCAPING. The need for clearing, grading, and/or landscaping of the site property represents an additional cost above those nominally required for an average site facility. Clearing costs would include the cost of such items as the removal of trees, shrubbery, rocks, debris, etc. Grading may sometimes be necessary to improve drainage on or about the site, or to provide screening in a particular azimuth sector. The prevention of soil erosion about the site, esthetics from a public relations viewpoint, reduction of reflection from the surrounding security fences, etc., all add factors that could require special landscaping of the site. This landscaping should be in the form of sodding, planting of shrubbery, trees, etc.

31. SITE SECURITY. Consideration must be given to the action necessary to prevent intrusion, and to protect the ASR/ATCRBS installation from vandalism or other damage. For the most part, a 6-foot chain-link security fence is adequate for these purposes. In general, all off-airport sites will require a fence.

32. UTILITIES.

a. The principal utility requirement for an ASR/ATCRBS site is the need for 3Ø, 120/208 volt electrical power. Two independent sources of such power are required to minimize the loss of ASR/ATCRBS operation due to power failure. The primary source of electrical power shall be from commercially available power within the vicinity of the site. Hence, sites nearest such power lines and/or distribution points are preferred; all other factors being equal. The power shall be delivered directly to the site or via a transformer substation installed adjacent to the engine generator room or van. The secondary source or standby power shall be provided by a 62.5 kVA or larger government-furnished engine generator at the ASR site.

b. Water and sanitation at an ASR/ATCRBS site may only be required when the site is to be manned on a full-time basis. In such cases, means for providing these conveniences need not rely on municipal, state, or county facilities, although these are preferred if readily available. Chemical toilets, along with wells for water, are acceptable alternatives. Before drilling wells, however, contact with local authorities should be made to establish the legality and safety of wells as a water source in the area. ASR/ATCRBS facilities on airport property do not require water and sanitation as they are not manned on a full-time basis.

CHAPTER 3. SITING PROCEDURES

SECTION 1. INTRODUCTION

33. INTRODUCTION.

a. The procedures recommended for siting terminal ASR/ATCBI systems are outlined in this chapter in terms of the following major tasks.

(1) Preliminary data acquisition.

(2) Preliminary site selection.

(3) Site survey.

(4) Site analysis.

(5) Preparation of siting report.

(6) Final site selection.

b. The specific work activities associated with each of these major tasks are described in the following sections along with a detailed description of the procedures recommended for carrying out these specific activities. For purposes of planning and scheduling of these siting tasks, a typical siting management plan is shown in figure 3-1.

SECTION 2. PRELIMINARY DATA ACQUISITION

34. GENERAL.

a. Following the receipt of an assignment to establish an ASR/ATCBI site for a given terminal area, the first task will be to acquire specific working data and information regarding the operations, coverage requirements, and constraints associated with the air terminal of interest. These data, which will be used throughout the various work phases of the siting effort, should include as a minimum:

(1) Airspace coverage requirements.

(2) Applicable maps and charts.

(3) Local climatological data.

b. In addition, the following documents are considered part of the required data base for siting operations and should be available for reference as needed.

(1) Flight Inspection Manual, FAA Handbook OAP 8200.1, Sept. 1968, as amended to date.

(2) Federal Aviation Regulations, Vol. XI, FAA, Oct. 1969, as amended to date.

(3) Airport Design Standards, Site Requirements for Terminal Navigation Facilities, FAA, AC 150/5300-2B, Nov. 22, 1971.

35. AIRSPACE COVERAGE REQUIREMENTS.

a. Specific ASR/ATCBI coverage requirements for the terminal area to be served are obtained from the cognizant Regional Air Traffic Division (ATD) and should include as a minimum:

(1) Data that defines a volume of airspace about the terminal or terminals (including satellite airports) to be covered. Generally, this will be defined indirectly by specifying the location of navigational fixes within the terminal airspace with priorities assigned to each according to primary and secondary requirements.

(2) The standard approach and departure flight paths classified according to the primary and secondary routes for aircraft entering or leaving the given airspace. In addition, contingency variations or changes in these flight paths should be identified and specified.

(3) Data that identifies the number and type of aircraft that will use the defined airspace and the present and expected level of aircraft activity.

(4) The specification of aircraft ground speed over the various air-routes and unusual maneuvers that can be expected within the given airspace.

(5) Satellite airport(s) coverage requirements.

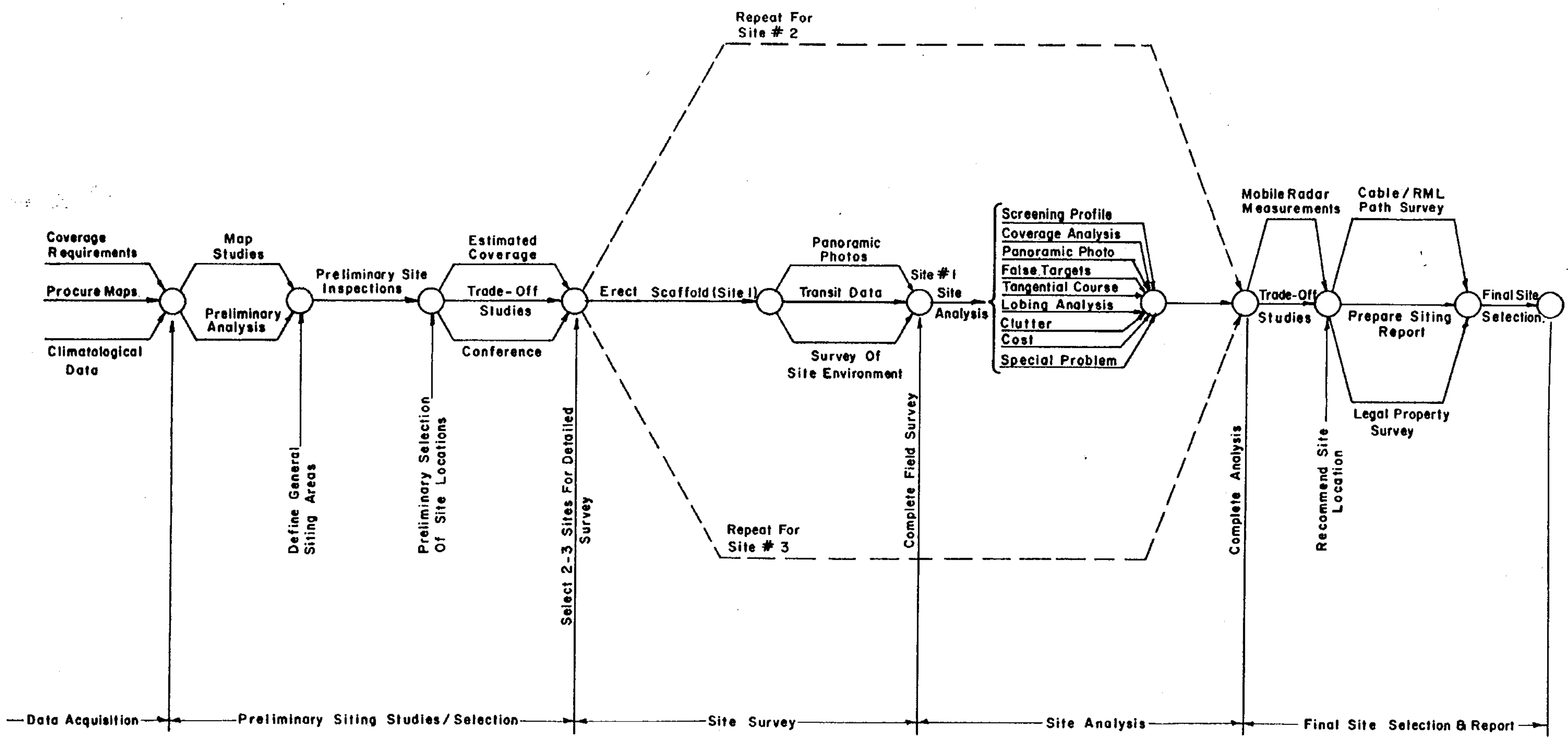
b. All data concerning coverage requirements for the terminal area of interest shall be approved and signed by the proper ATD personnel. Usually, this will be the chief of the regional Air Traffic Division or his designated representative. In addition, it is recommended that full acknowledgement and concurrence with these coverage requirements be obtained by ATD from the following regional officers:

(1) Chief, Airway Facilities Division.

(2) Chief, Flight Standards Division.

(3) Chief, Airports Division.

FIGURE 3-1. ASR/BEACON SITING MANAGEMENT PLAN



c. When requesting the above data from ATD, it is advisable that ATD and/or other cognizant agencies/representatives be advised as to fundamental ASR/ATCBI coverage limitations, particulary with respect to ASR range capabilities for certain aircraft (e.g., T-33) and the preferred minimum 0.25° screen angle.

36. MAPS AND CHARTS. Once the geographical area to be considered has been established, applicable maps and/or charts should be obtained for subsequent siting studies. Although all sources of pertinent maps should be investigated, the following is considered the minimum working set: (a) current 7½-minute and 15-minute applicable U.S. Geological Survey Quadrangle maps, (b) latest airport master plan, (c) moca chart of terminal area(s), (d) aeronautical charts, and (e) municipal, county, and state maps showing current and/or marked for future highway, housing, business, and industrial developments within the terminal or prospective site vicinity.

a. U.S. Geological Survey Maps.

(1) Quadrangle maps representing approximately 50 percent of the country are available from the United States Geological Survey Office, Washington, D.C. Local commercial map agencies also frequently market these quadrangle maps for their particular locale. Where such maps are employed, the date of survey should be noted, since older maps may lack certain details of importance.

(2) For certain areas, the Corps of Engineers had made maps of suitable topographic detail similar to the U.S. Geological Survey Quadrangle maps. Liaison with the appropriate regional office of the U.S. Air Force installations representative or the district engineer, Corps of Engineers, may produce additional maps based upon more recent surveys.

b. Airport Master Plan. The latest airport master plan for each of the airports that are under consideration for locating an ASR/ATCBI site can be obtained from the responsible airport managers, or the Airports Division of the FAA regional office. Upon receipt of a master plan it is advisable to contact the airport manager and Airports Division personnel to review its accuracy by locating and identifying all installations, facilities, underground construction, or other developments not graphically indicated, and annotate the plan accordingly. In addition, known future airport expansion, installations, and/or developments should be identified, confirmed by Airports Division, and so noted directly on the plan.

c. Minimum Obstruction Clearance Altitude (MOCA) Charts. MOCA charts for the terminal airspace of interest can be obtained from the regional Air Traffic Division Chief. These charts should be reviewed with cognizant representatives to identify existing departures from current FAR, part 77, for civil airports and the terminal airspace. Also, a review of petitions for waivers on file with ATD for future construction should be made to note how such obstructions will alter the navigable airspace within the terminal area, if approved.

d. Aeronautical Charts. Sectional, local, and terminal area aeronautical charts (as available) should be secured for the vicinity of the proposed radar site. In addition, appropriate instrument approach procedure and standard instrument departure (sid) charts should be obtained for the terminal area. These charts may be obtained from: Distribution Division, C-44, National Ocean Survey, Washington, D.C. 20235. The designated charts provide invaluable information for establishment of radar coverage requirements and capabilities.

e. Municipal, County, and State Maps. Municipal, county, and state maps may be obtained from the civil offices of the respective divisions of local and state governments. These maps should describe or be marked to indicate present or future vehicular traffic (highways, railroads, etc.) of significance, or industrial areas that may give rise to a corrosive atmosphere or rfi environment.

f. Supplemental Maps/Charts/Photographs. Many other maps which may provide essential pre-siting information are available through the Superintendent of Documents, Government Printing Office. These maps are listed in GPO price list PL-53 (Maps, Surveying, Engineering). Aerial photographs of the general area for site locations are also sometimes useful for the location and general evaluation of vacant land within an urban area. These photos can often be obtained from local commercial enterprises or the U.S. Geological Survey.

g. Local Climatological Data. Seasonal weather, climatological, and seismic data of possible significance to siting may be obtained for the locality of the proposed ASR/ATCBI installation. These data are published as Annual Climatological Summaries by the National Weather Service (NWS) for each locale in which a weather station is maintained. The annual summary may be obtained from the local NWS office, or from the National Climatic Center, Federal Building, Asheville, North Carolina 28801. The Local Weather Service or Environmental Protection Agency offices may, in some areas, also be able to provide records regarding the occurrence and altitude of temperature inversions in the area. This information may be significant in determining the seriousness and frequency of radar coverage changes caused by anomalous propagation effects.

h. Standard FAA Drawings.

(1) Typical site drawing (e.g. D-5409-1 for ASR-4B, 5, and 6; D-5825-1 for ASR-7).

(2) Access Roadway specification drawing (D-5980).

(3) 4/3 Earth Radius Coverage Chart (e.g., D-50979-2, 3, 4, and 8).

SECTION 3. PRELIMINARY SITE SELECTION

37. INTRODUCTION. The preliminary selection of candidate site locations is essentially a real estate elimination process that takes into account as many of the factors described in chapter 2 as is practical without the benefit of precise survey data. The objective of this process is to converge to a selection of about two to three potential site locations that represent the best of all factors considered. The following paragraphs define the approach and procedures for selecting candidate site locations. Many of these procedures make use of maps of the types described above. These are henceforth assumed to be on hand.

38. DETERMINE SITING AREA BOUNDARIES.

a. Area Boundaries. The boundaries of the general area in which a site may be located shall be determined on the basis of the distribution of fixes and air routes within the terminal airspace, together with the range, altitude cable distance, and "cone of silence" coverage limitations of the ASR/ATCBI system. (The ATCBI cone-of-silence range and altitude coverage is not considered to be the limiting factor in this investigation.)

b. Coverage Requirements. An alternative definition of coverage requirements in terms of a volume of airspace about the terminal will require the specification of critical coverage points which are equivalent to navigational fixes. The selection of these critical coverage points must be made in such a way that coverage of them will insure coverage of the required volume of airspace. Once these critical coverage points have been specified, the site analysis proceeds as if they were navigational fixes.

(1) Range Coverage Limitations.

(a) The objective of this investigation is to determine the permissible land area beneath the terminal airspace within which an ASR can be located and still meet the range coverage limitations imposed by specific aircraft when located at each of the navigational fixes about the given airspace. This investigation is of particular value and especially recommended where navigational fixes are distributed over a wide volume of airspace (approximately 20-40 nmi from the radar site) and the detection of small aircraft (e.g., Cessna 180, Piper Comanche) is a requirement.

(b) An outline of the procedures recommended for conducting this investigation is given below and includes an illustrative example. For purposes of this analysis, it is sufficient to assume slant range and ground range to all fixes as being identical.

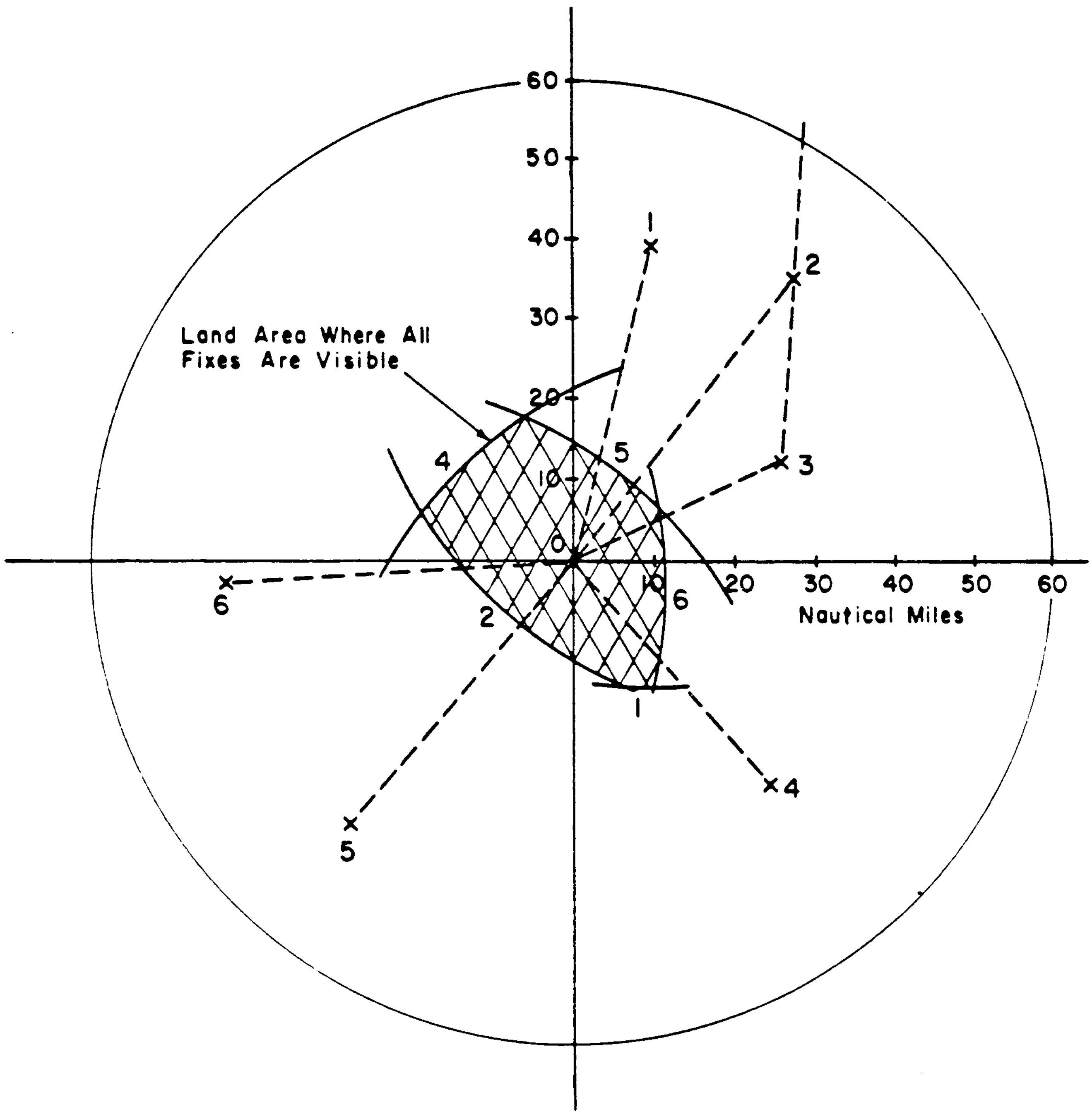
1. Locate and identify all given navigational fixes on an appropriately sized quadrangle map. One degree or 1:250,000 survey maps are recommended for this purpose, although sectional aeronautical maps scaled to 1:500,000 are adequate. Where fixes are specified relative to VORTAC or VOR installations, it is suggested that each such station be located by triangulation, taking measurements from the aeronautical charts and transferring them to the quadrangle map.

2. Using the locations of each fix as centers, draw circles whose radii correspond to the maximum detection range of the ASR for the smallest target size of interest. To obtain these maximum ranges, refer to the ASR vertical coverage charts (for a nominal $+2.5^{\circ}$ tilt angle) and aircraft cross-sections given in chapter 2. As a first approximation, the maximum detection range selected from these coverage charts should represent that range obtainable on the "nose" of the ASR coverage pattern. A technique for accounting for detectable range variations as a function of fix altitude is discussed subsequently.

3. Identify and mark the area common to all circles. This area identifies the permissible locations for ASR sites which satisfy the theoretical range coverage limitations of the given aircraft at each navigational fix. The best ASR site locations would be at the centroid of this area, all other factors being equal.

(c) To illustrate the above outlined procedures, consider the distribution of navigational fixes marked 1, 2...6 as shown in figure 3-2. The grid reference point shown is arbitrary and is shown centered somewhere near or at the airport. If we assume a 55 nmi range capability for the ASR (typical of coverage on "nose" of ASR-4B, 5, and 6 for small aircraft of the T-33 class), the allowable area for site locations can be determined by drawing 55 nmi circles centered about each of the fixes. The allowable siting area is that region common to all circles drawn about the fixes. The boundary of this area is shown as darkened arc lengths in the center of

FIGURE 3-2. DETERMINATION OF SITING LAND AREA AS A FUNCTION OF ASR/BEACON RANGE COVERAGE AND FIX DISTRIBUTION



the figure. The number shown alongside each arc segment identifies the fix that establishes that segment of the boundary.

(2) Altitude Coverage Limitations.

(a) The land area defined in the above analysis is based on the assumption that all fixes are illuminated by the beam center or nose of the ASR vertical radiation pattern. The purpose of this investigation is to refine the boundaries of this general land area by taking into account the fact that all fixes are not illuminated by the nose of the radiation pattern.

(b) The techniques for carrying out this investigation are essentially an extension of those outlined in a above. The principal difference being that the radii of the circles drawn from each fix are reduced in direct proportion to the reduction in range coverage that occurs at altitudes above or below the nose of the ASR vertical radiation pattern. To determine these range reductions, it is convenient to assume that the following conditions prevail.

1. The base of the antenna tower is located at a msl elevation corresponding to the AVERAGE MSL ELEVATION of the ground surface of the land area defined in (a) above.

* 2. The effective height of the antenna phase center if 25 feet above the antenna base (27 feet for ASR-5E, 6E, 7E, and 8). This height may be raised by 10-foot increments * if necessary to provide los visibility over the surrounding terrain.

* 3. The vertical coverage pattern of interest in the free-space pattern obtained for a +2.5° tilt angle referenced to the nose of the beam which corresponds to approximately 0.5° referenced to the lower 3 dB point. *

4. Optical and radar range and los are assumed equivalent.

5. Lobing, clutter, and/or other operational limitations brought about by surface reflections or screening may be neglected in this preliminary investigation.

(c) The following procedures should then be followed:

1. From topographical maps, determine the average msl elevation of the terrain within the boundaries of the general area established in (a) above.

2. Subtract this average msl elevation plus the assumed antenna height from the msl altitudes of each fix. Enter this difference in the third column of the worksheet shown in figure 3-3.

3. Determine the range coverage obtainable for each of the fixes as a function of their altitude above or below the nose of the ASR radiation pattern. A procedure for determining this range is described in terms of the illustration shown in figure 3-4. In this figure, the ASR-7 coverage contour for a small aircraft is shown. From this contour the maximum range coverage at the nose of the pattern is 55.7 nmi at an altitude of about 17,000 feet. This point is designated by the letter A in the figure. For fixes located above or below the point A, the range coverage capability will be reduced in proportion to the drop in antenna gain as we move off the nose of the antenna pattern. This reduction is determined by locating the fix at point B as shown in the figure, at an altitude, h, corresponding to the altitude difference computed in 2 above. The intersection, C, of the constant altitude line from B with the pattern contour defines the range, R, (shown as 47 nmi in the figure) of interest. This range should be entered in the last column of the worksheet and the process repeated for each of the specified navigational fixes.

4. Make the necessary revisions to the area found in the investigations carried out in a above by drawing circles about each fix using radii corresponding to the adjusted range values found in 3 above.

5. Care should be taken to consider all fixes in this investigation even though they were not found to be critical in establishing the boundaries on the basis of maximum coverage on the nose of the pattern. Some fixes could become prominent factors on the basis of these altitude coverage considerations.

(3) Cone-of-Silence Limitations. Further refinement of the above analysis should be made taking into account the coverage limitations of the ASR due to the so-called "cone-of-silence". To do this, it is recommended that the area determined above be redrawn on an appropriately sized chart marked to show all fixes, air routes, and the corresponding altitudes of each within the airspace above this area. The real estate to be avoided beneath fixes and air routes is determined by the area swept out along the ground surface by the base of a right circular cone as its apex travels along all air routes between all fixes. The apex angle of this cone is 130° and

FIGURE 3-3

DETERMINING RADAR COVERAGE AS A FUNCTION OF FIX ALTITUDE WORKSHEET

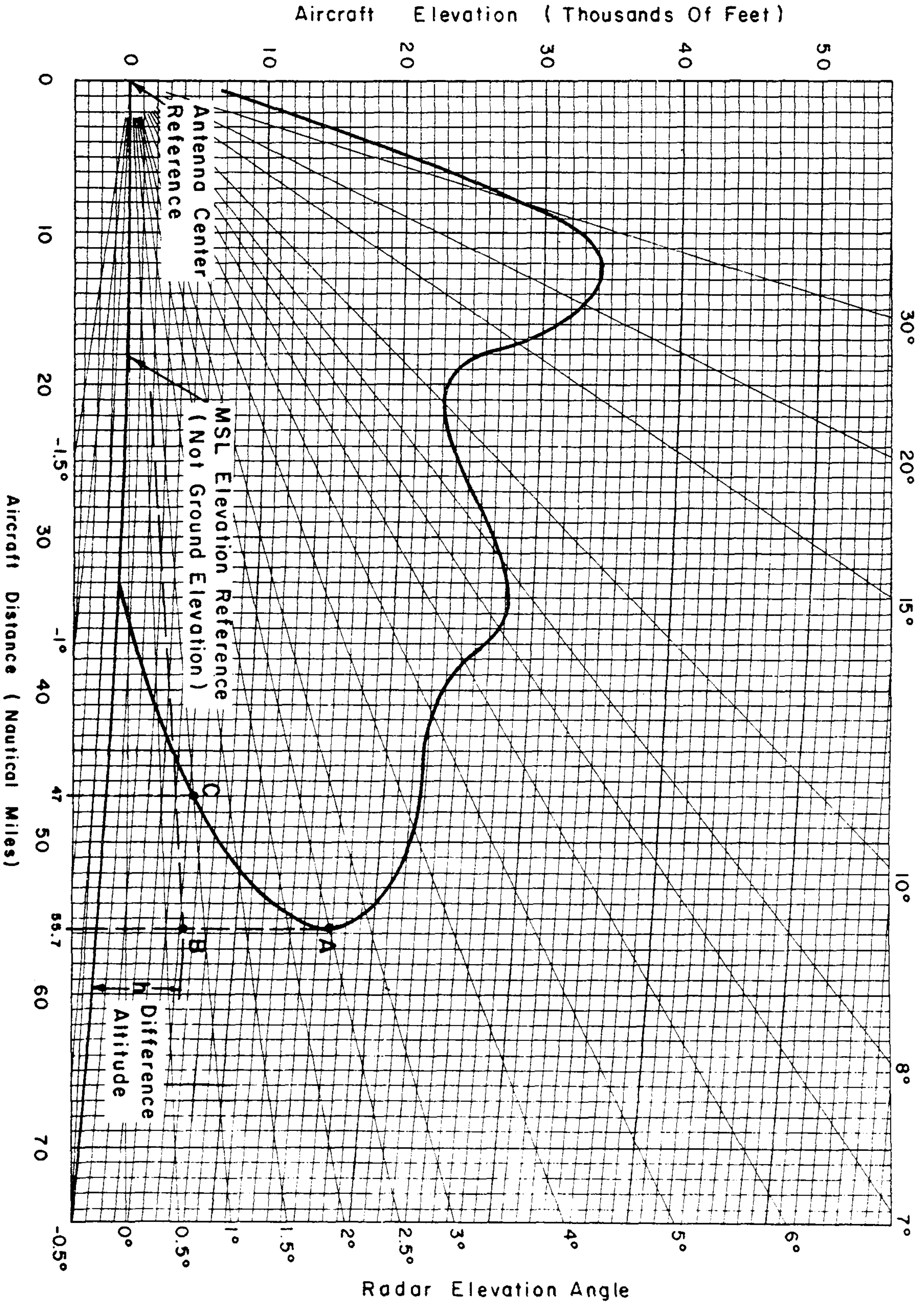
Assumed Antenna Height ____________ ASR Type ASR- ____________

MSL Elevation Of Antenna Center ____________ Aircraft Type ____________

FIX IDENTIFICATION	MSL ALTITUDE OF FIX (Feet)	DIFFERENCE BETWEEN FIX & ANTENNA CENTER ALTITUDES (Feet)	MAXIMUM COVERAGE RANGE TO FIX (From Coverage Diagram) (Nautical Miles)

FAA Form 6310-7 (12-73)

FIGURE 3-4. ILLUSTRATION OF REDUCTION IN RANGE COVERAGE CAPABILITY AS A FUNCTION OF FIX ALTITUDE



its height equals the agl (above ground level) altitude of the fix or point along the air route. This 130° apex angle assumes an R^4 stc curve is to be used. Higher values of stc attenuation will require the use of larger apex angles. An illustration of the results obtained using this procedure is given in figure 3-5.

c. The area defined by the above procedure determines the general area in which the ASR/ATCBI system must be sited to provide effective detection/tracking of aircraft over each fix and air route. Generally, this area will include the airport property and be sufficiently large in extent to contain many potential off-airport site locations as well. However, if the area found using this procedure is unduly restrictive, leaving little or no choice for site locations, discussions with ATD personnel may be in order to consider whether any relaxation, modification, or relocation of the given airway/fix requirement is tolerable.

39. PRELIMINARY INVESTIGATIONS. The objectives of these preliminary investigations are (a) to locate and identify available siting property within the general land areas established in the above analysis, and (b) to select, from these properties, a set (e.g., two to three) of preferred site locations for in-depth survey and analysis. These investigations will include map studies, visits, and some analysis to ascertain the availability and suitability of the particular properties as site locations, taking into account as many of the criteria for good siting as possible.

a. Airport Sites.

(1) When the general area established for siting includes all or part of the airport grounds, the following guidelines should be used to identify and locate property on the airport that can be used for ASR/ATCBI sites.

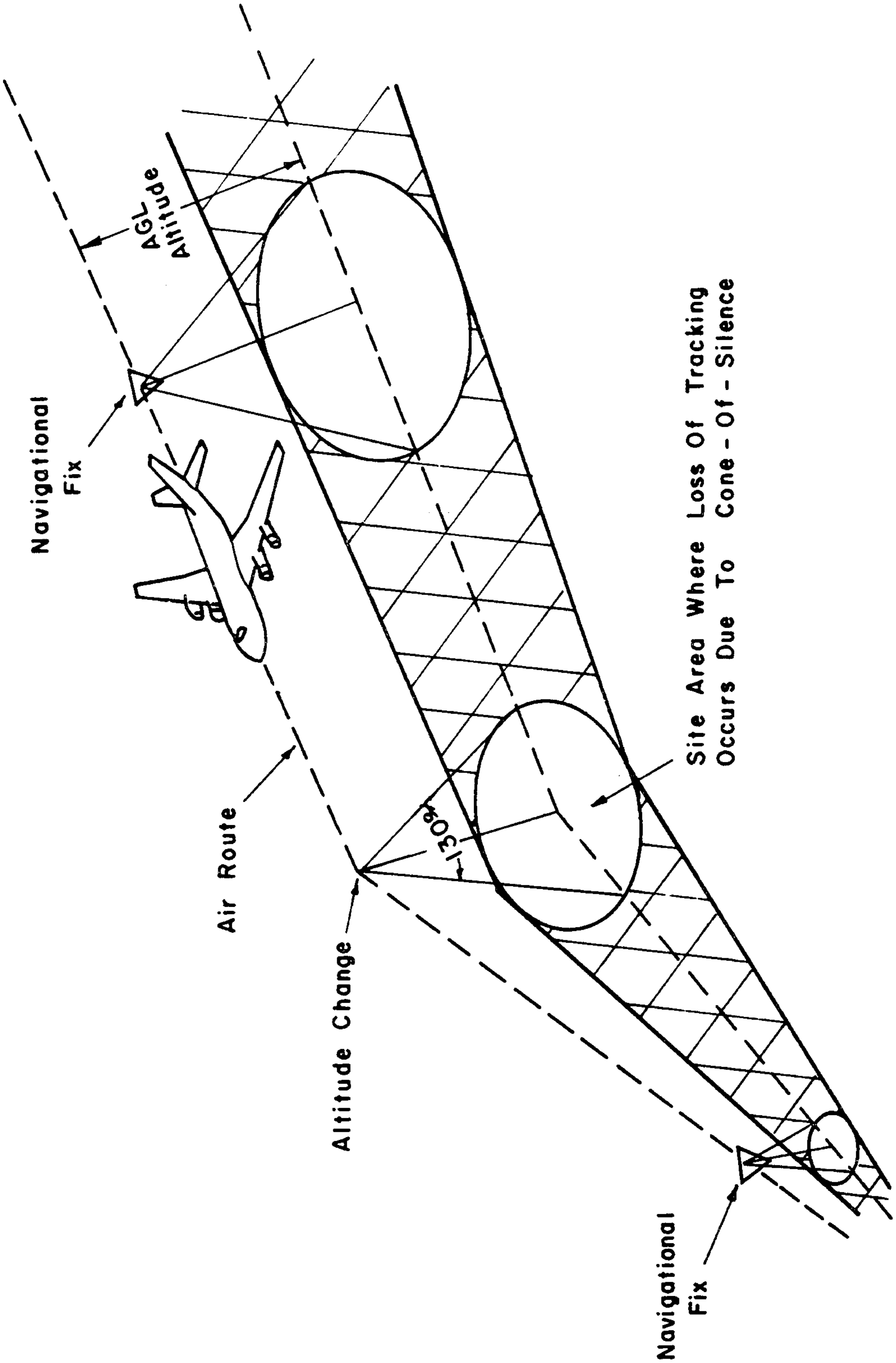
(a) The site shall not be located closer than one-half mile from the end of any existing or planned runway.

(b) The site shall not be closer than 2,500 feet from any existing or planned electronic equipment installation or facility. Further, the site shall not be less than one-half mile from Weather Bureau radars and radiosonde equipment. Violation of the latter criteria requires a Washington waiver.

(c) The site shall not be closer than 1,500 feet from any above-ground object (i.e., fences, towers, hangars, buildings, etc.) thay may interfere or cause degradation in the ASR/ATCRBS operation.

(d) Preference should be given to remoting of data from the ASR/ATCBI receivers to the indicator site via landlines.

FIGURE 3-5. ILLUSTRATION OF LAND ELIMINATION TECHNIQUE BASED ON CONE-OF-SILENCE



To do this the radar should be located such that the maximum routed cable length between radar and indicator sites is within the maximum allowable cable length distance indicated in tables 1-1 and 1-2, for the type of ASR/beacon system being sited.

(2) Airport property eliminated by the above criteria can be marked directly on a scaled copy of the airport master plan. In so doing, property available for site locations can be readily identified. Before considering these site locations further, it is suggested that the maximum permissible antenna height at each of these locations be determined by referring to FAR, part 77--Objects Affecting Navigable Airspace, and where applicable, by examining the moca charts for the airport in question.

b. Off-Airport Sites.

(1) An important concern in locating potential off-airport sites is to find property that is available through purchase or long-term lease. This property should be at an elevation that overlooks the surrounding terrain to the extent necessary to provide the desired coverage and should be more or less isolated from above-ground obstructions that may interfere or cause reflections in the radar/beacon operation.

(2) State, county, municipal, and topographical maps, together with aerial photographs where appropriate, should be used to identify and locate the suitable off-airport property. Within the limits of these maps and photographs, off-airport property studies should be made to identify and locate property that meet the following criteria:

(a) The property does not overlook any sizeable number of busy thoroughfares (highways, expressways, railways, etc.).

(b) The property is not located in an area zoned for commercial buildings or high-rise apartments.

(c) The property is not located closer than 2,500 feet from any local broadcast stations, or any industrial facility.

(3) In general, off-airport sites should be considered only as a last resort. Off-airport facilities are more subject to tangential course problems on runway approaches and to los runway approach coverage problems; they often require more costly RML remoting; and the FAA has less control over land usage in the vicinity of the site.

40. PRELIMINARY SITE INSPECTION. Having established the necessary legal permission, visits to each of the candidate site locations should be made and discussions with local government or business officials as necessary should be held to obtain the following information:

a. Screening Characteristics. Visual inspection of the environment and terrain surrounding the property using a hand level and magnetic compass, should be made to ascertain the quality and extent of the screening that exists. Both close-in and distant screening objects (i.e., hills, buildings, tree growth, horizon, etc.) should be identified over the entire 360° azimuth sector. Estimates of the range and heights of the screen objects relative to the property elevation should also be made. Snapshot photographs may serve as a helpful aid in recording/documenting many of these features for future reference.

b. False-Target Sources. Potential sources of beacon reflections such as fences, metal structures, hangars, towers, etc., within 1 nmi from the property should be identified. The size and/or extent of these reflecting surfaces should be obtained along with an estimate of their range from the site.

c. Terrain and Environmental Features. The environment and terrain characteristics should be documented by noting soil type, surface roughness, hilly areas, bodies of water, swamps, farmland, forests, urban areas, mountains, etc., on or near the property under consideration. On the basis of this data, a qualitative estimate of the extent and/or severity of the radar clutter to be expected should be attempted along with the identification of land sectors which may support lobing.

d. Accessibility. The existence of or need for roads to gain access to the property should be determined. Where road construction or improvement is necessary, estimates delineating the extent and type of construction or improvement shall be made.

e. RML/Landline Requirements. The required cabling distance for connection of the radar and indicator sites should be determined. Where this is incompatible with the maximum ASR and ATCBI cable lengths, an RML installation is indicated. In this case determine the los distance between the radar and indicator sites.

f. Electrical Power. Nearby access to three phase electrical power should be established. Estimate the nature and extent of the construction or installations necessary to provide power at the site.

g. Nearby Processing/Mining Industries. Chemical, sewage treatment, mining, or quarry operations located near or within the vicinity of the candidate site should be identified. Investigations should then be carried out to determine if any corrosive discharges, dust, chemical pollutants, shock, or vibrations produced by these individual operations are serious enough to cause mechanical or electrical failures in an ASR/ATCBI system.

h. Surface Traffic. Estimates of the length and direction of highways, expressways, railways, or roads that are visible from the property should be noted.

i. Drainage. The soil conditions, relief, and grading of the property terrain should be assessed from a drainage standpoint. Special note should be made of any leveling or grading necessary to improve drainage of the property.

j. Sanitation. The requirements for sewer and water connections to the candidate site should be determined. For convenience, a simple form such as shown in figure 3-6, may be used as a combination checklist/data sheet in the conduct of the preliminary site inspections.

41. PRELIMINARY SITE ANALYSIS. The purpose of this analysis is to determine the (two to three) most promising candidate site locations for in-depth survey and investigation. The analysis that will be carried out to support these decisions includes but is not necessarily limited to: (a) determining the approximate extent to which the given coverage requirements can be met at each of the candidate site locations, (b) estimation of extraordinary installation, operational, and/or maintenance costs that are required at each location, (c) identification of tangential course situations from each of the site locations, and (d) selection of site locations for in-depth survey and analysis. Since the data to be used in the analyses is only semi-quantitative at best, it should be recognized that absolute or precise results cannot be obtained at this preliminary stage. Hence, in the suggested approach that follows, the level of effort extended should reflect the need for relative comparison rather than an exacting and/or laborious assessment of candidate site locations.

a. Antenna Height for LOS Visibility. The purpose of this analysis is to estimate the antenna heights necessary for los visibility to each of the navigational fixes from the site under consideration. The principal factors to be considered in this analysis are the screening objects (close-in and distant) surrounding the candidate site. Using topographical maps together with the screening data recorded during preliminary inspections, the antenna heights necessary to obtain los visibility to each fix or sector of fixes should be determined and recorded separately. The highest antenna height required for los visibility is the one of interest. Plots such as los boundary diagrams or vertical coverage charts may be used where necessary to expedite these analyses.

b. Cost Estimates. In addition to the cost of acquiring the property, cost estimates relating to extraordinary site improvements, system

FIGURE 3-6

PRELIMINARY SITE INSPECTION CHECKLIST

SITE INSPECTED :	PAGE 1 OF 2
DATE :	PERSONNEL :

SITE ACCESSIBILITY : (note roads or improvements req'd, with est. of cost)

RML / LANDLINE REQUIREMENTS : (note LOS or cable dist. to IFR room, as applicable)

ELECTRICAL POWER PROVISIONS : (avail. of comml. pwr. and loc. of nearest access pt.)

SANITATION : (note any sewer, water connections req d.; est. cost)

TERRAIN TYPE : (note gen. char. of terrain near site)

DRAINAGE : (note any special grading / leveling req'ts.; est cost)

ENVIRONMENT : (note nearby natural or other sources of harmful radiation, shock, vibration, corrosive atmospheres)

FAA Form 6310-6 (12-73)

FIGURE 3-6. (Continued)

SITE INSPECTED :	PAGE 2 OF 2
SURFACE TRAFFIC : (est. length, dir., dist. of visible roadways & R.R. lines)	
SCREENING CHARACTERISTICS : (est range, ht. of close - in and distant screening objects for all azimuths)	
CLUTTER / LOBING ASSESSMENT : (est. severity of clutter in unscreened areas, note regions of poss. lobing)	
REFLECTORS : (note size, range of potentially harmful reflectors)	

FAA Form 6310-6 (12-73)

operations, and maintenance requirements should be made and tabulated for each potential site. Among the items for special consideration would be:

(1) Extensive and/or unusual road construction or improvements.

(2) Special installations to provide sanitary, water, and/or electrical power.

(3) Requirements for RML/cable data links.

(4) Grading, landscaping, or other property improvements.

(5) Tree removal or maintenance.

c. Tangential Course Analysis. The location and number of tangential course problems from each of the candidate site locations should be determined. This can be done by marking all primary and secondary flight paths in and out of the terminal airspace on a scaled map, on the los chart or equivalent, and identifying those flight paths which are tangent or nearly tangent to circles drawn from the site in question.

42. SELECTION OF SITES FOR SURVEY. The set of sites selected for in-depth survey should represent the most promising among those candidate sites investigated. To provide some assistance in making these choices, the following guidelines are submitted to facilitate trade-offs, comparison, and compromise among the various factors to be considered.

a. Maximum preference is given to those sites having the best potential for meeting the given coverage requirements. This potential should be evaluated by comparing or assessing the following factors for each candidate site with respect to coverage requirements.

(1) The range coverage capability of the ASR for the smallest aircraft of interest. Specify/describe the extent to which it is not expected to achieve these range coverage requirements.

(2) The ASR/ATCBI los visibility to the navigational fixes of interest. Specify the number of fixes that are not visible because of screening obstructions.

(3) The number of potential false target reflecting surfaces surrounding the site. The location and extent of possible beacon false target replies should be estimated.

(4) The azimuth sector in which ASR/ATCBI lobing may occur. Relate this to possible coverage problems.

(5) The expected runway and final approach/departure coverage.

(6) The extent of and sectors in which clutter can be expected. Estimate the possible losses in coverage.

(7) The extent of surface traffic visible to the ASR/ATCBI site location.

(8) The number of fixes and/or airways contained in or passing through the ASR/ATCBI "cone-of-silence".

(9) The number and location of all tangential course problems.

b. Airport sites are preferred over off-airport sites because of the usually better control of nearby construction, installation, and/or other development that could interfere with ASR/ATCBI operation.

c. Sites requiring cable data links less than 10,000 feet are preferred over those requiring RML equipment because of cost.

d. Sites should not be located near industrial operations whereby the ASR/ATCBI system may be exposed to corrosive discharges, electrical interferences, shock, and/or excessive vibrations.

e. Sites surrounded by undeveloped and/or natural areas are preferred over those in heavily congested urban areas, business districts, etc. This preference, however, is predicated on the knowledge that no known plans for future development exists in these undeveloped areas.

f. Site locations that provide a good deal of low-angle, close-in, natural screening against clutter, lobing, and false target sources are highly desirable.

g. Excessive site improvements for the purpose of screening, utility installation, providing road access, drainage, weather protection, tree removal, etc., are costly and should be avoided if at all possible.

h. Sites requiring contained annual maintenance such as trimming of trees, grading, drainage, road repair, etc., should be avoided.

SECTION 4. SITE SURVEY

43. INTRODUCTION.

a. The data and information to be obtained during the in-depth survey of each site may be separated into two principal categories, (1) communications-electronics, and (2) engineering and construction. The communications-electronics data relates, first of all, to the location of the ASR/ATCBI antenna and to the environmental factors that affect the operational performance of the radar/beacon system. These include the (1) effective height of the antennas, (2) screening angles about the site, (3) earth surface characteristics related to radar propagation, and (4) manmade reflection objects or surfaces surrounding the site.

b. Communications-electronics data also relates to the location, orientation, and space requirements for RML antenna towers or cable lines as required for communications between the ASR/ATCBI site and the TRACON indicator site.

c. Engineering and construction data that will be obtained relate to making the site operational. This will include surveys and investigations to determine the requirements for (1) water, electrical power, and sanitation, (2) road access, (3) grading, landscaping, and/or drainage, and (4) special construction or installations.

d. Although these factors have been considered in preliminary investigations, many of the results obtained were primarily derived from qualitative and semi-quantitative data. Because this data may be incomplete, or in some cases erroneous, it is necessary to verify their accuracy. This is indeed the primary purpose of the in-depth site survey. The following paragraphs describe the tasks and procedures recommended for carrying out this in-depth survey.

44. PRE-SURVEY COORDINATION. After the sites to be surveyed have been selected, a field siting team consisting of at least one radar/electrical engineer, a civil engineer, and one technician should be designated to coordinate and carry out the survey effort. One of the first responsibilities of the engineers will be to contact and/or convene the necessary conferences and meetings with cognizant individuals/representatives/agencies to expedite the following:

a. Review preliminary investigations and confirm results obtained for each of the sites selected for in-depth survey.

b. Select heights above ground level (agl) at which the detailed survey shall be made for each site.

c. Establish the order in which the sites will be surveyed.

d. Set a date and tentative time schedule for conducting the survey at each site.

e. Obtain the necessary legal approvals to conduct the survey at each site.

f. Review, assign, and schedule all tasks to be performed at each site.

g. Schedule and make arrangements for the transportation of personnel and equipment to the various site locations.

45. EQUIPMENT NEEDS. The following items represent typical technical equipments which are recommended to accomplish the site survey:

a. Adjustable scaffolding to provide a surveying platform at the height levels (spaced 10 feet apart) of interest at each of the sites.

b. Surveyor's transit capable of 1 minute resolution or better.

c. Stadia rods, level, and surveyor's tape.

d. 35 mm reflex camera with a lens having a minimum focal length of 85 to 90 mm. An assembly should also be provided for mounting and alinement of the camera with the transit vertical and horizontal reference planes. In addition, a lens recticle calibrated to produce azimuth and elevation degree marks directly on each photo is advised.

e. Photographic film, exposure meter, cable release, and lens filters.

f. 6x to 8x binoculars with a 35 mm to 56 mm objective lens.

g. Optical rangefinder with range capability of approximately 50 to 3,000 feet.

h. Abney hand level.

i. Pocket transit.

j. Tapes, 50 feet and 100 feet.

k. Drafting equipment.

l. 10-inch protractor.

m. Triangles.

n. 24-inch straight edge.

o. Data sheets, worksheets, logbooks, etc.

46. SCAFFOLD ASSEMBLY.

a. It will be necessary to erect a scaffold assembly at each of the sites under investigation to provide a surveying platform at the antenna height of interest. Since the antenna height selected in previous studies is based on preliminary studies only, it is advised, although not always necessary, that the survey be made at three levels, corresponding to (1) the nominal height selected, and (2) ±10 feet above and below this height. This will require that the scaffolding be adjustable. In erecting this scaffolding, special precautions should be taken to assure adequate footing and guy wire supports for stability and personnel safety. The scaffolding tower should be guyed at all corners every 30 feet or less. It is important that the platform deck be firm and rigid to eliminate unwanted instrument movement.

b. An alternative to the use of scaffolding is the crane-mounted bucket or "Cherry Picker". When this is a feasible alternative, it is generally less expensive and time consuming than the use of scaffolding. Guy wires are still required for stability.

47. SCREENING PROFILE MEASUREMENTS.

a. The purpose of the screening profile measurement is to collect precise screen angle data from which los visibility contour diagrams can be constructed. Data contained in the los diagram is used to determine the los coverage capability that can be expected for the ASR/beacon system at the antenna height and site location under consideration.

b. The screening angles are measured using a surveyor's transit instrument to determine the elevation angle of all screening objects through 360° in azimuth as viewed from each of the prospective antenna heights. These antenna heights correspond to the height(s) selected on the basis of preliminary investigations.

c. The screening profile of concern, for the most part, will be the skyline profile about the site location. However, where an applicable amount of navigable airspace exists beneath this skyline los in the region between the site location and skyline object, it is required that this airspace be accounted for by making the appropriate survey. This condition, which is principally found in mountainous regions, is illustrated in the examples shown in figures 3-7 and 3-8. Figure 3-7 illustrates a situation where a considerable sector of navigable airspace exists between the two lines-of-sight established by the close-in hill and distant mountain skyline. The size of this sector is dependent on the distance between the mountain and site location and the size of the los angle difference, $(\theta_d - \theta_c)$ shown in the figure.

d. To determine the close-in screen profile about the site location, it should be recognized in figure 3-7, that the close-in los passes over the intervening hills, buildings, or other objects. between the close-in screening objects and the distant mountain.

e. Figure 3-8 illustrates a case where the low-angle screening profile may be somewhat more difficult to establish when surveying. Here no distanct and/or contiguous screening objects exist between the site location and the base or foothills of the mountain. Under these circumstances, a virtual screening profile along the base of the mountain should be established by lowering the surveying

FIGURE 3-7. ILLUSTRATION OF CLOSE-IN AND DISTANT OR SKYLINE SCREEN PROFILES

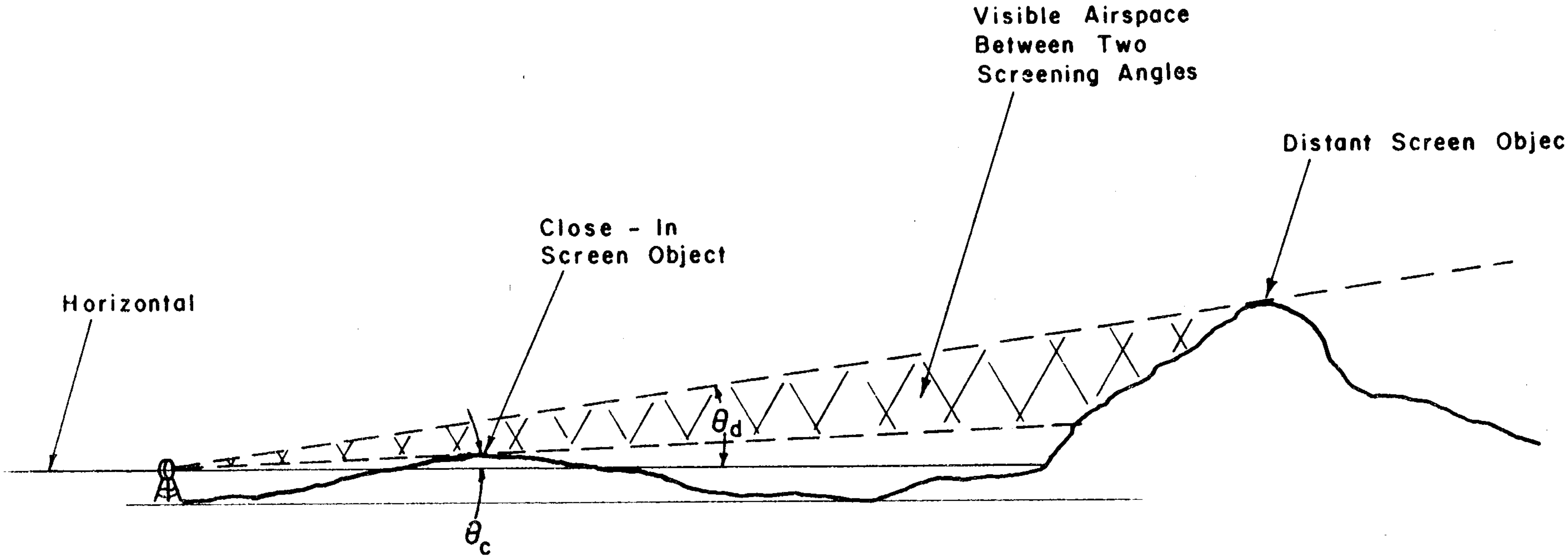
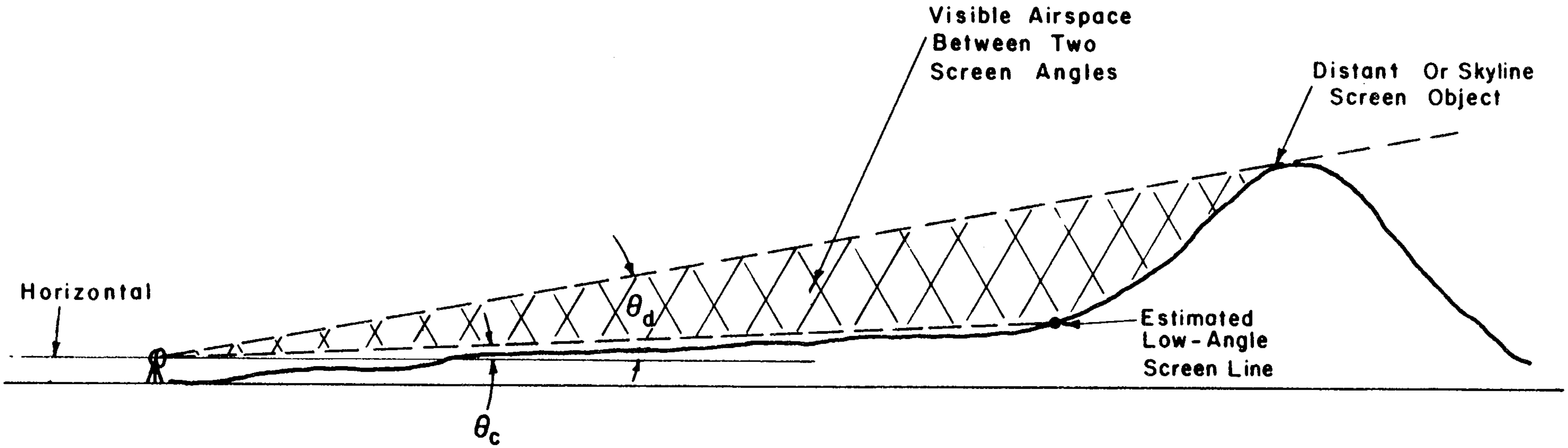


FIGURE 3-8. ILLUSTRATION OF DIFFERENCE BETWEEN LOW-ANGLE AND DISTANT OR SKYLINE SCREEN PROFILES



instrument until visually encountering any object between the site and mountain slope. The recorded low-angle los should pass over all intervening terrain, buildings, objects, etc.

f. As many observations of the vertical angles to the successive screening objects are taken as is necessary to define the 360° profile. Where the profile is highly irregular such as in mountain regions, readings of the vertical angle should be made to significant points on the skyline or close-in profile; that is, to the successive peaks and valleys that describe the profile. Azimuth intervals will, therefore, very but should not be made smaller than 1° except for cases of unusual or rare profile irregularities. Vertical angles above and below the local horizontal should be read to the nearest (1.0') minute.

48. TRANSIT SURVEY PROCEDURES.

a. Set up and level the transit at the location and height selected for the antenna. Make the necessary calibrations/adjustments to orient the transit with respect to magnetic north and correct for compass reading distortions caused by steel scaffolding. Select a true north reference and record for future reference and data conversion. A stake or suitable distant object will serve equally well. Set a marker at the center of the tower for future reference. Number and mark each tripod leg extension as well as each tripod leg and plumb bob point on the deck. This will permit resetting the transit at the same location and elevation with sufficient accuracy to continue the horizon profile work, should an interruption occur.

b. Enter pertinent data identifying the site by name, number or other designation, and describing the site location, ground elevation (msl), survey height (agl), etc., on the Screen Angle Survey Data Sheet (figure 3-9). Care should be taken to include the height of the transit tripod as well as that of the scaffold platform in determination of survey height. Specify whether the data is for the close-in or skyline profile and proceed as in steps c through g.

c. Sight the instrument on the screening object, using the vertical circle tangent screw for alinement of the intersection of the vertical and middle horizontal crosshairs with the profile of the screening object.

d. Enter the azimuth angle (to the nearest minute) of the screen object in the azimuth column marked TO and in the column marked FROM on the next line.

e. Enter the vertical angle (to the nearest minute) in the second major column. Care should be taken in reading the vernier correctly for plus and minus angles.

FIGURE 3-9

SCREEN ANGLE SURVEY DATA SHEET

Site Identification ____________ Close-In / Low Angle Screen ________

Site Location { Longitude ________ Skyline / Distant Screen ________
{ Latitude ________

Survey Elevation (AGL) ________ Recorder ________________

Site Elevation (MSL) ________ Date ________

AZIMUTH (Mag. North)		AZIMUTH (True North)		SCREEN ANGLE	SCREEN DISTANCE (Nautical Miles)		SCREEN ANGLE	DESCRIPTION OF SCREEN OBJECT
From	To	From	To	(Optical)	Estimated	Measured	(Radar)	

FAA Form 6310-5 (12-73)

f. Enter the estimated or measured distance to the screening object and identify the screen object as "distant horizon," "buildings," "nearby trees," etc. in the last columns. Distance estimates can be made by reference to known landmarks or by study of accurate site vicinity topographical maps.

g. Repeat steps c, d, e, and f until all data are obtained through 360° in azimuth. Frequent checks should be made to see that the instrument remains level as screening measurements progress. Particular attention should be given to the bubble whose axis is parallel to the axis of the telescope, and any necessary readjustments of the leveling screws should be made.

49. PANORAMIC PHOTOGRAPHS.

a. The panoramic photograph is intended to provide a pictorial representation of the visible skyline as viewed from the radar site and, also, to show the character of the surrounding terrain, buildings, fences, etc., comprising the reflection surfaces for the ASR/ATCBI. It also serves to supplement the measured screen angle data by emphasizing significant points of merit when assesing and comparing the various site locations.

b. The process of obtaining a panoramic view of the site surroundings consists of successive takes of as many separate exposures as are required to photograph the 360° azimuth about the site. It is recommended that each photograph extend over a maximum of 20° in azimuth, requiring a total of at least 18 to 19 photographs to obtain the full 360° panoramic. Panoramics should be taken at each of the antenna heights from which the screen angle measurements were taken.

c. The following procedures may be used as a guide in taking the panoramic photographs:

(1) Load the camera. Daylight black-and-white or color film of fine-grain, moderate speed (ASA 125 for black-and-white, ASA 64 for color) is recommended.

(2) Mount the camera on the tripod at the antenna height used in making the screen angle measurements.

(3) Bring the camera to a fine focus on the horizon using the focus adjust. Scan the camera 360° in azimuth to assure that the distant screening profile falls within the field of view.

(4) Select an appropriate filter to compensate for any haze, glare, shadow, or overcast conditions that may prevail.

(a) For black-and-white panchromatic film, yellow (K2, No. 8), deep yellow (G, No. 15), and red filters (A, No. 25) give progressively greater haze penetration in that order. In addition, these filters provide progressively sharper contrast between clouds and the sky, buildings and the foliage, etc.

(b) Polarizing filters are extremely useful in either black-and-white or color photography. They do not alter any of the colors in the scene, but intensify them by removing glare from tiny reflections that are largely invisible to the naked eye. They are also useful in controlling reflections from non-metallic surfaces such as glass, plastic, stone, painted structures, etc. Polarizing filters also darken blue sky and generally intensify sharp detail.

(c) In color photography, the effect of atmospheric haze is to reflect invisible ultraviolet radiation which in turn causes an excessive bluishness. These effects can be cut down or eliminated by using a skylite (1A) or ultraviolet (UV) filter.

(5) Orient the camera with respect to true north or with respect to some known reference point in azimuth. Record the azimuth reference point.

(6) From the light-meter reading, select the values for shutter speed and aperture (f-stop). Select the highest aperture (larger than f/8) possible for a 1/125 second or faster shutter speed. The higher the f-number, the greater the depth of field obtained. A new speed and aperture setting is usually required about four times in 360° unless the sun is directly overhead and there are no clouds. If a filter is used for better definition, contrast, etc., the f-number or shutter speed should be corrected in accordance with the filter manufacturer's instructions.

(7) Make as many exposures as may be required to obtain the complete panoramic. Each frame should include about a degree of overlap between successive frames to minimize end distortion and allow for waste in the printing process and later assembly of the complete panoramic. Since each frame will cover approximately 20° in azimuth, approximately 19 exposures will be needed to photograph the full 360° azimuth.

(8) Make such notes as may be required to identify the separate takes. Azimuth references to prominent skyline features are especially worthwhile. A simple record of each photo taken will eliminate taking two shots of one azimuth or double exposure. It is recommended that the film for any one level be processed and inspected prior to removing or lowering the scaffold tower.

50. ADDITIONAL DATA. In addition to photographs and screen angle measurements, observations made at the time of preliminary site inspection, and recorded on the Site Inspection Worksheet (figure 3-6), should be verified and refined where necessary during the site survey. In particular, careful examination of the surroundings for sources of clutter, vertical lobing, and reflecting surfaces should be made for each site surveyed. Data recorded should include:

a. Clutter Estimates:

(1) General terrain type(s).

(2) Range and azimuth dimensions of areas where severe clutter is expected.

(3) Range and azimuth of potentially large permanent echoes.

b. Vertical Lobing Estimates:

(1) Location of relatively smooth, horizontal surfaces within the radar field of view.

(2) Maximum height of surface irregularities in each area.

(3) Range and azimuth dimensions of each area.

c. Reflector Estimates:

(1) Location, orientation of moderate to large reflecting surfaces within 2,500 feet of site.

(2) Location, orientation of large reflectors within 5,000 feet of site.

(3) Estimated lengths, direction, location of visible roadways, railroad lines, and runways.

d. Cost Data: All data covering soil condition, drainage, site preparation, road access, electrical power, cable length and routing, duct lines, handholes, etc., necessary to estimate total cost of establishing ASR/ATCBI site at the surveyed location.

SECTION 5. SITE ANALYSIS

51. INTRODUCTION. In this section, methods and procedures for processing and analyzing information gathered from the preliminary studies and site survey are presented. The analysis procedures described should be applied to each site actually surveyed. This will provide a systematic compilation of radar and beacon performance information, such that a meaningful site recommendation can be formulated. The required analyses (described in the following paragraphs) cover the following:

a. Site panoramic photograph.

b. Screening analysis.

c. LOS altitude coverage analysis.

d. ASR coverage analysis.

e. Beacon coverage analysis.

f. Beacon vertical lobing analysis.

g. ASR vertical lobing analysis.

h. Beacon false-target analysis.

i. Clutter analysis.

j. Tangential course analysis.

k. Second-time-around analysis.

l. Cost estimate.

m. Environmental impact analysis.

52. SITE PANORAMIC PHOTOGRAPH. The panoramic photographs obtained during the site survey represent an important part of the data collected. The major value of these photographs is as a convenient reference in support of current or future site investigations and analysis. Some anticipated applications of the photographs include: (a) a pictorial display of the terrain features about the site, (b) a reference aid in identifying/locating prominent or troublesome reflecting objects (buildings, hangars, fences, highway traffic, etc.) about the site, (c) a check and cross-reference for screen angle transit data, and (d) a convenient reference base for troubleshooting of future ASR/ATCBI problems caused by modification of the site vicinity through construction (e.g., buildings, roads, grading) and/or natural changes (e.g., vegetation growth). The panoramic photograph is prepared from the individual overlapping exposures taken at the antenna site. They should be formed into a single strip by matching, cutting, and joining the individual prints. The assembled panoramic is then marked to indicate the cardinal directions in azimuth, local horizontal, degrees azimuth and elevation, and salient points or objects appearing in the panoramic.

53. SCREENING ANALYSIS. The purpose of this analysis is to determine the radar antenna height necessary to achieve los visibility to the required navigational fixes from each of the site locations considered.

This analysis is preceded by the preparation of a screen angle graph. The screen angle graph is a plot of the angular elevation of both the close-in and distant (or skyline) los profile as viewed 360° in azimuth from each site location surveyed. The graph should be plotted in the rectilinear form shown in figure 3-10.

a. Preparation of Screen Angle Graph.

(1) The radar screen angle graph is derived from optical screen angle data taken during the site survey and entered in the Screen Angle Survey Data Sheet (figure 3-9). Optical screen angles are converted to radar screen angles with the aid of equation 2-12 (p. 85). (The equation accounts for "normal" refraction of radar signals based on the 4/3 earth radius model. A derivation is given in appendix 3.) This equation is rewritten below to allow direct computation of angles in minutes.

$$\theta_{rs} = \theta_{os} + \frac{3d_s}{56} \qquad (3\text{-}1)$$

where

θ_{rs} = radar screening angle in minutes

θ_{os} = optical screening angle in minutes

d_s = distance to screen object in nautical miles

(2) After completing the screening profile plots, the azimuth and elevation angle of each navigational fix should be identified and marked directly on the screen angle graph. The azimuth and elevation angles of runway fixes should also be plotted on the screen angle graph. These are located at 300 feet agl, and at a point 1 nmi from the ends of each runway.

(3) Determination and plotting of all fix locations can be facilitated through data entry in columns C through H of the los coverage worksheet, FAA Form 6310-1 (11-73), shown in figure 3-11. The fix azimuth and range data of columns C and D are determined from map studies, whereas fix height in column E is obtained directly from the ATD coverage requirements. Fix height above the survey height (column F) is determined by subtracting the msl survey height from each of the values in column E. The elevation angle of each fix (column G) can then be determined from equation 3-9 of appendix 3, or from the accompanying radar coverage charts. As an additional step it is advised that the elevation angle of each fix be

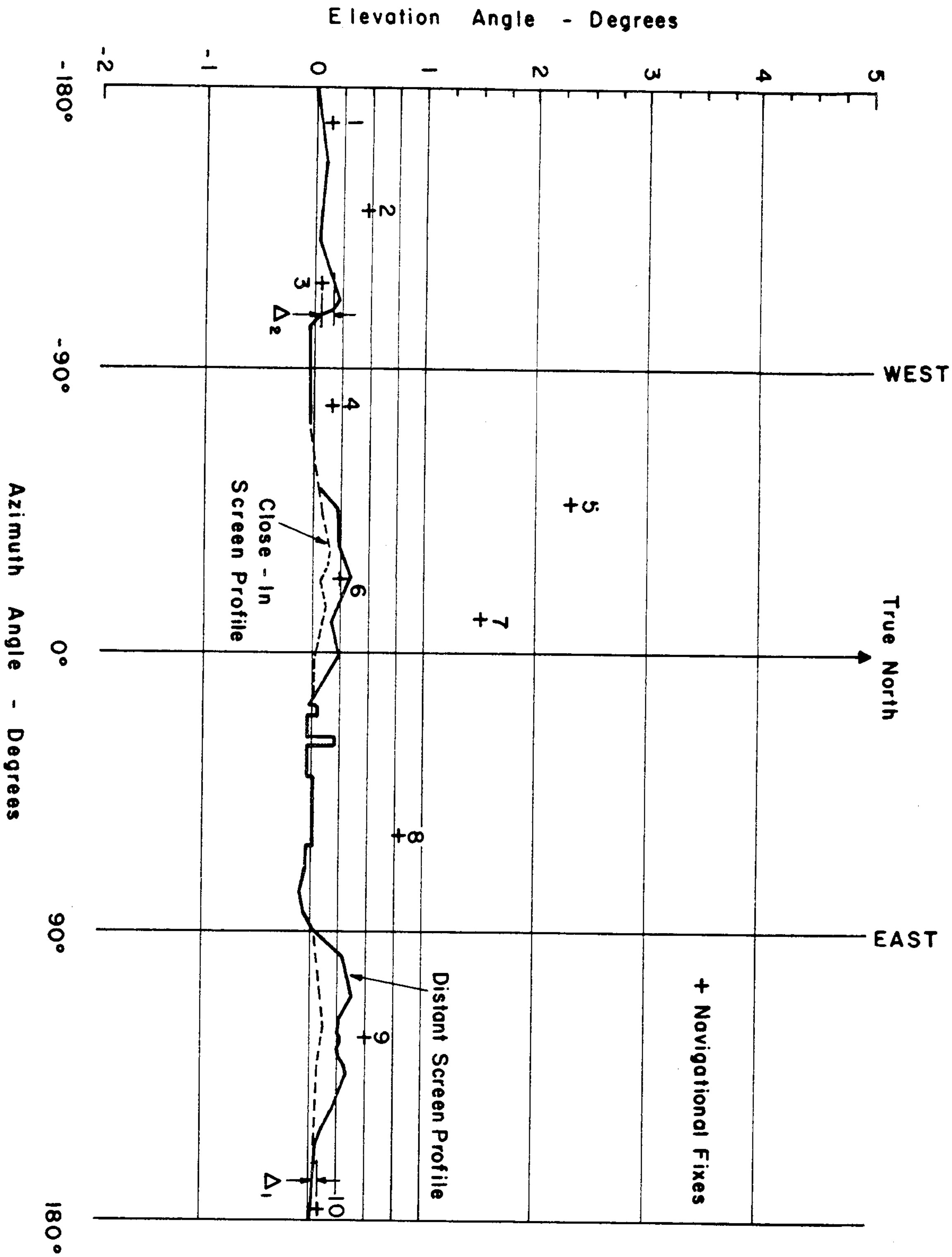


FIGURE 3-10. SCREEN ANGLE GRAPH

FIGURE 3-11

LOS COVERAGE WORKSHEET

SITE:	RADAR TYPE:	CONDITION: ☐ LP-FAIR ☐ CP-HVY PRECIP
SITE LOCATION: LATITUDE LONGITUDE	SITE ALTITUDE: FT MSL SURVEY HEIGHT: FT AGL ANTENNA HEIGHT: FT MSL	DATE: PREPARED BY:

Ⓐ No.	Ⓑ Name Of Fix	Ⓒ Fix Azimuth (Deg.True)	Ⓓ Fix Range (n.m.)	Ⓔ Fix Height (Ft. MSL)	Ⓕ Fix Ht. Above Antenna (Ft)	Ⓖ Fix Elevation Angle (Deg.)	Ⓗ Adj. Fix Elevation (Ⓖ-0°5') (Deg.)	Ⓘ Measured Screen Angle Radar (Deg.)	Ⓙ LOS Coverage			Ⓚ Radar Coverage For 2.5° Tilt	
									Yes	No	Marg.	Yes	No

Maximum Tilt Angle For Coverage Of All Fixes ________

FAA Form 6310-1 (11-73)

reduced by a safety factor of 5 minutes to account for uncertainties due to transit measurements, plotting, range estimation errors, etc. This corresponds to a lowering of the msl altitude of a fix located at 60 nmi by approximately 500 feet. As range to the fix decreases, this altitude safety factor will become correspondingly smaller. The adjusted elevation angles are recorded in column H of the worksheet, and the location of the adjusted fixes plotted on the screen angle graph.

(4) Radar screen angles at the azimuth of each fix can be determined directly from the screen angle graph and recorded in column I of the worksheet. Finally, column J of the worksheet is completed as follows. If the adjusted fix elevation angle (column H) is greater than the measured radar screening angle (column I), full los coverage is provided. On the other hand, if the screening angle is greater than the measured fix elevation angle (column G), no los coverage is possible. For the intermediate condition, where the radar screen angle is between the columns G and H, coverage is considered marginal because of the uncertainty introduced by the 5-minute safety factor. Worksheet column K entries are discussed in paragraph 55 below.

b. Analysis.

(1) An analysis of the screen angle graph should be made to answer the following:

(a) Are all navigational fixes visible from the site at the antenna height selected?

(b) If all fixes are visible, to what minimum height can the antenna be lowered and still provide los visibility?

(c) If some fixes are screened from los visibility, to what height must the antenna be raised in order to provide los visibility?

(2) The answer to the first question can be found by inspection of the screen angle graph. Navigational fixes above the screen angle profile are visible; those below are not. One special case, however, may develop where the answer is not so obvious. This occurs when the navigational fix lies somewhere between the close-in and distant screening profiles as illustrated by fix 6 in figure 3-10. In such instances, it will be necessary to determine if the range to the fix falls within the range between the close-in and distant screen objects.

(3) For the case when all navigational fixes are located above the screen profile, it is appropriate to consider how much the

antenna can be lowered and still provide los visibility to all fixes. This will be dictated by that navigational fix whose elevation angle is closest to the screen elevation profile in the screen angle graph. For example, let the fix designated 10 in figure 3-10 represent the closest fix to the screening profile (for purposes of this discussion, we have assumed that fixes 3 and 6 are not present). The angular displacement between the fix and the screen profile is shown as Δ_1. If the fix is located at a distance greater than that of the screening object, lowering the antenna height results in a reduction of Δ_1. (For fixes whose distances are less than that of the screening object, lowering of the antenna height INCREASES Δ_1. Hence, in this investigation we are concerned only with the fix having the least separation at a distance greater than the screening object.) Assuming this is to be the case, the value of Δ_1 determines the extent to which the antenna can be lowered. This is given by the following equation (which is derived in appendix 3):

$$h_2 = h_1 - \frac{1.769\ d_f d_s}{(d_f - d_s)} \left|\Delta_1\right| \qquad d_f > d_s \qquad (3\text{-}2)$$

where:

h_2 = lowered antenna height in feet

h_1 = antenna height in feet at which survey data was taken

d_f = distance to navigational fix in nautical miles

d_s = distance to screening object in nautical miles

$\left|\Delta_1\right|$ = magnitude of angular separation between fix and screening object measured from the graph in minutes.

(4) For the case where a navigational fix is screened or lies below the screen angle profile a similar analysis is made to determine the height to which the antenna must be raised to provide the desired los visibility. Here, however, the angular separation, Δ_2, of concern, is that defined by the fix having the largest angular displacement below the screen profile. In figure 3-10, fix 3 is shown as being the one furthest below the screen profile and thus becomes the defining Δ_2 for raising the antenna height. The value to which the antenna should be raised is given by the following equation:

$$h_2 = h_1 + \frac{1.769\ d_f d_s}{(d_f - d_s)} \left|\Delta_2\right| \qquad d_f > d_s \qquad (3\text{-}3)$$

where h_1, d_f, and d_s are the same as in the previous equation, and:

h_2 = raised antenna height in feet

Δ_2 = magnitude of angular separation in minutes when the fix lies below the screen profile

(5) It should be noted that the accuracy to which the antenna heights can be determined from the above two equations depends significantly on the following two factors. (Uncertainties in Δ have been accounted for previously in terms of the 5-minute safety factor used.)

(a) The ratio d_f/d_s of the fix distance to the screening object distance, and

(b) The accuracy in measuring the two distances d_f and d_s (either from map studies or the rangefinder).

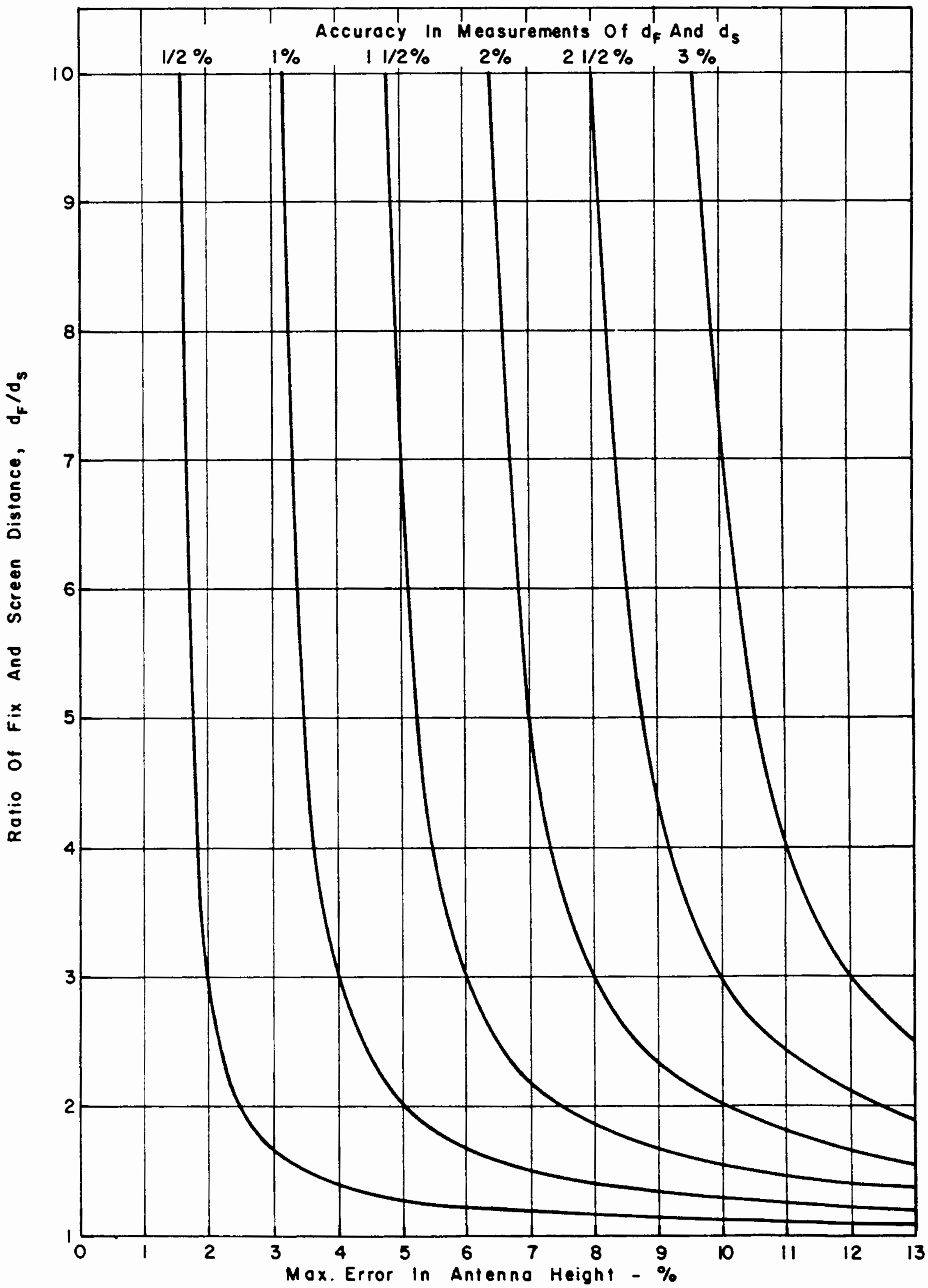
(6) Mathematically, if the accuracy in determining the distances, d_f and d_s, is x%, then the worst possible percentage error in the antenna height is given by the equation:

$$\text{Max. \% Error} = \pm x \left[2 + \frac{\frac{d_f}{d_s} + 1}{\frac{d_f}{d_s} - 1} \right] \qquad d_f > d_s \qquad (3\text{-}4)$$

(7) To assist in determining the percentage error in the antenna heights obtained using the above techniques, a plot of the above equation for various combinations of x and d_f/d_s is shown in figure 3-12. A review of these plots reveals a significant loss in accuracy as the distance between the fix and screen object decreases. The screening analysis procedure is illustrated in appendix 6.

(8) The significant result obtained in the above analysis is the minimum antenna height necessary to provide los visibility to all fixes from a given site location. In most cases, however, this minimum height will not be physically realizable because ASR/ATCRBS tower heights can only be varied in 10-foot increments. Hence, the actual minimum antenna height to be specified will correspond to the nearest achievable height above the minimum value determined from the screening analysis.

FIGURE 3-12. PERCENT ERROR IN ANTENNA HEIGHT AS A FUNCTION OF SCREEN OBJECT AND FIX DISTANCE



54. LOS ALTITUDE COVERAGE ANALYSIS. Radar los coverage of the controlled airspace can be readily determined with the aid of a los boundary diagram. The diagram is a plan view of the radar range visibility limits about the antenna site at specific altitude levels. It is prepared using the radar screening angle data indicated in figure 3-9 and offers a different perspective for assessing radar visibility than that of the screen-angle graph. Its major use is in assessing los visibility of air routes between the navigational fixes in the terminal area. Also, since the diagram is plotted on polar coordinate paper and shows all air-routes in the terminal areas, it is convenient to use in identifying and locating tangential course problems for subsequent studies.

a. Preparation of LOS Boundary Diagrams. The radar los boundary diagram should be prepared on FAA Drawing D-50979-1 (figure 3-13) or its equivalent. Because of the numerous altitude levels at which aircraft can operate in the terminal area, it is advisable to consider plotting several boundary diagrams using different range/altitude scaling in order to avoid confusion. The choice of altitude levels of interest will depend upon the altitude levels the aircraft will fly in the terminal airspace. Best results are obtained if altitudes of about 300 feet, 600 feet, and 1,000 feet above the radar antenna are considered on one diagram and a second diagram prepared for 1,000, 2,000, 3,000, 4,000, and 5,000 feet levels. Boundary diagrams for other altitude levels, either above or below the radar antenna, may also be prepared as necessary to determine the minimum visible altitudes at the maximum range (∿60 nmi) for the ASR. The appropriate msl altitude should be marked on each plotted los contour.

b. Procedures.

(1) The necessary information to construct the los boundary diagram is obtained from the transit data taken in the field. The los altitude/range cutoff worksheet (figure 3-14), FAA Form 6310-2 (11-73), is a convenient means of tabulating the information concerning screen angles, azimuth sectors, and the resultant los cutoff range to the various altitude levels of interest. In transferring data from the screen angle survey data sheet (figure 3-9) to the los altitude/range cutoff worksheet, it is recommended that, to avoid meaningless detail in the plot, suitable averaging or quantizing techniques be made to enlarge the azimuth sectors to be plotted. One such approach is to define azimuth sectors on the basis that the screening angle profile within the sector does not vary by more than 10 minutes. The screening angle over this azimuth sector is then tested as being constant. To eliminate any errors in subsequent analysis of the los boundary diagram, the maximum screen angle over this azimuth sector should be used for determining the corresponding range cutoff distances as a function of altitude.

FIGURE 3-13. POLAR COVERAGE CHART

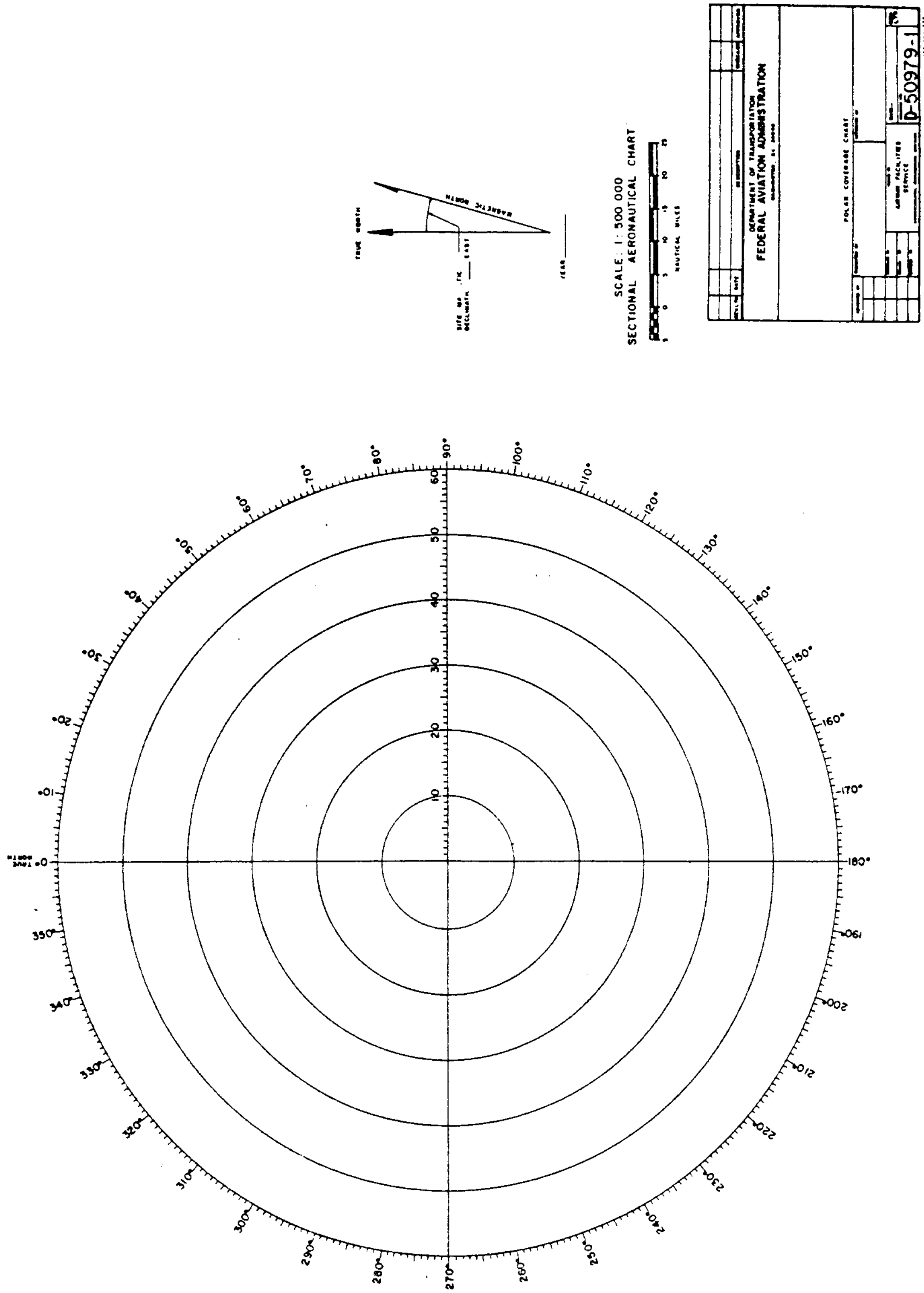


FIGURE 3-14

RADAR LOS ALTITUDE RANGE CUTOFF WORKSHEET

SITE IDENTIFICATION: ______	SITE COORDINATES: ______	DATE: ______
ANTENNA HEIGHT ______ FT. MSL	LONG. ______ LAT. ______	PREPARED BY. ______

1		2	3	4	5						
AZIMUTH (True North)		RADAR SCREEN ANGLE	SCREEN DISTANCE NM	SCREEN OBJECT	RADAR LOS CUTOFF RANGE IN N.M. ALTITUDE IN FEET						
From	To				300	600	1000	2000	3000	4000	5000

FAA Form 6310-2 (11-73)

(2) For each azimuth sector quantized, the azimuth angles bounding those sectors should be entered in column 1 of the worksheet and the corresponding radar screen angle entered in column 2. The screen distance entries (column 3) should correspond to the range to the screen object with the largest positive screen angle or largest angle in a positive direction if there are objects with a negative screen angle. The object defining this angle should then be identified by name in column 4. All other objects within this same azimuth sector are disregarded.

(3) Knowing the altitude (relative to the msl elevation of the antenna) and the screen angle, the cut-off ranges for the various altitude levels of interest are determined from a 4/3 earth-radius screen angle chart given in appendix 3. After all entries are complete, the radar los coverage diagram (illustrated in figure 3-15) is plotted as follows:

(a) With the proposed site located at the center, mark off the azimuth sectors defined for the screen angles in the worksheet.

(b) Using the cut-off range for the altitude of interest, as the radii, draw an arc enclosing the azimuth sector.

(c) Repeat step (b) for each azimuth sector listed on the worksheet.

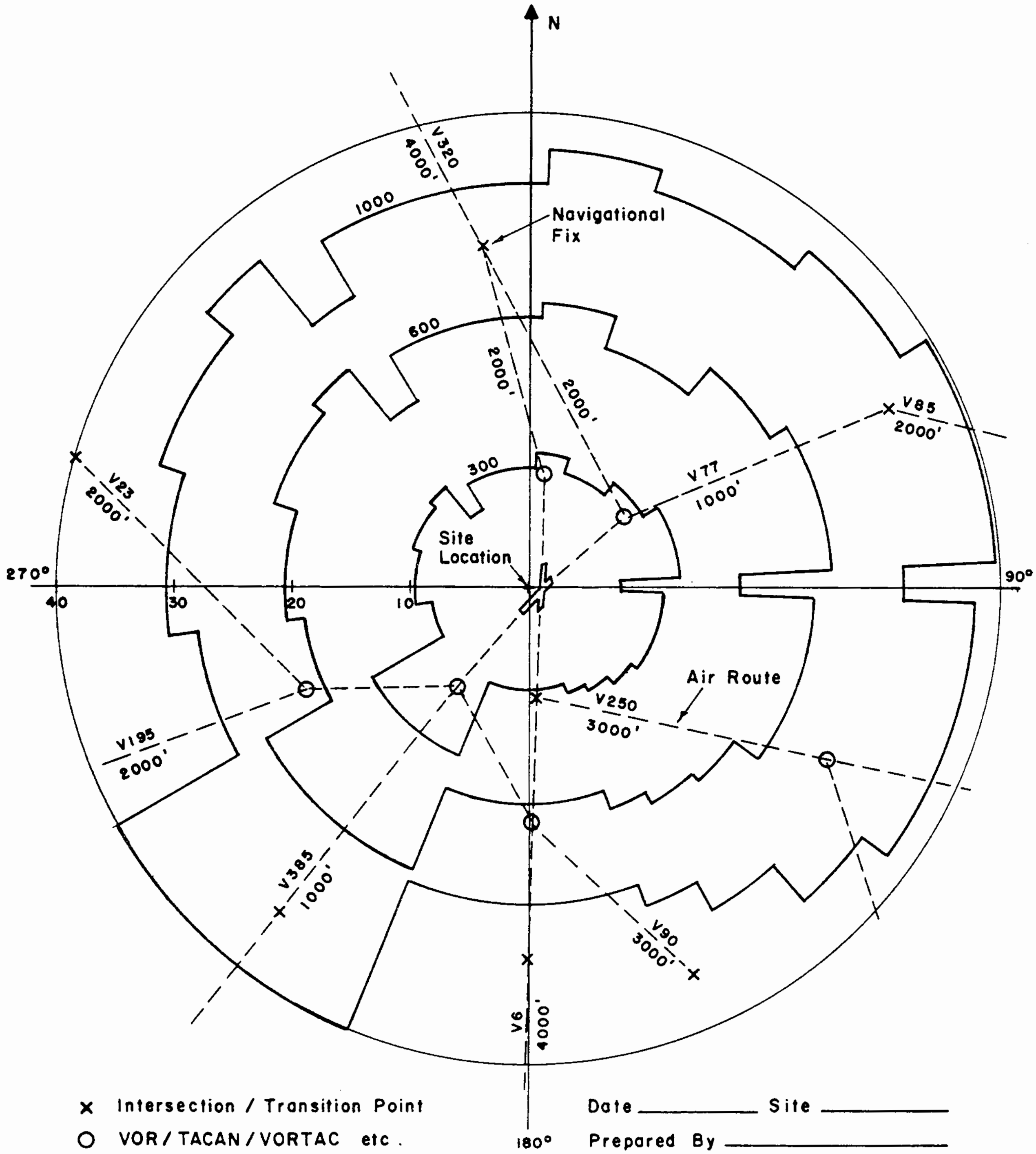
(d) Connect the arc lengths by the radial line segments between successive azimuth sectors.

(e) Repeat steps (b) through (d) for each altitude of interest. To facilitate ease in subsequent studies, different range scales may be required for plotting the various altitude contours. In such cases, it is recommended that more than one diagram be prepared.

(f) Complete the drawings by labeling to show altitudes, true north, map scale, site identification, etc.

(4) After constructing the radar los coverage diagram(s), the navigational fixes about the terminal airspace should be located and marked directly on the diagram. The azimuth and distance of each fix relative to the site location can be obtained directly from the screen-angle graph and map study computations prepared earlier. All interconnecting air routes are then drawn in straight lines between the various fixes and labeled. The minimum msl altitude at which aircraft can operate (specified by ATD, flight safety, and moca charts) over the air routes shown, should be marked directly on the diagram alongside each air route line segment.

FIGURE 3-15. RADAR LOS BOUNDARY DIAGRAM



c. Analysis.

(1) Two general results can be obtained from an analysis of the combined radar los coverage and air route diagram. One is tc establish the los visibility, or lack thereof, of aircraft operating at their respective minimum altitudes over each air route in the terminal area. The second is to identify and locate all potential tangential course problems that can develop as aircraft travel over these air routes.

(2) To establish visibility of the air routes, the minimum operating altitude of each air route segment is examined relative to the range/altitude contour plots. The rule for establishing visibility of any point along the air route is as follows:

> The range and azimuth of the point along the air route must fall within a region bounded by a contour whose altitude is lower than that specified for the air route.

(3) Clearly, when all points along an air route segment meet this criteria the entire segment will be visible. Any sequence of points not meeting this criteria should be marked and bounded by a cross-hatched rectangle to indicate the lack of los visibility.

(4) Tangential course conditions where the mti capability of the ASR may be seriously impaired can be identified by noting on the combined altitude contour/air route diagram where, if any air routes are tangent or nearly tangent to any diameter circle about the site location. These potential problem zones should be marked and/or tabulated for further investigations as discussed in paragraph 60.

(5) If it should be desired to extend the coverage analysis to include a runway approach coverage analysis (i.e., coverage to touchdown) a chart such as the one illustrated in figure 8 of appendix 3 may be useful for presenting glide slope coverage. An illustrative example of the application of los analysis procedures is given in appendix 6.

55. ASR COVERAGE ANALYSIS.

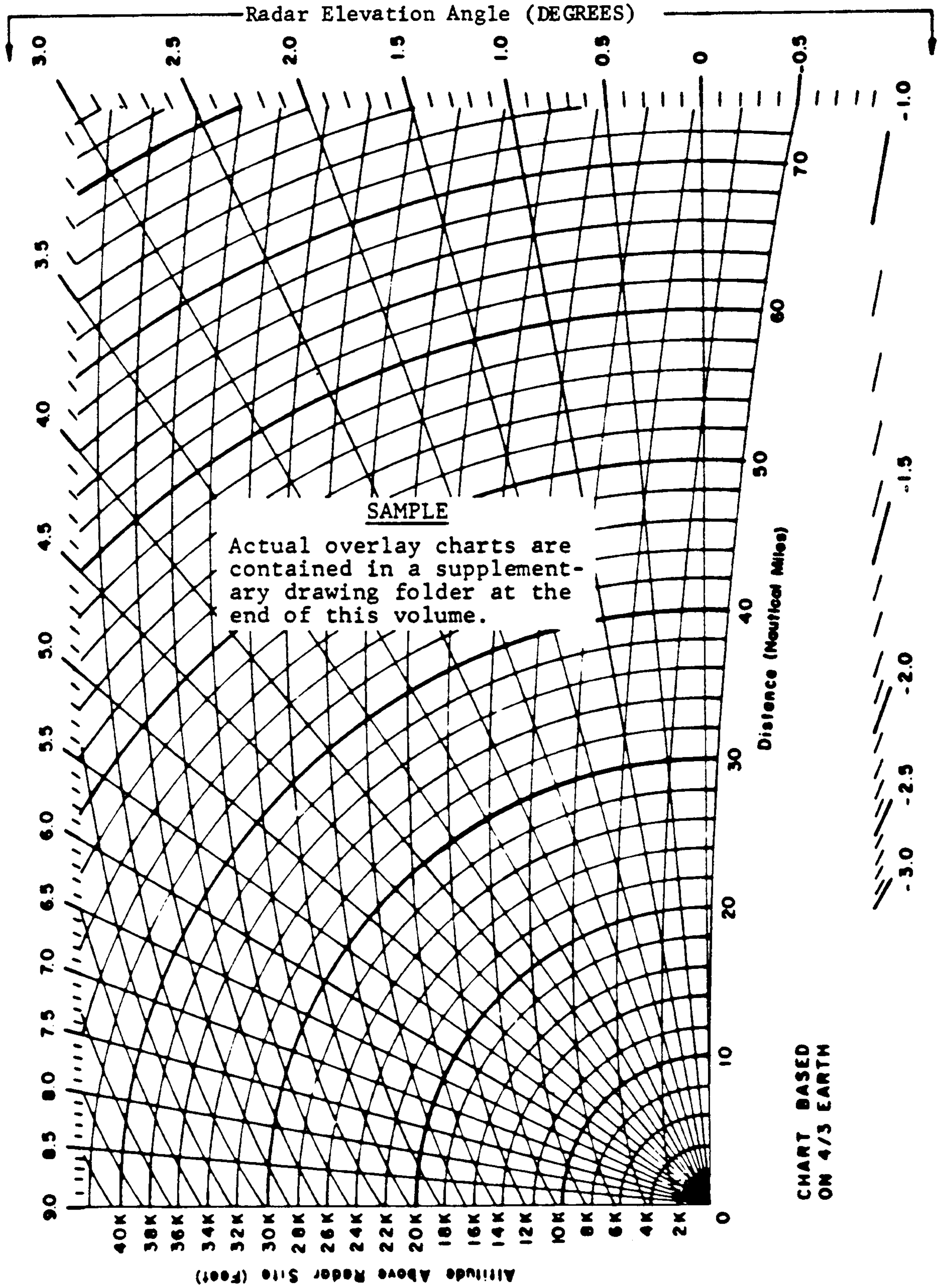
a. Introduction. For an ASR site to provide adequate surveillance of the controlled airspace, two conditions must be met, namely, (1) all required navigational fixes must be visible on a direct los from the radar and (2) given los visibility, the radar must be capable of detecting all aircraft of interest at the range and altitude of each fix. LOS visibility of each fix (or its absence) has been determined through the previous analysis. In the procedure outlined here, plots of ASR vertical detection capability are used to determine the adequacy of FREE-SPACE radar coverage for the antenna height selected and a nominal antenna tilt. In addition, the analysis provides information on the maximum permissible tilt angle without loss of radar coverage. This represents refinement of a similar analysis (see paragraph 38b(2)) carried out during preliminary work.

b. Radar Coverage Indicator Chart. The procedures given here make use of the radar coverage indicator (rci) chart of figure 3-16, together with an appropriate rci overlay chart (figures 3-17 through 3-21). (The drawings following in the body of the text, figures 3-16 through 3-21, are samples. The actual overlay charts are contained in the supplemental drawing folder bound at the end of this volume.) The latter give free-space ASR coverage of a T-33 aircraft under several polarization/climatological conditions.

c. Overlay Chart Selection. Single overlay charts containing coverage contours representing three conditions (i.e., lp--fair weather, cp--fair weather, cp--heavy rain) are given for the ASR-4B, 5, and 6, and * for the ASR-7, respectively. Three charts are given, respectively, for the ASR-5E, 6E, 7E and ASR-8, each covering one of the propagation conditions. On these charts two coverage contours are shown, one for ASR-5E, 6E, 7E or ASR-8 operation with the main antenna only, and one for ASR-5E, 6E, 7E or ASR-8 operation in the dual beam mode. * The siting engineer should select for use that rci overlay contour which corresponds to the radar being sited and the worst-case climatological conditions expected at the site locale.

* d. Procedure. Two slightly different analysis procedures are described below, one applicable to ASR-4B, 5, 6, and 7 radars, and the other for ASR-5E, 6E, 7E and 8 radars. *

(1) Procedure for ASR-4B, 5, 6, and 7. Using the coverage requirements entered in the los coverage worksheet (figure 3-11), locate the range and adjusted elevation angle of each fix on the rci chart of figure 3-16. Also on this chart, mark the locations of such other critical coverage points as may be judged important. When this is completed, apply the appropriate rci overlay contour (from figure 3-17 or 3-18). The overlay should be initially adjusted for proper alignment and a nominal tilt * angle of 2.5° (nose of beam). Using the selected contour, * determine if coverage of the required fixes can be achieved. If the fix location is within the boundary of the contour, free-space radar coverage is possible; otherwise, coverage is not achieved. This information is recorded in column K of the los coverage worksheet (figure 3-11). Further, by rotating the overlay, determine and record the maximum tilt angle which will allow coverage of all fixes. The minimum acceptable tilt angle is determined primarily from clutter considerations, as discussed in paragraph 56.



* FIGURE 3-16. RADAR COVERAGE INDICATOR (RCI) CHART *

FIGURE 3-17. RCI OVERLAY CHART - ASR-4B, 5, and 6

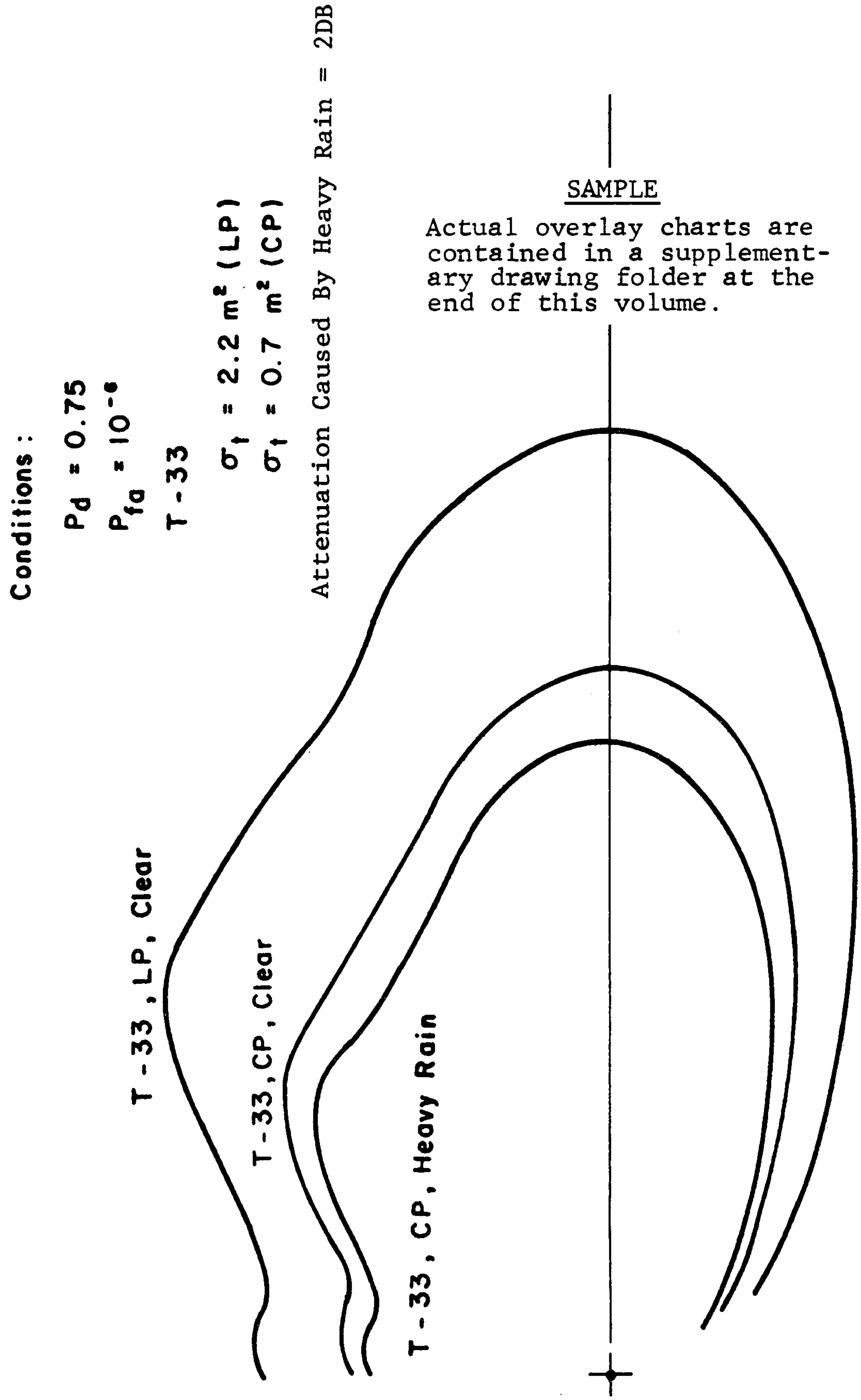
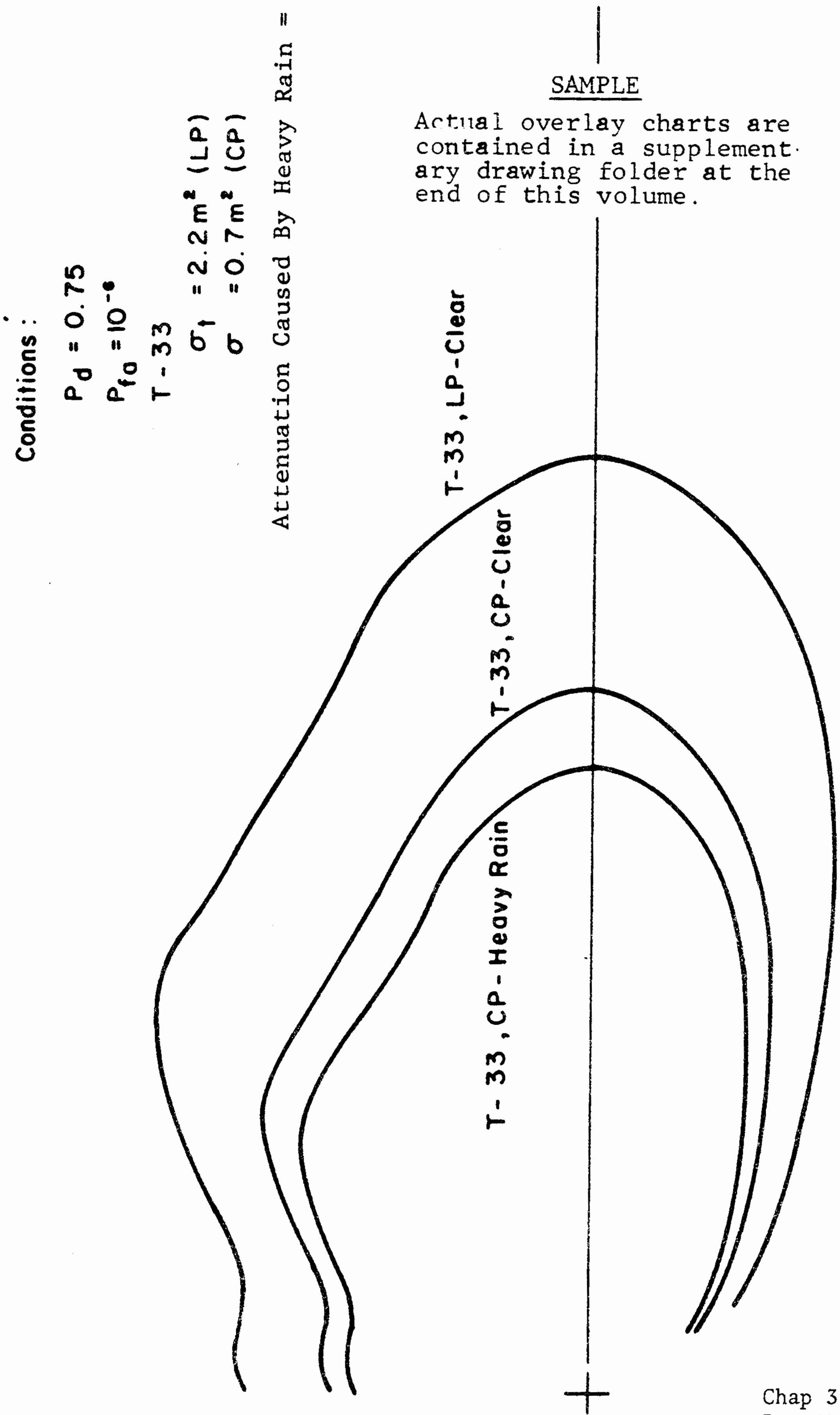
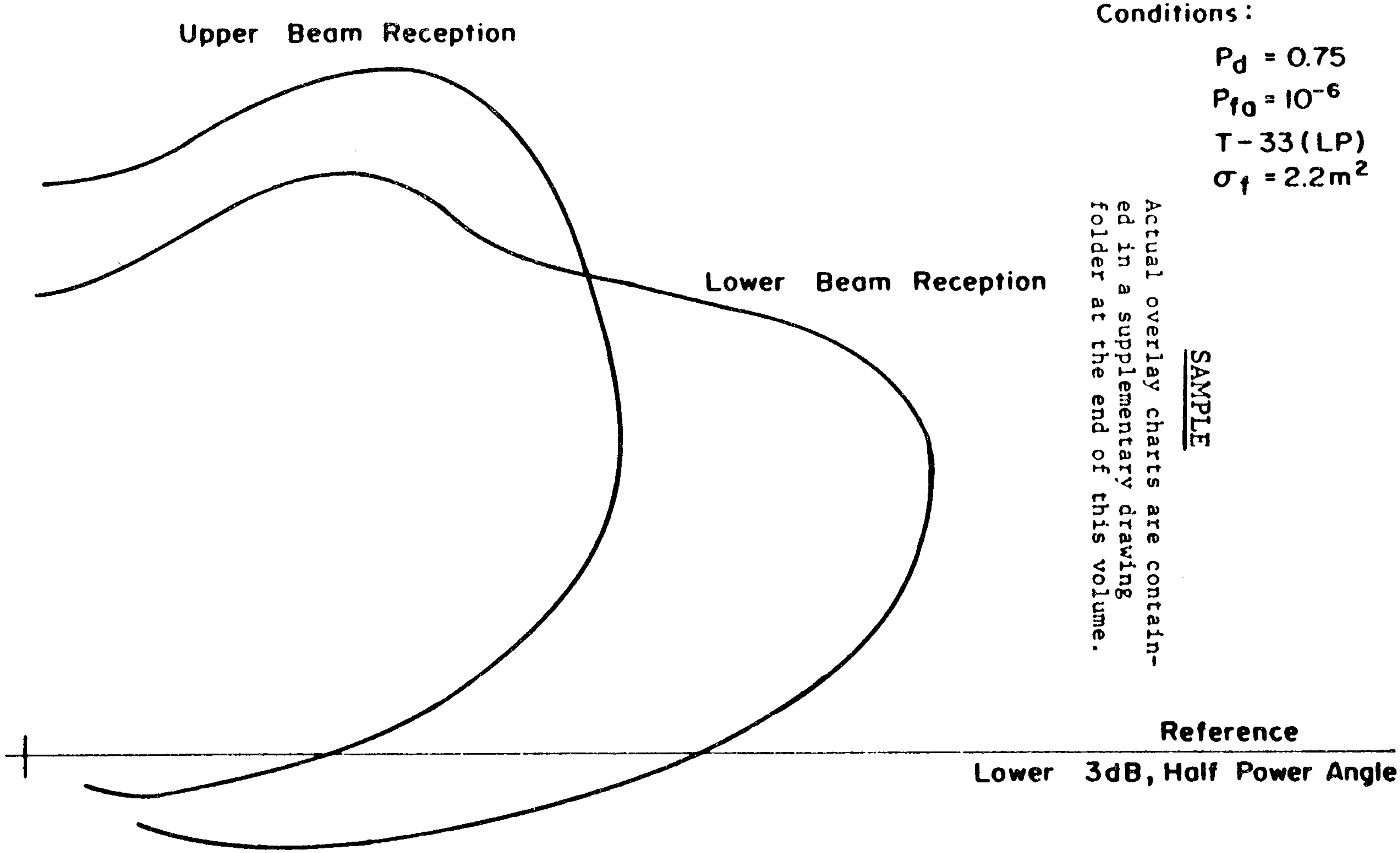


FIGURE 3-18. RCI OVERLAY CHART — ASR 7



* FIGURE 3-18A. RCI OVERLAY CHART, ASR-5E AND 6E, LP-CLEAR



SAMPLE

Actual overlay charts are contained in a supplementary drawing folder at the end of this volume.

* FIGURE 3-18B. RCI OVERLAY CHART, ASR-5E AND 6E, CP-CLEAR *

Conditions:

$P_d = 0.75$

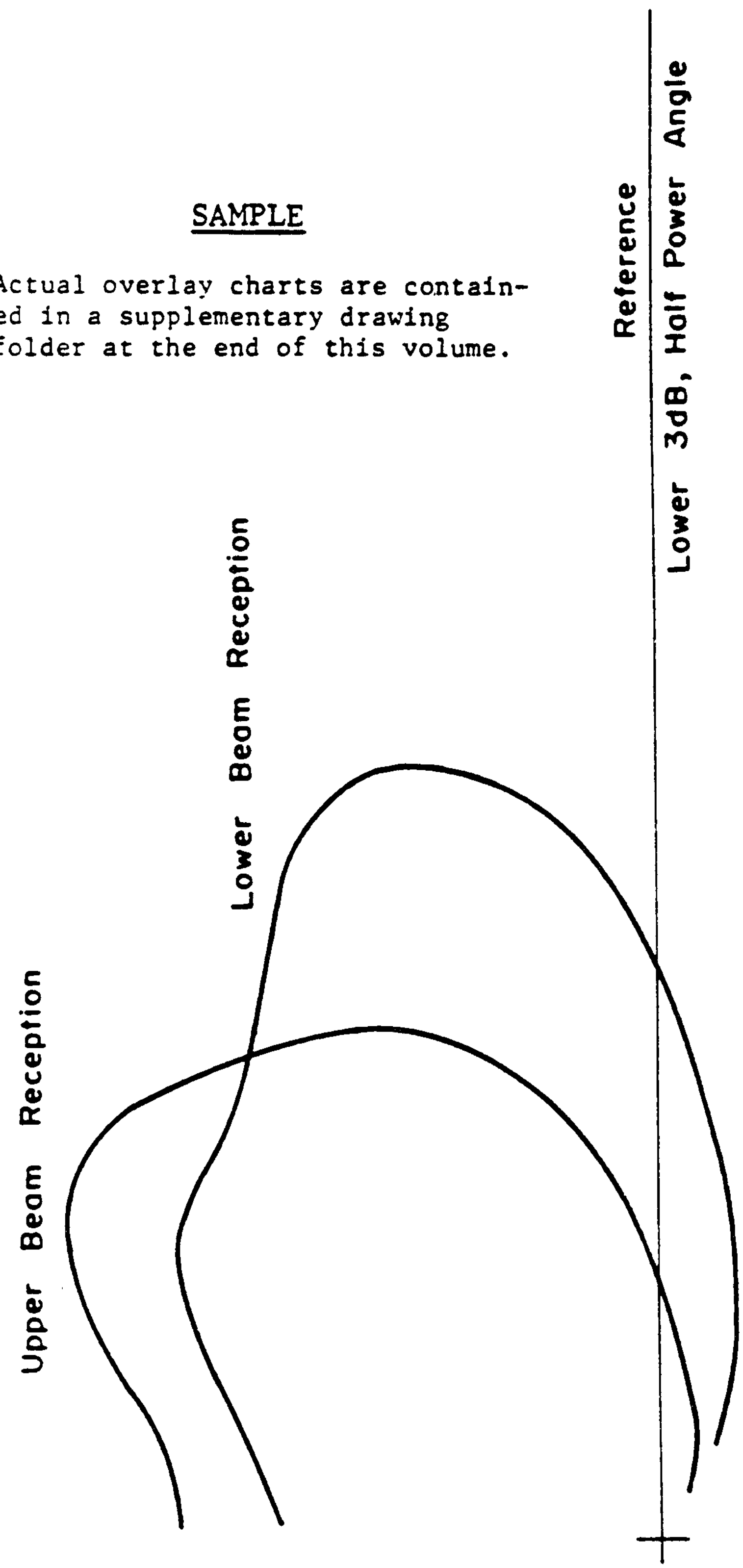
$P_{fa} = 10^{-6}$

T-33(CP)

$\sigma_t = 2.2m^2$

SAMPLE

Actual overlay charts are contained in a supplementary drawing folder at the end of this volume.



* FIGURE 3-18C. RCI OVERLAY CHART, ASR-5E AND 6E, CP-HEAVY RAIN *

Conditions:

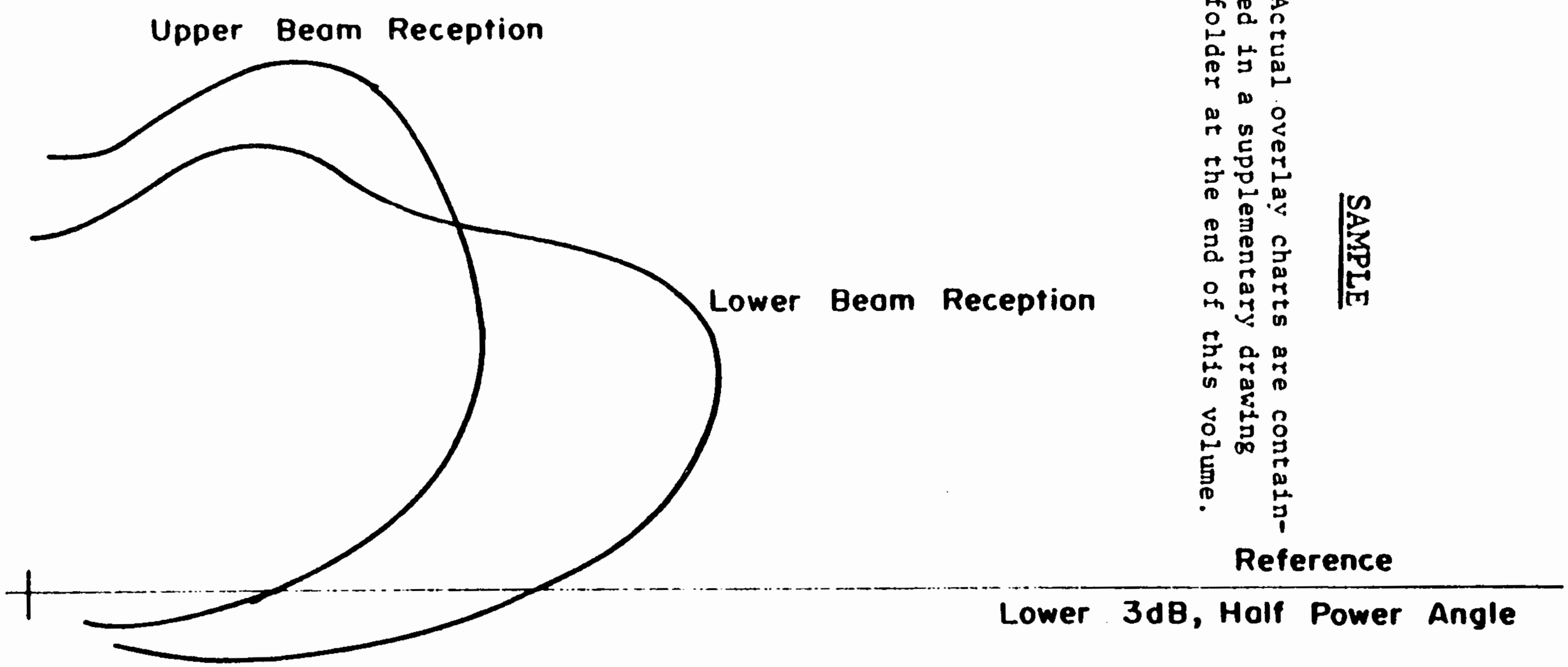
$P_d = 0.75$

$P_{fa} = 10^{-6}$

T -33 (CP)

$\sigma_f = 0.7 m^2$

Attenuation Caused By Heavy Rain = 2dB



SAMPLE

Actual overlay charts are contained in a supplementary drawing folder at the end of this volume.

* FIGURE 3-18D. RCI OVERLAY CHART, ASR-7E LP - CLEAR *

Conditions:

$P_d = 0.75$

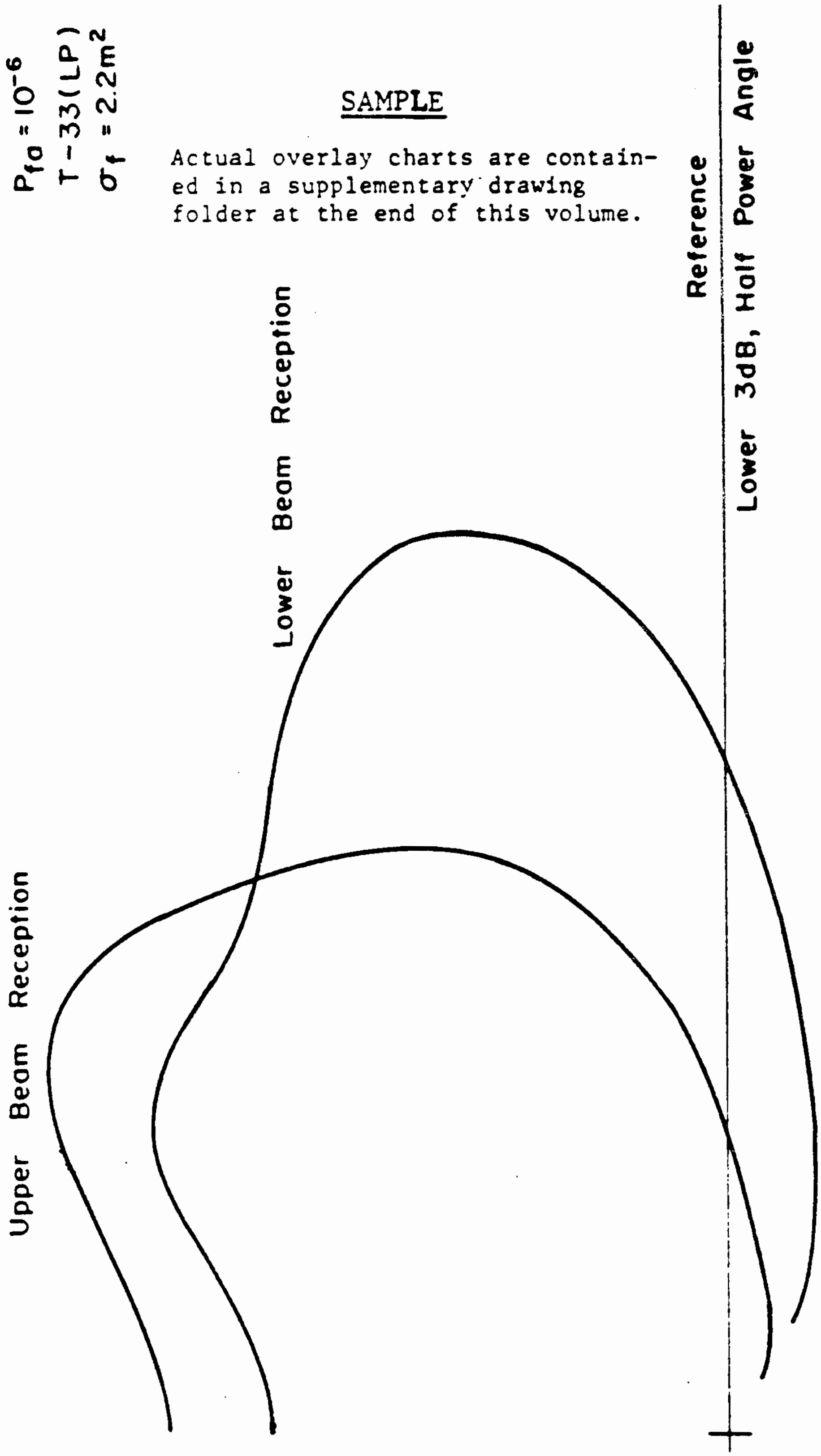
$P_{fa} = 10^{-6}$

T-33(LP)

$\sigma_t = 2.2m^2$

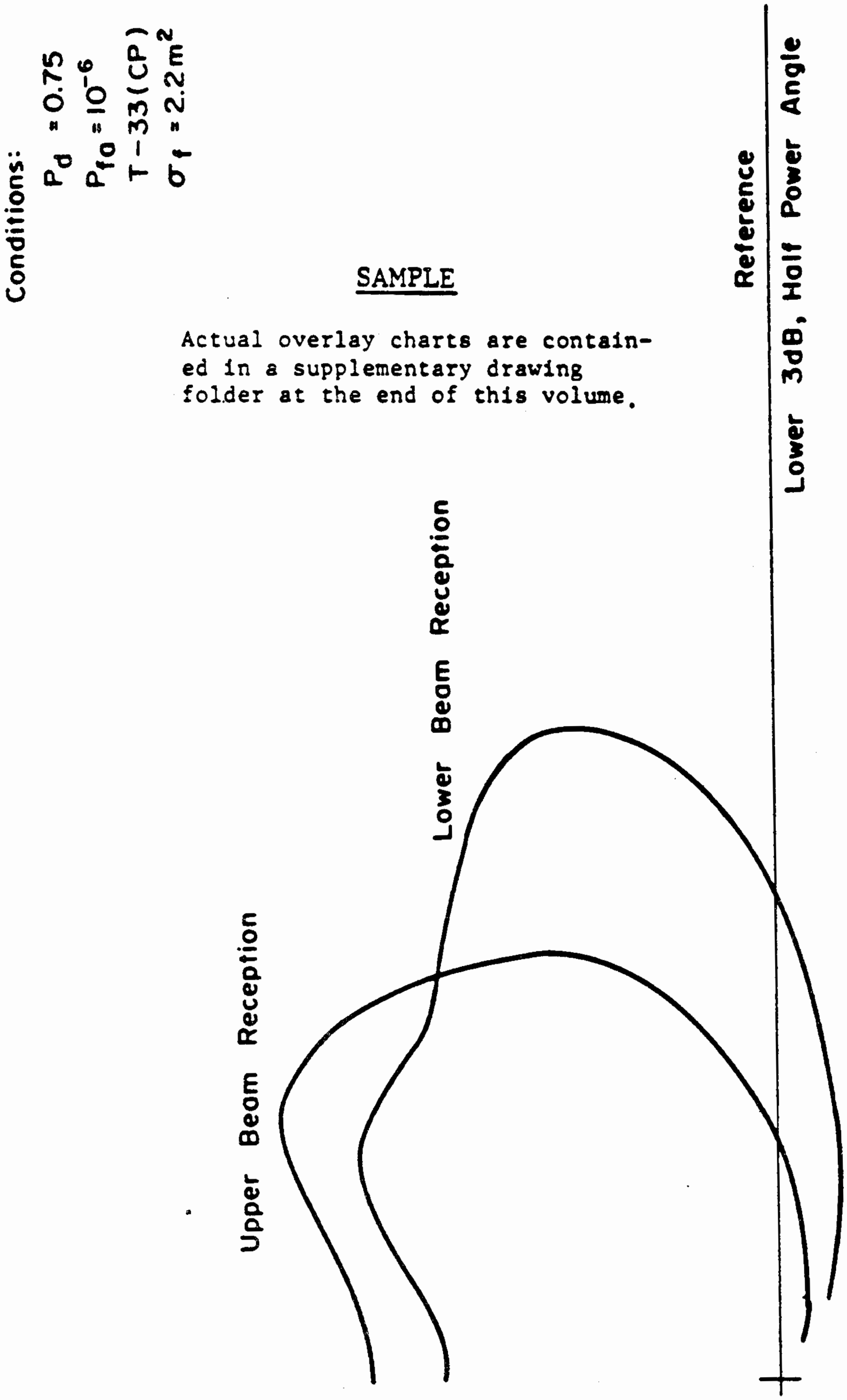
SAMPLE

Actual overlay charts are contained in a supplementary drawing folder at the end of this volume.



SAMPLE

Actual overlay charts are contained in a supplementary drawing folder at the end of this volume.



* FIGURE 3-18E. RCI OVERLAY CHART, ASR-7E, CP-CLEAR *

* FIGURE 3-18F. RCI OVERLAY CHART, ASR-7E, CP-HEAVY RAIN *

Conditions:

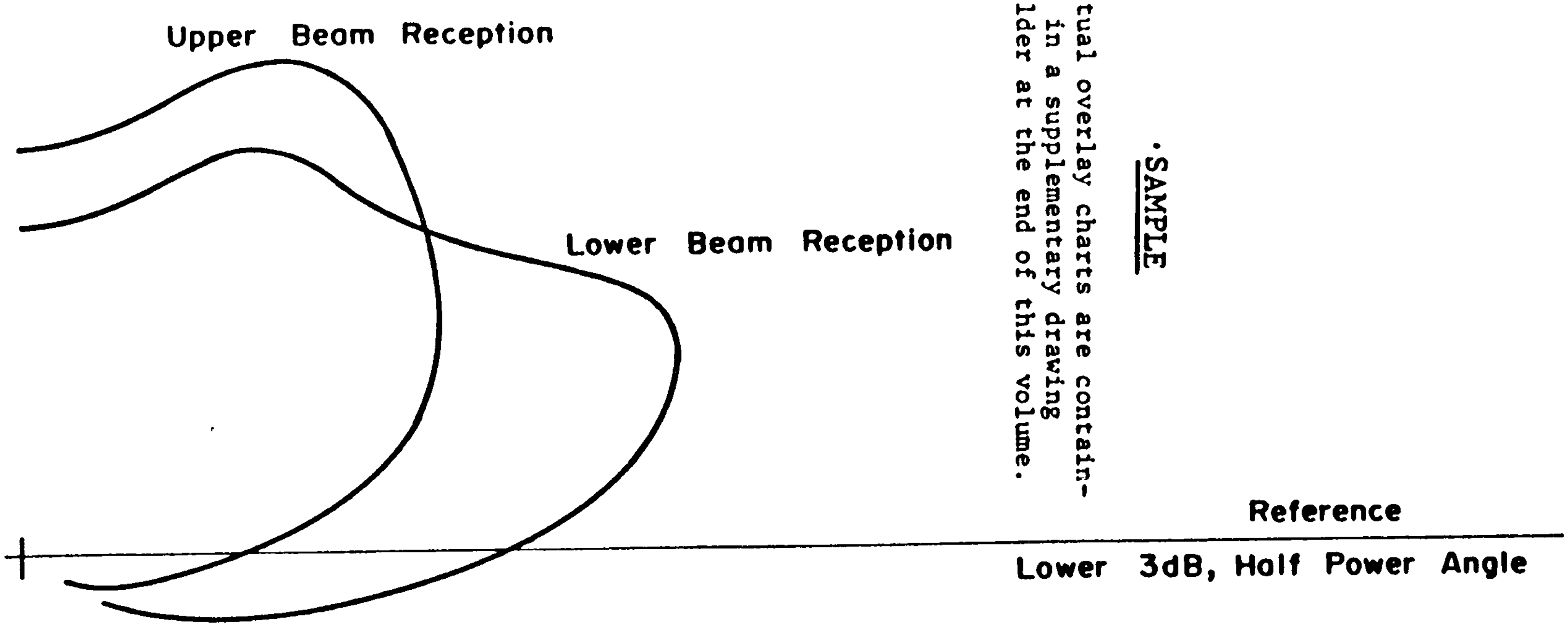
$P_d = 0.75$

$P_{fa} = 10^{-6}$

T -33 (CP)

$\sigma_f = 0.7m^2$

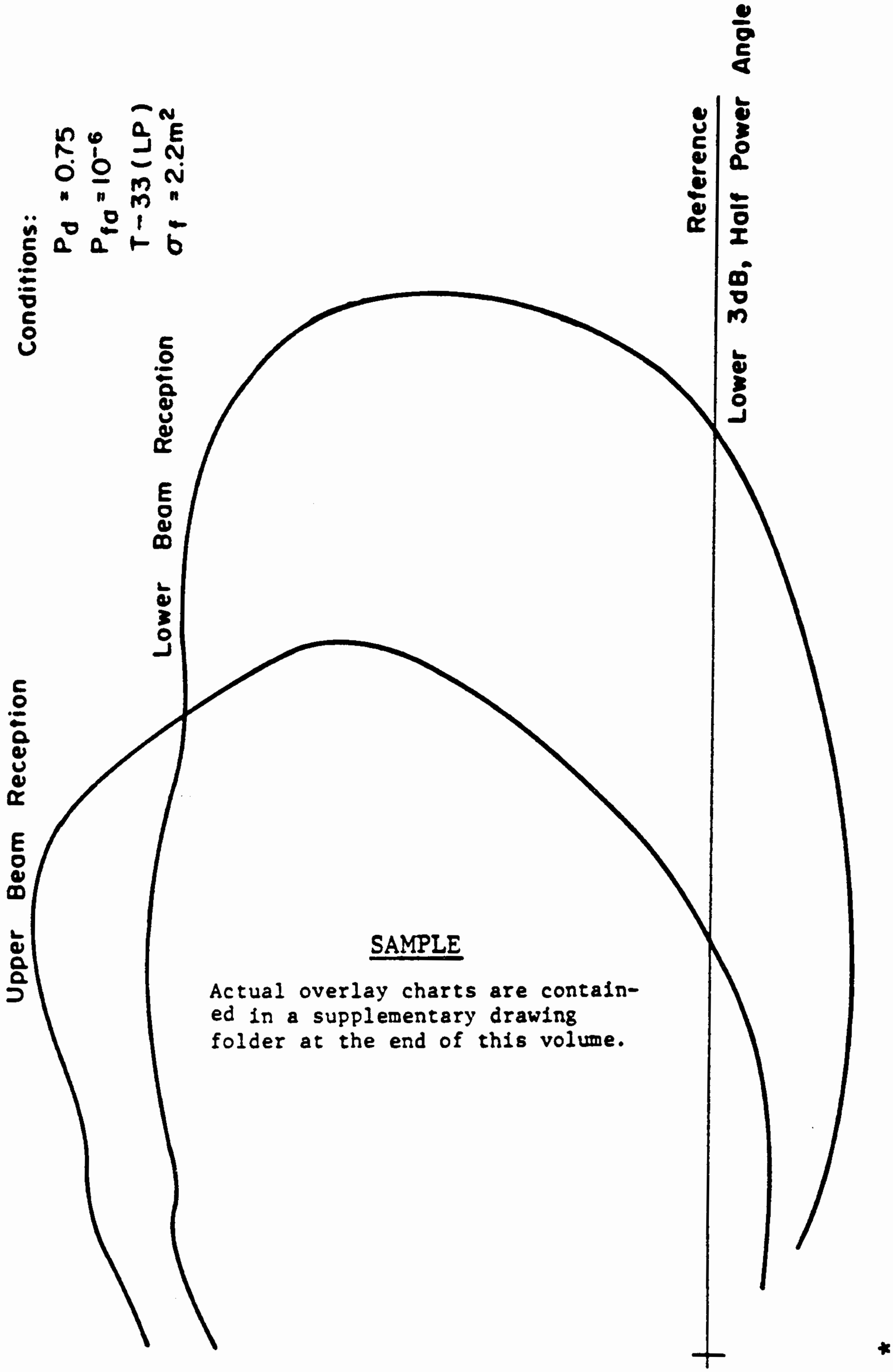
Attenuation Caused By Heavy Rain = 2dB



·SAMPLE

Actual overlay charts are contained in a supplementary drawing folder at the end of this volume.

FIGURE 3-19. RCI OVERLAY CHART, ASR-8, LP-CLEAR *



SAMPLE

Actual overlay charts are contained in a supplementary drawing folder at the end of this volume.

*

*

FIGURE 3-20. RCI OVERLAY CHART, ASR-8, CP-CLEAR

Conditions:

$P_d = 0.75$

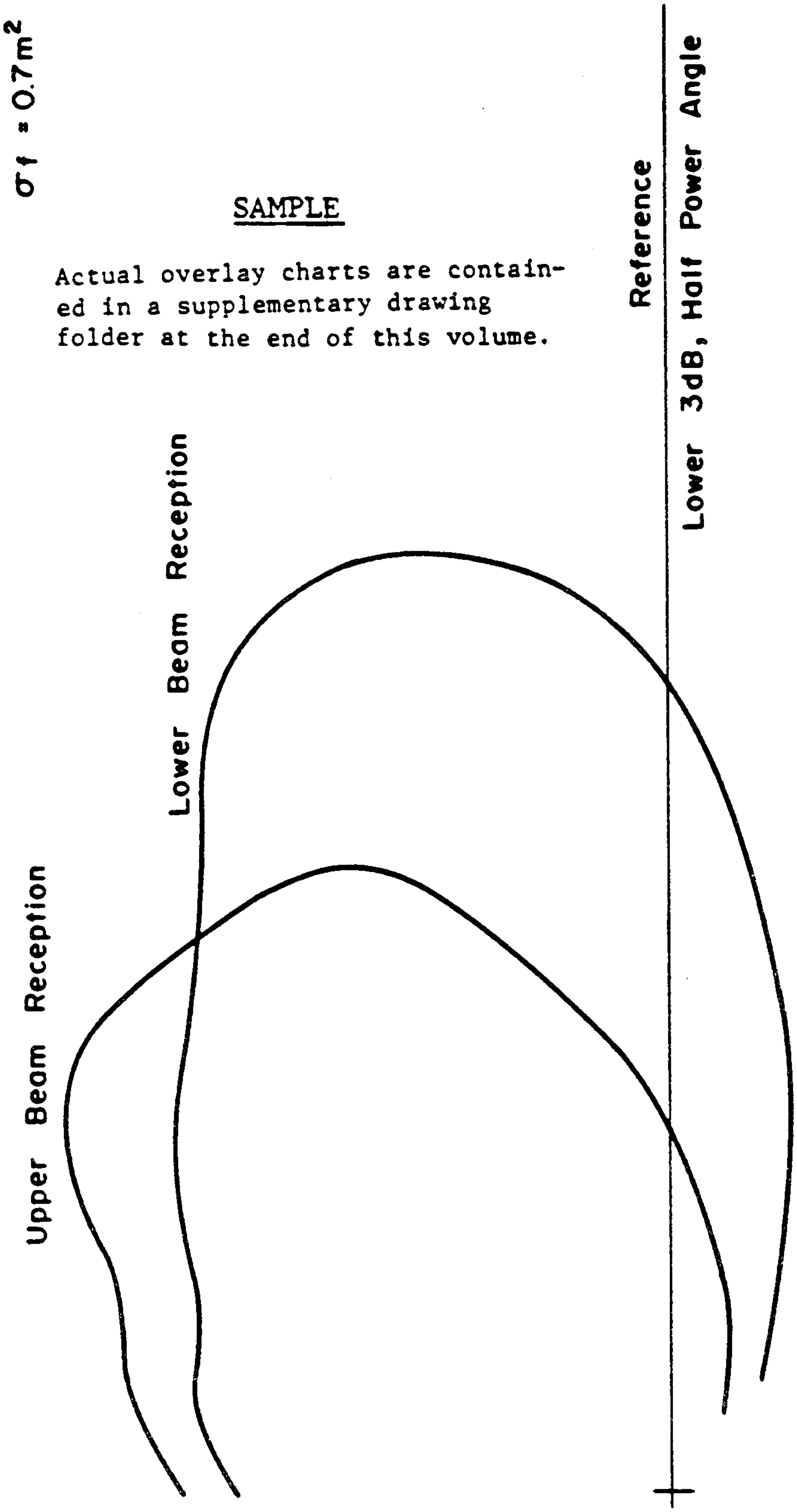
$P_{fa} = 10^{-6}$

T-33 (CP)

$\sigma_t = 0.7m^2$

SAMPLE

Actual overlay charts are contained in a supplementary drawing folder at the end of this volume.



*

FIGURE 3-21. RCI OVERLAY CHART, ASR-8, CP-HEAVY RAIN *

Conditions:

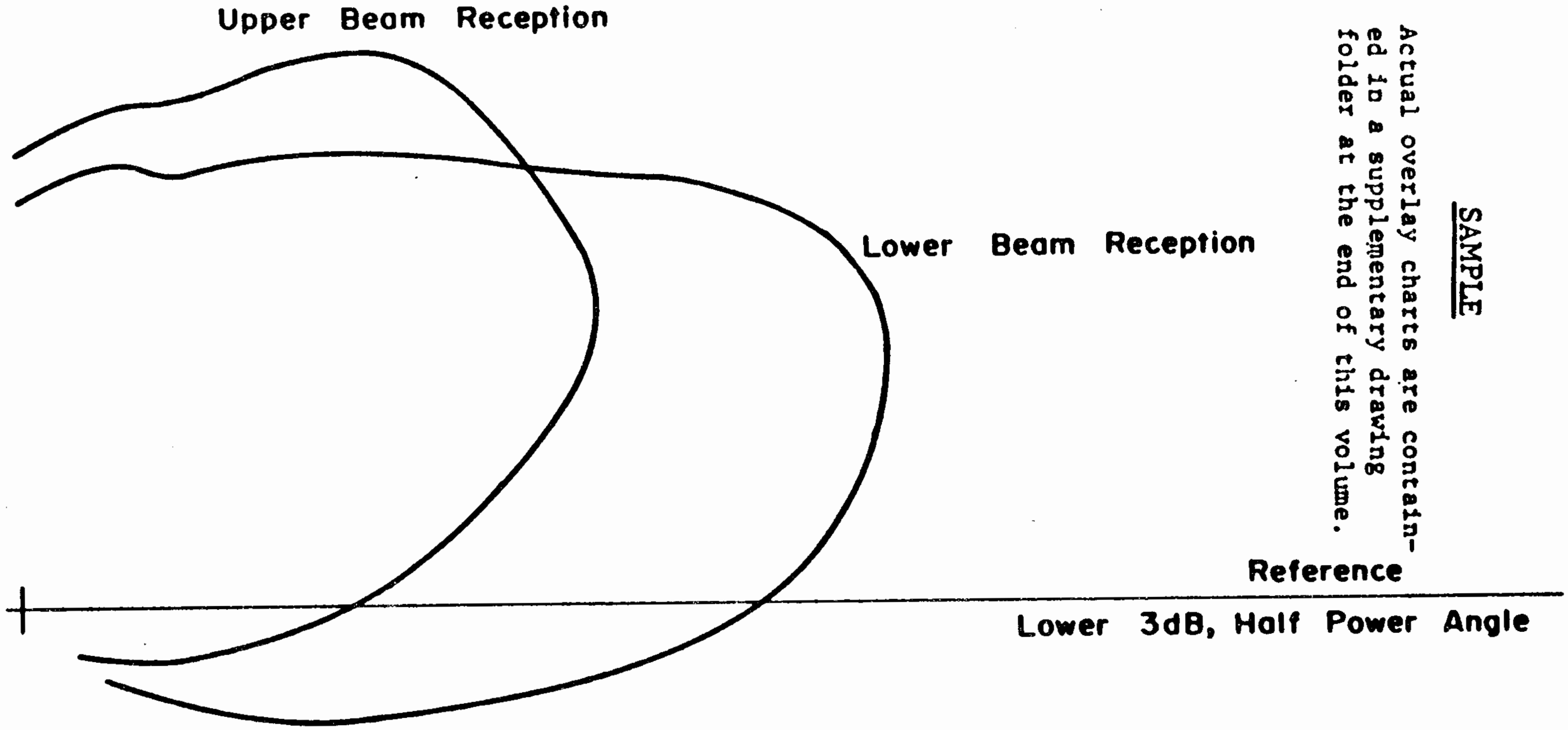
$P_d = 0.75$

$P_{fa} = 10^{-6}$

T -33 (CP)

$\sigma_f = 0.7m^2$

Attenuation Caused By Heavy Rain = 2dB



SAMPLE

Actual overlay charts are contained in a supplementary drawing folder at the end of this volume.

*

* (2) Procedure for ASR-5E, 6E, 7E and ASR-8. *

(a) Using the coverage requirements entered in the los coverage worksheet (figure 3-11), located the range and adjusted elevation angle of each fix on the rci chart of figure 3-16. Also on this chart, mark the locations of such other critical coverage points as may be judged important. When this is completed, apply the appropriate rci overlay contour * (from figures 3-18A, 18B, 18C, 18D, 18E, 18F, 19, 20, or 21). * The overlay should be initially adjusted for proper alignment and a nominal tilt angle of 0.5° for the lower 3 dB point of the main beam (the corresponding tilt angle for the nose of the beam is 2.5°). Using the main beam only contour from the selected chart, determine if coverage of the required fixes can be achieved. If the fix location is within the boundary of the contour, coverage is possible; otherwise, coverage is not achieved. This information is recorded in column K of the los coverage worksheet (figure 3-11). Further, by rotating the overlay, determine and record the maximum tilt angle that will allow coverage of all fixes.

* (b) Other important ASR-5E, 6E, 7E and 8 siting considerations * deal with the minimum acceptable tilt angle for radar coverage, and determination of the appropriate range for switching from dual-beam to main-beam-only operation. These factors are determined primarily from clutter considerations, as discussed in paragraph 59.

(3) Interpretation of Results. The above procedure should allow determination of whether or not acceptable radar coverage of the required fixes is possible from the selected site location and antenna height. If adequate coverage is possible, the derived data also indicates the maximum permissible tilt angle for coverage of all fixes and critical points. It should be remembered at this point that radar coverage capability considered here assumes FREE-SPACE conditions and, therefore, does not include the degrading effects of vertical lobing, clutter, etc. These effects must be considered before final coverage assessments and tilt angle selections are made. An illustrative example of the application of ASR coverage analysis procedures is given in appendix 6.

56. BEACON COVERAGE ANALYSIS. Achievement of adequate free-space beacon coverage normally presents no problem in situations where los visibility to all desired fixes exists. This good coverage is possible because of the very high power capability of ATCBI equipment, and because only a one-way path is involved on interrogation and reply. Interference considerations dictate, however, that beacon interrogators be operated at the lowest possible output power capable of providing the required spatial coverage. This power level is estimated using the following procedure.

* a. Procedure. Using the ATD coverage requirements, which have already been located on the rci chart (figure 3-16), apply the appropriate beacon overlay chart (figure 3-22 for the ATCBI-3 with antenna FA-7202, figure 3-23 for the ATCBI 4 or 5 with antenna FA-8043, or figure 3-23A for any of the ATCBI's with antenna FA-9764) and adjust for a nominal tilt angle of 2.5°. From the chart parameters note the smallest beacon power required for coverage of all fixes, and the maximum required range. Note that the drawings shown in the handbook text (figures 3-22, 3-23 and 3-23A) are samples; the actual overlay charts are contained in the supplemental drawing folder bound at the end of this volume. *

b. Analysis. The beacon power determined by the above procedure is the lowest which will provide the requisite coverage. This proper level is used in calculating the effects of beacon lobing from equations presented in chapter 2. To account for substandard propagation an operational transmitter output 3 dB above this level should be specified. It should also be noted here that the P_d values plotted in figures 3-22, 3-23, and 3-23A represent interrogator output measured * at the antenna. To achieve this condition the transmitter output must be increased by an additional amount equal to the one-way transmission line and plumbing losses for the particular installation. * The beacon coverage analysis procedure is also illustrated in appendix 6.

57. VERTICAL LOBING ANALYSIS. Previous coverage analyses were based on free-space antenna patterns; they are correct only for situations where the local terrain is rough and does not produce vertical lobing. The objectives of a vertical lobing analysis are to identify the azimuth sectors about a site in which lobing can be expected to occur, and to analyze the effect of such lobing upon the ability of ASR/ATCBI equipment to meet the established coverage requirements. The accuracy of this analysis will depend upon the quality of site survey data covering surface roughness, surface reflectivity, and the size and location of land areas over which these conditions prevail.

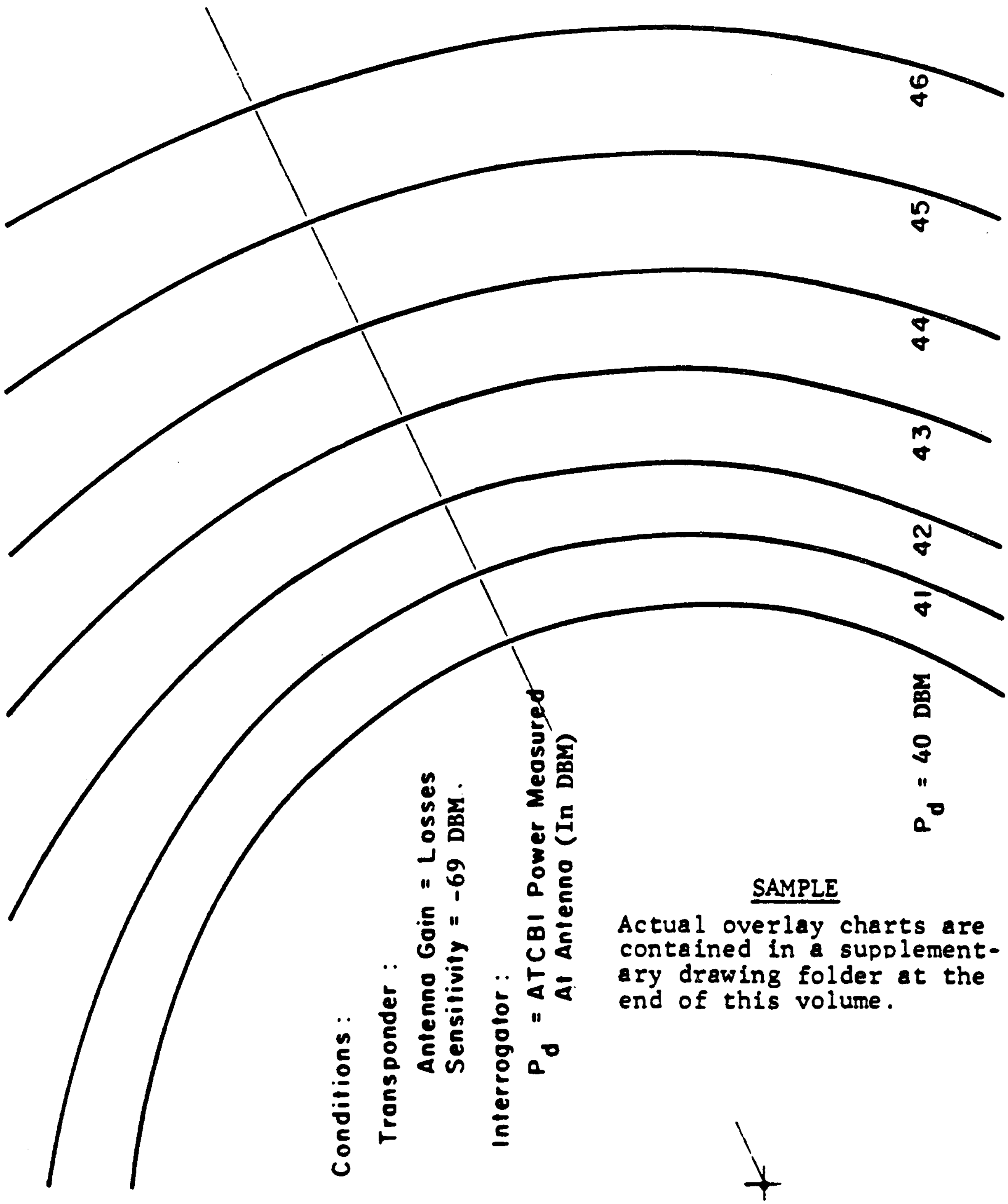
a. Existence of Lobing.

(1) The suggested procedure for determining if it is reasonable to expect the occurrence of vertical lobing at a given site is outlined below. The procedure is applicable to both radar and beacon lobing analysis.

(a) From site survey observations and panoramic photographs, identify the azimuth sectors containing relatively flat terrain. Determine the msl elevation of each "flat" region and the range to its near- and far-points. The latter, of course, will not extend beyond the horizon.

(b) Determine the effective height of the radar antenna above each flat terrain region by subtracting the terrain msl elevation from that of the antenna. Use this effective

FIGURE 3-22. RCI OVERLAY CHART - ATCBI-3



SAMPLE

Actual overlay charts are contained in a supplementary drawing folder at the end of this volume.

FIGURE 3-23. RCI OVERLAY CHART - ATCBI - 4

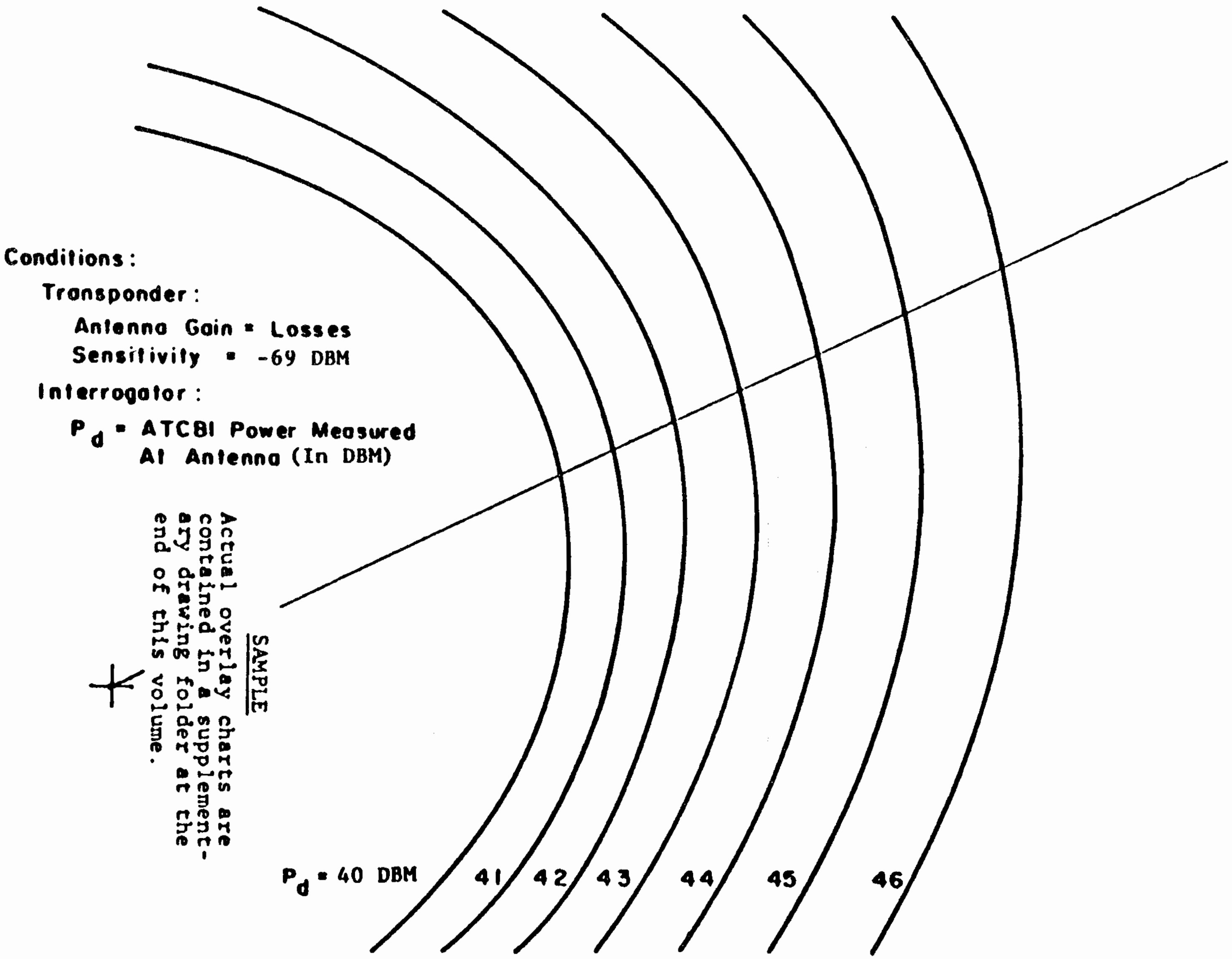
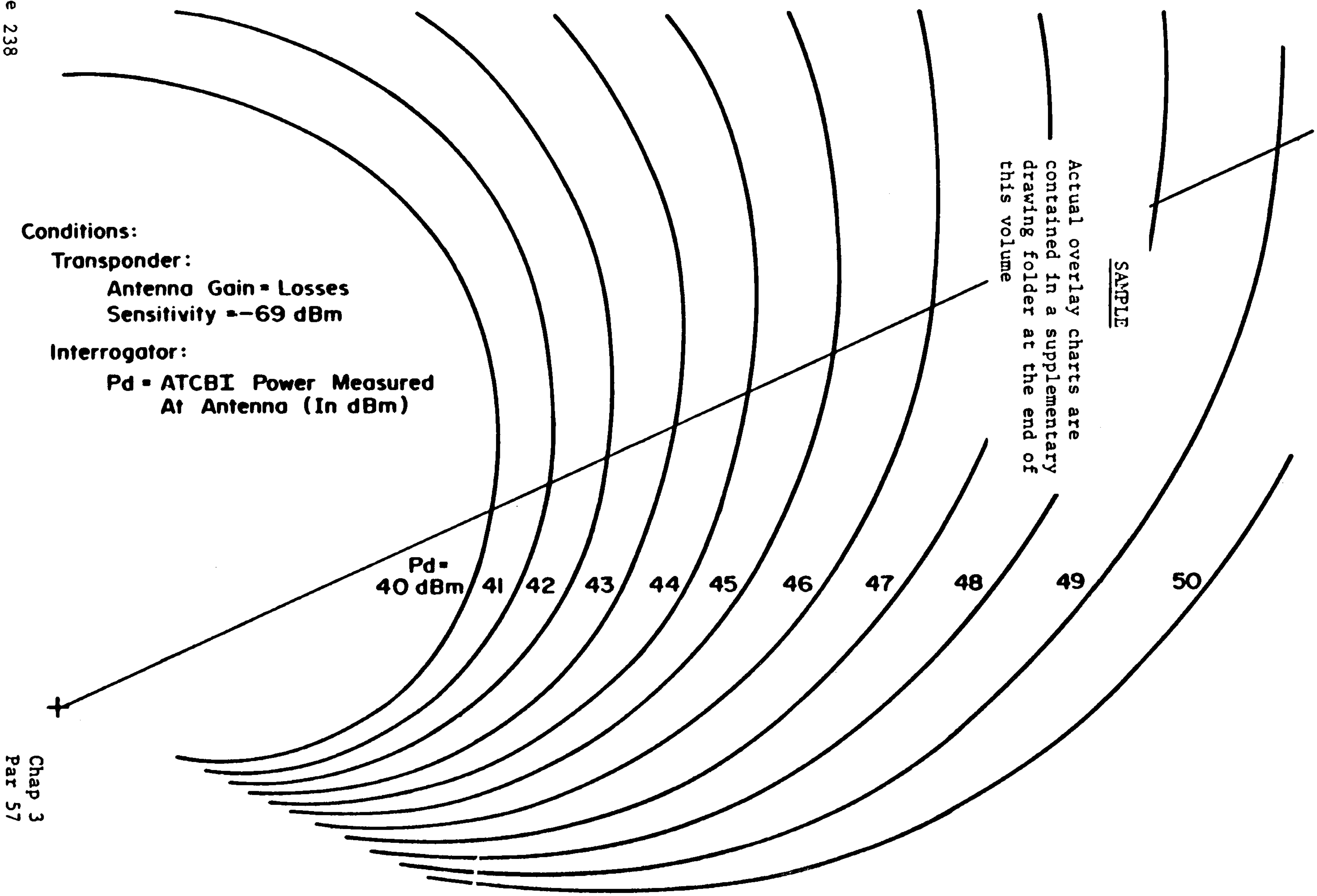


Fig. 3-23 RCI OVERLAY CHART - ATCBI-4

FIGURE 3-23A RCI OVERLAY CHART — ATCBI - 3,4,5 / ANTENNA FA - 9764 *



*

height to compute the location of the first Fresnel zone in each area for various null orders. Range to the near-point, reflection-point, and far-point of the Fresnel zones are given by equations 2-33 and 2-34 (p. 119). These may be simplified as follows to yield distances in nautical miles:

$$d_{1n} = k_n h_a^2 f \quad \text{(near point)} \qquad (3\text{-}5)$$

$$d_1 = k_r h_a^2 f \quad \text{(reflection point)} \qquad (3\text{-}6)$$

$$d_{1f} = k_f h_a^2 f \quad \text{(far point)} \qquad (3\text{-}7)$$

where:

h_a = effective antenna height, in feet

f = operating frequency, in MHz.

The values of the constants in these expressions are given in table 3-1 for various nulls, and the distances are plotted in figures 2-39 through 2-44 for lower order nulls.

(c) Determine the grazing angle, ψ_n, to each null reflection point from the expression

$$\psi_n = \text{Tan}^{-1} \frac{h_a}{d_1} \qquad (3\text{-}8)$$

Since ψ_n is also equal to the null angle, θ_{min}, it can also be determined from figures 2-19 and 2-20, for lower order nulls.

(d) Using the values of ψ_n calculated above, determine the critical height of surface irregularity, Δh_c, from figure 2-38, or equation 2-32 (p. 106). Record and compare these values with the average measured or estimated surface irregularity for the corresponding terrain regions under study. The latter data may be taken during site survey operations, or derived from topographical maps.

(2) Conduct the above radar lobing determination for each "flat" region and repeat for beacon lobing, using appropriate antenna height and frequency in step b. For co-sited installations, the ATCBI antenna is 5 feet above the ASR feedhorn for beacon antennas FA-7202 and FA-8043, it is 6.8 feet above the ASR feedhorn for beacon antenna FA-9764.

Table 3-1

FRESNEL ZONE PARAMETERS

Order of Null	k_n	k_r	k_f
1	8.9577×10^{-8}	3.3431×10^{-7}	1.2477×10^{-6}
2	6.6385×10^{-8}	1.6715×10^{-7}	4.3761×10^{-7}
3	5.0304×10^{-8}	1.1144×10^{-7}	2.4686×10^{-7}
4	4.1788×10^{-8}	8.3577×10^{-8}	1.6715×10^{-7}
5	3.3588×10^{-8}	6.6861×10^{-8}	1.2458×10^{-7}
10	2.1454×10^{-8}	3.3431×10^{-8}	5.2094×10^{-8}
15	1.5500×10^{-8}	2.2287×10^{-8}	3.2046×10^{-8}
20	1.2200×10^{-8}	1.6715×10^{-8}	2.2903×10^{-8}

b. Interpretation of Results.

(1) Compare the position and extent of the land areas determined in steps a and b.

(a) If none of the flat surveyed area lies within the first Fresnel zone, no lobing should be expected as long as the heights of the ASR and ATCBI antennas do not exceed the values used in computations.

(b) If the "flat" area identified covers the first Fresnel zone completely, lobing can be expected to occur PROVIDED the average irregularity of the surface does not exceed Δh_c. If the irregularity is greater than Δh_c, the surface is too rough to support lobing reflections.

(c) If the surveyed area extends only partially over the first Fresnel zone, the occurrence of lobing is uncertain. This uncertainty can be resolved somewhat by considering surface smoothness and by comparing the position of the surveyed area relative to the position of the "reflection point" within the first Fresnel zone. No lobing will be produced by a surface whose average irregularity is greater than Δh_c. For smooth surfaces, areas nearest the reflection point contribute most heavily to the total reflection, the contribution decreasing in importance the further the area is from this point.

(2) It should be noted, when conducting this analysis, that the presence of vertical reflecting surfaces (e.g., buildings or fences) near the Fresnel zone may screen or break up a lobing pattern which may otherwise occur. This fact may be used to avoid lobing effects through careful selection of site location, or through installation of fences to eliminate lobing (see reference 8).

c. Effects of Lobing on Coverage.

(1) If vertical lobing is expected and cannot be prevented by screening or adjustment of antenna height, an analysis should be made to determine the impact such lobing will have on the coverage capabilities of the ASR and beacon. This assessment may be made as follows:

(a) Locate and identify those navigational fixes that lie in the azimuth sector(s) where vertical lobing is expected to occur.

(b) Using the antenna height[1] specified by screening considerations (paragraph 53), determine that elevation angle of each of the navigational fixes relative to the site location. If the elevation angle to a fix exceeds the critical grazing angle (specified above for the given terrain roughness) by more than one quarter the angle of the first null, it can be ignored insofar as lobing effects are concerned,

(c) For those identified navigational fixes whose elevation angles are less than the critical grazing angle, compute the earth gain factor η at this elevation angle by letting θ in equation 2-22 (p. 94) equal the elevation angle to the fix (in radians).

(d) Determine if coverage is obtained at each fix using the relationships derived in paragraph 22b of chapter 2 (see equation 2-29 (p. 95) and 2-30 and 2-31 (p. 102)).

* $R_r = \eta R_f$ (for ATCBI @ 1030 MHz) (for ASR-4B, 5, 6 and 7 @ 2700-2900 MHz) (for ASR-5E, 6E, 7E, and 8 main antenna only @ 2700-2900 MHz) (3-9) *

or

* $R_r = \sqrt{\eta_e \eta_t}\, R_f$ (for ASR-5E, 6E, 7E, and 8 dual beam antenna @ 2700-2900 MHz) (3-10) *

If the actual range R to a fix is less than the value R_r, then coverage is obtained. If not, no coverage is obtained.

(e) Similar consideration may be given to lobing effects on coverage of traffic or other points in the air route structure.

(2) When severe lobing effects are predicted, attempts should be made to specify a new tilt angle which will enable satisfactory coverage to be achieved. Changing the antenna tilt will change the antenna gain factor in the direction of the target and reflection point. Tilt will not affect the reflection point or null angle and will not change the basic lobing pattern. If no acceptable tilt angle will remove the coverage

---

* [1] In these computations it should be remembered that for co-sited installations the ATCBI antenna is higher than the ASR plane center by 5 feet when antennas FA702 or FA-8043 are used and by 6.8 feet when antenna FA-9764 is used. *

deficiency, a new antenna height may be selected and the analysis repeated. Screening considerations should not be ignored in selecting new antenna heights.

(3) If serious lobing difficulties are present for all usable height/tilt angle combinations, consideration must then be given to (a) alternate site locations, (b) mitigation of the effect by installation of fences, etc., (reference 8, or 3) altering air route structure or control procedures to minimize operational problems caused by lobing. The latter action would require consultation and concurrence by ATD personnel.

(4) An illustration of the application of vertical lobing analysis procedures is given in appendix 6.

58. FALSE-TARGET ANALYSIS. Evaluation of potential ATCBI sites should include an analysis of the expected severity of beacon false-target effects associated with each particular site location. This analysis is largely graphical and follows techniques described in paragraph 22e of chapter 2.

a. Procedure. On a horizontal coverage chart (FAA Drawing D-50979-1) centered about the radar site, locate all significant air routes and plot the location of all potentially harmful reflectors identified at the site survey. For each reflector:

(1) Plot azimuth radials 1° beyond the extremities of the reflecting surface. This defines the angular region where beacon false targets may appear because of this reflector.

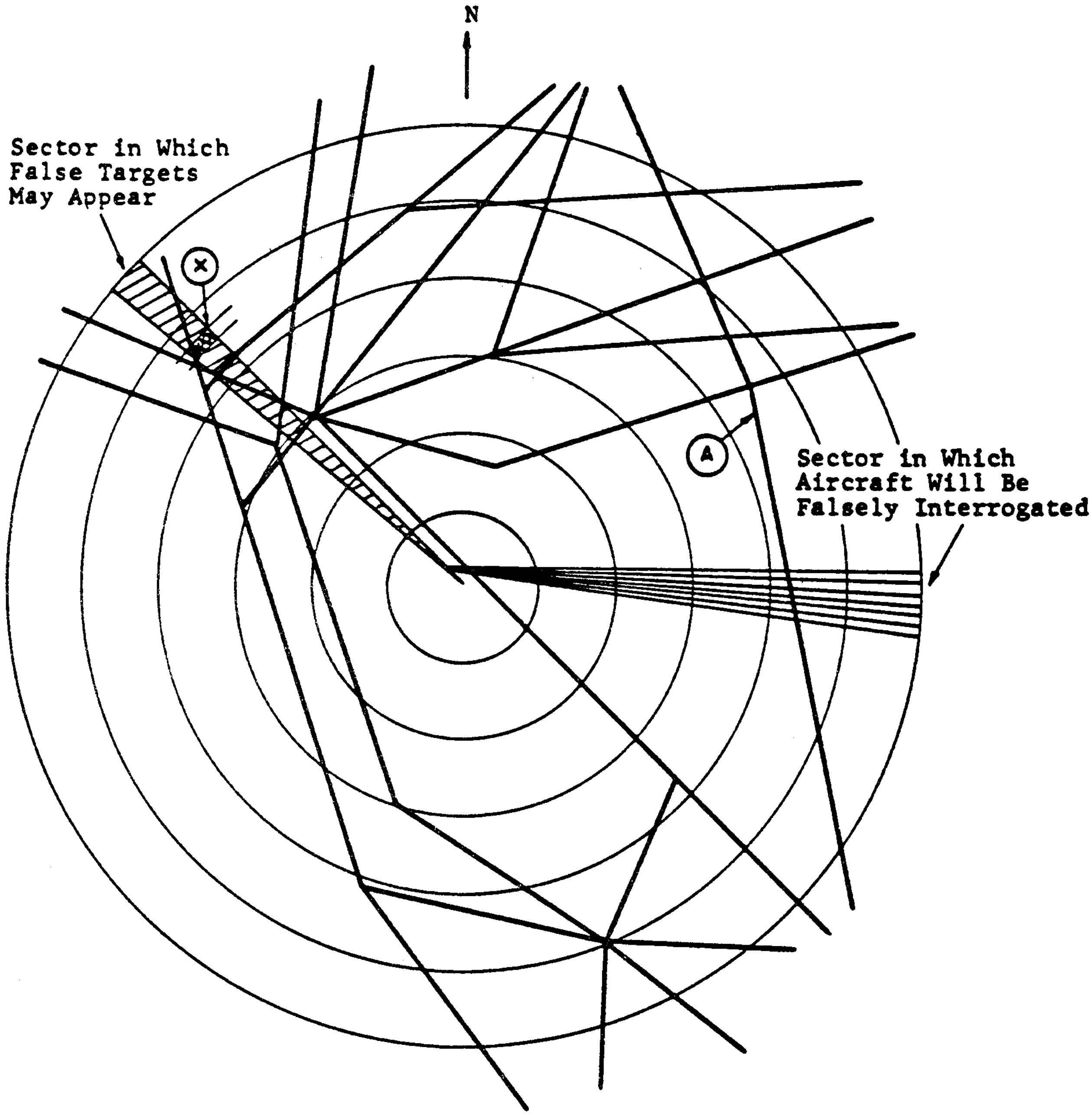
(2) Plot the path of signals reflected from the extended reflector surface due to the above radials. Reflector orientation, required for these plots, can be determined from maps, the airport master plan, or site survey data.

(3) Using the reflector dimensions and ATCBI power determined above, compute minimum range, R_1, between target and reflector for false targets. This is done with the nomographs of figures 2-48a and b. Note this range on the diagram.

(4) Note airways crossing the reflected signal sector at ranges less than R_1 from the surface. Translate the affected range segment to the false target radial sector, taking into account the radar to reflector range, R_2.

b. Analysis. Once the regions of appearance and of origin of false targets are identified, the severity of the problem is readily determined. Situations where traffic in one active airlane can create false targets in another airlane are clearly unacceptable. An example case is presented in figure 3-24. In the example, a

FIGURE 3-24. EXAMPLE OF FALSE TARGET ANALYSIS



hazardous condition could develop when regular commercial traffic on airline (A) is falsely interrogated by a reflected path, producing apparent targets in the region (X), which, itself, contains regular commercial traffic. In such a situation consideration should be given to (1) removal or masking of the reflecting structure (see reference 9 for masking details), (2) selection of a different ASR/ATCBI site, or (3) revision of the air route. The latter possibility should only be considered as a last resort and would, of course, require coordination and approval from Air Traffic and Flight Standards Divisions.

59. CLUTTER ANALYSIS. ASR coverage of targets can be seriously degraded by the effects of clutter. It is therefore recommended that a worst-case clutter analysis, using the principles outlined in paragraph 23c(3) of chapter 2, be carried out to provide estimates of: (a) range/azimuth parameters for mti and antenna beam switching of the ASR-8 radar, (b) * range parameters for mti and antenna beam switching of ASR-5E, 6E, and 7E * (c) mti switching range for ASR-4B, 5, 6, and 7, and (d) system clutter coverage capability and tilt angle dependence.

a. Clutter Boundaries. From map studies and site survey operations, determine the boundaries of the region of clutter visibility, from the radar site. The maximum range of the clutter zone along a given azimuth radial is simply the range to the radar horizon, or to a screening object, whichever is smaller. In rugged terrain the clutter visibility region may be discontinuous because of the presence of multiple screening objects. In general, the maximum range of clutter will vary for different azimuth angles in accordance with the terrain and screening features. The overall clutter visibility boundary may be plotted on a polar diagram similar to those already drawn for los visibility.

* b. Antenna Switching Range (ASR-5E, 6E, 7E, 8).

(1) As mentioned in chapter 1, the selection of a single or dual beam antenna configuration for the ASR-5E, 6E, 7E and 8 radars is largely dictated by clutter considerations. The high beam * antenna is used in the clutter region to the extent of its coverage capability. For target ranges beyond the coverage capability of the radar in its dual beam mode, however, the single (main) beam mode must be employed, even if clutter is present. The single beam mode is also used for all ranges where no clutter is visible.

* (2) The maximum allowable range for switching from dual to single beam operation depends on the antenna tilt angle and target/polarization/climatological conditions as indicated in table 3-2 for ASR-5E, 6E, 7E and 8. The range information in this table was derived by application of the ASR-5E, 6E, 7E and 8 RCI overlay charts, respectively. For various assumed tilt angles, the maximum switching range is defined by the intersection of the coverage overlay for dual beam operation with *

* the earth's surface. For the ASR-5E, 6E, and 7E system the maximum allowable range for switching from dual to single beam operation remains constant in azimuth, while for the ASR-8 it can be set at different ranges in each of eight azimuth sectors. *

*

Table 3-2

MAXIMUM ANTENNA SWITCHING RANGE FOR ASR-5E, 6E, 7E AND 8

Antenna Tilt Angle 1/ (Degrees)	Maximum Allowable Range for Dual Beam Operation (Nautical Miles)								
	Fair Weather LP Operation			Fair Weather CP Operation			Heavy Rain CP Operation		
	ASR-5E,6E	ASR-7E	ASR-8	ASR-5E,6E	ASR-7E	ASR-8	ASR-5E,6E	ASR-7E	ASR-8
-2.0°	32.5	31	40	24.5	23.5	30.5	22.0	21	27.5
-1.5°	29.5	27.5	35.5	22.0	20.5	27	19.0	18.5	24
-1.0°	24.5	24	32	19.0	18	24	17.0	15.5	21
-0.5°	21.0	19.5	28	16.0	15.5	21	14.5	13	19
0°	17.0	15.5	24	12.5	13.5	18	12.0	11	16.5
0.5°	13.0	12.5	21	9.5	10.5	15	9.5	9	14
1.0°	10.0	9.5	17	7.5	8.0	13	8.0	7	11.5
1.5°	8.5	8	14	6.5	6	10.5	6.0	6	9.5
2.0°	7.0	6.5	11	5.5	4.5	9	5.0	5	8

1/ Referred to lower 3 dB, half power point of lower beam.

*

* (3) For the maximum acceptable tilt angle, as defined in the previous analysis (and indicated on the worksheet of figure 3-11), the maximum ASR-5E, 6E, 7E and 8 antenna switching ranges will usually be set as indicated in table 3-2 for the condition being examined. Exceptions would occur in those azimuth sections where the clutter boundary diagram indicated clutter visibility to be limited to a shorter range. In such cases, antenna beam switching would be adjusted for the shorter ranges indicated in the diagram. *

c. MTI Switching.

(1) In most instances employment of the radar capability will be required for detection of targets in clutter. A preliminary estimate of the range at which this mti operation can be discontinued can be found by consideration of data plotted on the clutter boundary diagram.

* (2) For ASR-4B, 5, 5E, 6, 6E, 7, and 7E systems the mti switching range would ordinarily correspond to the maximum range extent of all clutter affecting a significant portion of the radar's azimuth scan. For the ASR-8 radar, however, separate mti switching ranges are selected for each of 20 contiguous azimuth sectors. The maximum clutter range in each of these sectors should be selected for initial setting of the range azimuth gating unit which is part of the ASR-8 unit only. *

d. Clutter Coverage Analysis.

(1) Clutter computations basically involve determination of the signal-to-clutter ratio at various range points within the clutter zone, for different values of antenna tilt angle. This ratio can then be used to determine if target detection is possible.

(2) If mobile radar equipment is available for collection of clutter data, this should be used since it will provide an accurate measurement of the particular clutter background associated with the site. As an alternative, ASR equipment already installed in a nearby location may be used to collect clutter data. Data gathered by this means, though not as accurate as mobile radar data, is probably preferable to purely theoretical clutter predictions.

(3) From the measured data, site survey operations, or map studies, identify the ground areas of maximum clutter within view of the radar. Consideration should be concentrated on those areas azimuthally within 1.5° of overhead airways or fixes.

(4) When no measured data is available, estimate clutter effects as follows:

(a) For several range points within the clutter zone, calculate the clutter grazing angle, ψ, from

$$\psi = \mathrm{Tan}^{-1}\left(\frac{h_a - h_r}{6080R}\right) \quad (3\text{-}11)$$

where:

h_a = msl antenna height at site, in feet

h_r = msl elevation, in feet, of terrain at range R

R = range to detection point, in nautical miles

(b) Determine clutter area A_c from equation 2-39 (p. 132). This reduces to the form

* 1. For ASR-4B, 5, 6, and 7

$$A_c = 6060.4 \text{ R Sec } \psi \quad (3\text{-}12)$$

2. For ASR-5E, 6E, and 7E

$$A_c = 5858.4 \text{ R Sec } \psi \quad (3\text{-}12A)$$

3. For ASR-8

$$A_c = 4218.2 \text{ R Sec } \psi \quad (3\text{-}13)$$ *

(c) Determine normalized clutter cross section σ_c from table 2-3 or 2-4, and compute the actual clutter cross section σ_c from equation 2-40 (p. 132).

$$\sigma_c = A_c \sigma_o \quad (3\text{-}14)$$

(d) Determine the transmit and receive antenna gain G_t and G_r in the direction of a target at this range and at the maximum elevation of concern. Also determine the corresponding gain G_{tc} and G_{rc} in the direction of the clutter patch. Antenna tilt angle, α, must be accounted for in these gain determinations. Initial calculations should use the maximum value of α as determined from figure 3-11.

(e) Compute s/c from equation 2-38 (p. 132),

$$s/c = \frac{\sigma_t G_t G_r}{\sigma_c G_{tc} G_{rc}} \quad (3\text{-}15)$$

using the smallest value of σ_t expected. For a T-33 aircraft, σ_t = 2.2 square meters (lp), σ_t = 0.7 square meters (cp). It should be remembered here that for ASR-4B, 5, 6,

* and 7, and for ASR-5E, 6E, 7E and 8 in their single (main) beam modes, $G_t = G_r$ and $G_{tc} = G_{rc}$. The equalities do not hold, however, for the ASR-5E, 6E, 7E and 8 in the dual beam mode. *

(f) In areas containing discrete clutter sources, (buildings, water towers, mountains, etc.) estimate the clutter cross section, σ_c, in much the same manner as for a target of similar dimensions. Use this value to determine s/c as above.

(5) When actual clutter power data is available from field measurement it should be used directly in clutter analysis. To be useful, clutter power measurements must be made using the same frequency, pulse width, polarization, antenna beamwidth, and height as the ASR. In this case:

(a) For each range point considered within the clutter zone, compute received signal power, S, from equation 2-44 (p. 137)

$$S = \frac{P_t G_t G_r \lambda^2 \sigma_t}{(4\pi)^3 R^4} \qquad (3\text{-}16)$$

using the smallest σ_t expected. If lobing is expected above the clutter area, the appropriate expression for signal power, S, becomes

$$S = \frac{P_t G_t G_r \lambda^2 \sigma_t}{(4\pi)^3 R^4} \eta_e^2 \eta_t^2 \qquad (3\text{-}17)$$

(b) Compare the computed value with measured (and converted) clutter power at the same range to determine s/c.

e. Interpretation of Results.

(1) Clutter boundaries, antenna switching range, and mti switching range(s) are determined directly in the respective analyses above. Clutter coverage may be determined from the computed values of s/c. It can be assumed that target detection at the range being examined will occur satisfactorily in the mti mode if:

*

$$s/c \geq \begin{cases} -14.3 \text{ dB (ASR-4B, 5, 5E, 6, 6E, 7, and 7E)} \\ -17.3 \text{ dB (ASR-8)} \end{cases}$$

*

if this condition is not met, assume no detection occurs.

(2) Clutter analysis is repeated for all clutter areas considered potentially troublesome and a general judgment formed as to the severity of the overall clutter problem. If clutter obcures a significant portion of the controlled airspace, consideration should be given to (a) altering antenna height to reduce the visible clutter area, (b) modifying the return from large scatterers by removal or masking, (c) selection of another radar site affording better natural screening, or (d) modification of the coverage requirements (requires coordination with ATD). If clutter is not seen to present a serious operational problem, consideration may also be given to lowering the antenna tilt angle below its maximum value, thereby achieving better long range coverage of low altitude targets. This action, will, of course, increase ground illumination and worsen any existing clutter problems.

(3) An illustration of the application of clutter analysis procedures is given in appendix 6.

60. <u>TANGENTIAL COURSE ANALYSIS</u>. Each radar siting analysis should include examination of potential tangential course problems which may be associated with the particular site. Such an analysis will indicate the presence or absence of tangential courses which for the radar's mti receiver, can cause loss of targets in the controlled airspace. Techniques to be followed are described in detail in paragraph 22e of chapter 2. Basic procedures are outlined below.

a. <u>Procedure</u>. On a coverage chart (FAA Drawing D-50979-1) centered about the radar site, locate all significant air routes and note target ground speeds for each as determined during preliminary siting data acquisition. The los boundary diagram already contains this data and may be used for tangential course analysis. For each target path within the boundaries of mti usage which approaches tangency with a circle about the radar:

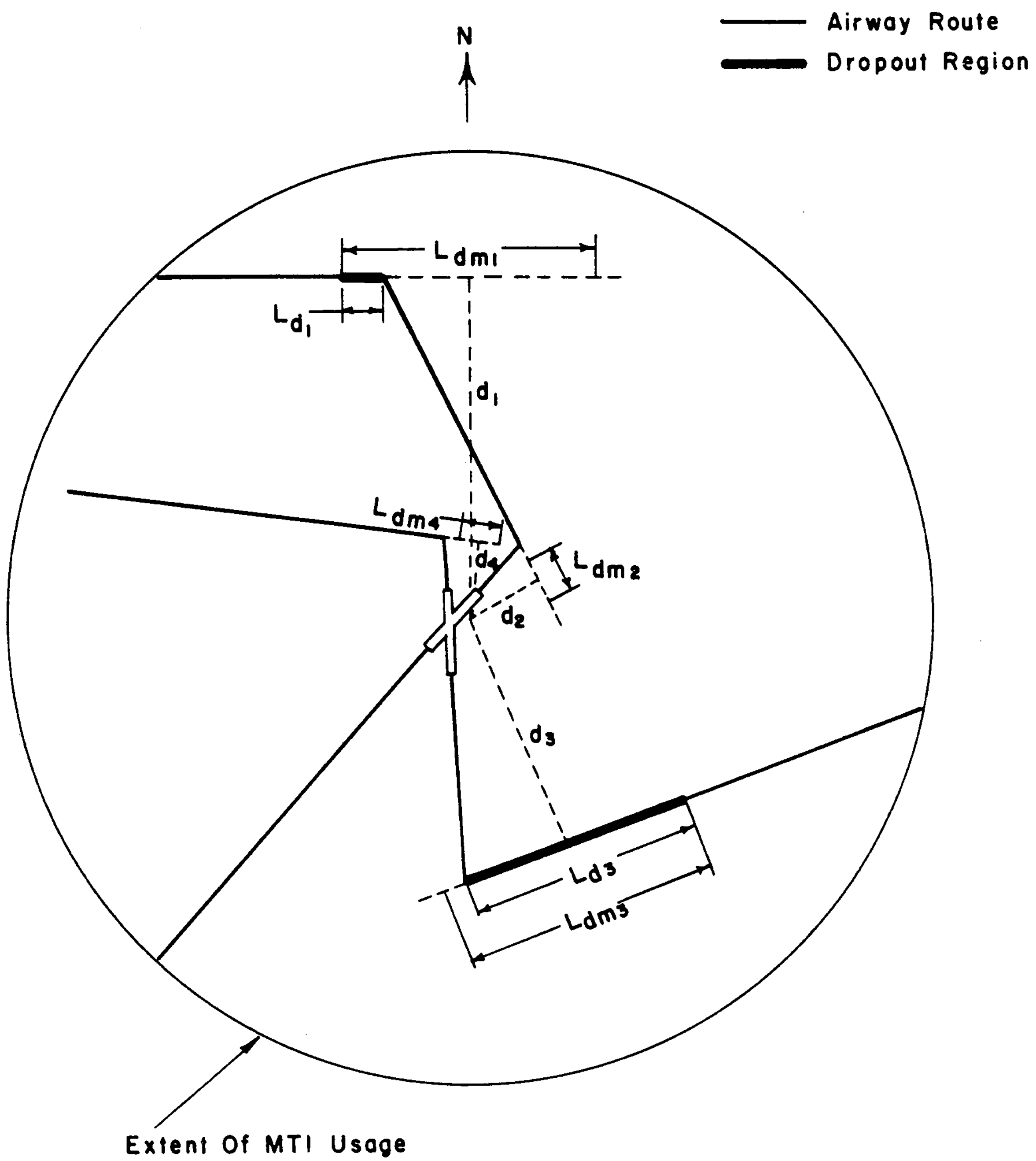
(1) Construct a perpendicular from the radar site to the extension of the airway path.

(2) Determine the maximum dropout region length, L_{dm}, from figure 2-51, using the previously determined target ground speed for the airway in question, and assuming the minimum detectable radial velocity, v_{rm}, is 20 kt.

(3) Determine the actual dropout distance, L_d, by noting the length of overlap (if any) of the airway with the region L_{dm}. This is illustrated in figure 3-25.

(4) For any L_d so determined, evaluate the duration, T_d, of coverage loss from figure 2-53. Compare this with the maximum tolerable dropout time, T_D, as determined from equation 2-52 (p. 149).

FIGURE 3-25. ILLUSTRATION OF TANGENTIAL COURSE ANALYSIS



$$T_D = \frac{120}{w_r} \tag{3-18}$$

The tangential course analysis procedures are illustrated in appendix 6.

b. Analysis. In cases where for each tangential course $T_d < T_D$, there are no intolerable signal losses and the site can be considered free of significant tangential course problems. Where one or more courses exist in which $T_d \geq T_D$, however, coverage losses will occur. These problems should be resolved, by either (1) selecting another site, (2) modification of air route patterns, or (3) acceptance of the situation. The latter approach will require coordination and agreement by both Air Traffic and Flight Standards Division representatives.

61. SECOND-TIME-AROUND (STA) ANALYSIS. STA echoes are produced by targets or clutter at distances greater than the first range ambiguity. If of sufficient amplitude, target returns from the sta region are detected and displayed at an apparent range equal to their distance beyond the point of ambiguity. Sufficiently strong clutter from this region will also be displayed; it is not canceled in the mti receiver when the radar prf is jittered. A brief investigation of potential sta problems should be carried out as part of radar site selection. This may be done as indicated below.

a. Procedure.

(1) From maps and aeronautical charts, locate air routes and large clutter sources (primarily mountains) at ranges from 60 to 200 nmi. Determine their height and their los visibility from the radar site.

(2) This may be done with the aid of long-range radar coverage profile paper (e.g., FAA Drawing D-31500) and the screen angle data developed in previous analyses. For each visible airway or clutter echo source:

(a) Estimate radar cross section and determine detectability. This may be done with the aid of radar coverage diagrams plotted in figures 2-1 through 2-6. Where necessary these curves may be extrapolated for larger targets by noting that range coverage increases as σ^4, other parameters remaining fixed.

(b) If the estimated target/clutter is detectable at the true range, an sta echo can be expected. In such a case, determine the apparent echo range, R_a, and azimuth

$$R_a = R - R_A \tag{3-19}$$

where:

R = true range of echo source

R_A = nearest ambiguous range less than R.

R_A can be found from figure 1-9. The apparent azimuth corresponds to the true azimuth of the echo source.

b. Analysis. Once all sta echoes are determined, their apparent ppi position should be compared with the location of normal returns from traffic in the controlled airspace. If confusion of echoes represents a threat to safe operations, consideration should be given to (1) altering the radar prf to a value which places sta echoes at less troublesome ppi positions (such changes would require coordination with Frequency Management personnel), (2) changing antenna height/tilt to reduce sta source visibility or detectability, or (3) selecting an alternate radar site.

62. COST ESTIMATE. A complete cost estimate for each surveyed site shall be prepared. This will include all pertinent cost factors necessary to insure that the completed site, buildings, associated structures, and site access will be adequate for the purpose intended. Unusual cost factors attributable to unique local conditions should be accurately defined and justified. The standard cost items to be included are: building and tower foundations, tower erection, t/r building, fencing, other buildings, other towers (RML, etc.), site grading, access road construction, electrical installation, power termination, engine generator installation, air conditioning installation, substation installation, duct line and handholes, cable pulling, engineering, and construction supervision. In cases where sites are not comparable on all Government-furnished items, (e.g., GFM engine generator required at one location but not at others) the estimates should reflect true comparable costs of each location. A cost estimation worksheet, FAA Form 6310-4 (11-73), is shown in figure 3-26.

63. ENVIRONMENTAL IMPACT ANALYSIS. Data shall be gathered for the preparation of either a draft environmental impact statement or a negative declaration pertinent to the siting operation. Guidance in performing an environmental impact analysis can be obtained from FAA Order 1050.1A entitled "Procedures For Considering Environmental Impacts of Proposed FAA Actions," and by contacting FAA regional personnel.

64. OTHER ANALYSES. In addition to conducting siting analyses described above, the engineer should undertake such other studies as are required for the resolution of specific problems related to the particular siting operation in question. He should also locate any required RML equipment and form a preliminary determination of the probable locations of mti reflectors, associated with the particular site. RML siting information is necessary for accurate estimation of the cost of establishing an ASR/ATCBI site at the location.

FIGURE 3-26

COST ESTIMATE

PROJECT AND LOCATION ____________________ SHEET 1 OF 2

ESTIMATED BY __________ REVIEWED __________ DATE OF ESTIMATE __________

ITEM DESCRIPTION	UNIT	COMPUTATION AND MATERIAL LISTS	UNIT COST	TOTAL COST ITEM	SOURCE OF COST DATA
1. Building Foundation					
2. Tower Foundation					
3. Tower Erection					
4. T/R Building					
5. Fencing And Gates					
6. RML Towers (s)					
7. Duct Lines & Handholes					
8. Cable Pulling					
9. Site Grading					
10. Site Surfacing					
11. Access Road (Impr.)					
12. Access Road (New)					
Grading & Compacting					
Surface Prep.					
13. Culverts					

FAA Form 6310-4 (11-73)

FIGURE 3-26 (CONTINUED)

COST ESTIMATE

PROJECT AND LOCATION ______________________________ SHEET 2 OF 2

ESTIMATED BY ______________ REVIEWED ______________ DATE OF ESTIMATE ______________

ITEM DESCRIPTION	UNIT	COMPUTATIONS AND MATERIAL LISTS	UNIT COST	TOTAL COST ITEM	SOURCE OF COST DATA
14. T/R Bldg & Tower Electrical					
15. Substation, Terminal Pole & Power Entr. To Bldg.					
16. Power Line					
17. Engine Generator Inst.					
18. Air Conditioning					
19. Engineering					
Per Diem					
Travel					
Local Transp					
20. Construction Superv.					

FAA Form 6310-4 (11-73)

SECTION 6. SITING REPORT

65. DISCUSSION.

a. The purpose of the siting report is to describe and summarize the results of the investigations, surveys, and analysis associated with the siting effort. It is intended to provide a record of, as well as an engineering data source for the site, and may be regarded as the source file for, information relative to the construction, installation, flight check, and commissioning of the site.

b. The siting report should present the necessary information in a logical form readily understandable by the user, and all pertinent data which has a bearing on the recommendations as to site suitability or preference shall be included.

c. A sample outline of the content and organization of the siting report is given in appendix 4. The specific content is flexible and should be adapted as applicable to the particular siting activities and findings. The basic organization format, where a statment of the problem and a summary of results and conclusions precede the detailed accounts, analysis, investigations, etc., should be adhered to in order to provide for a quick and comprehensive review of the siting effort without resorting to details.

d. A minimum of nine copies of the report should be prepared and the distribution of the report should include the following:

Office	No. of Copies
FAA Regional Offices	
1. Air Traffic Division	1
2. Airway Facilities Division	1
3. Flight Standards Division	1
FAA Local Site Offices	
1. Airway Facilities Sector Chief	1
2. Air Traffic Facility Chief	1
FAA Washington Offices	
1. Air Traffic Service	1
2. Airway Facilities Service	1
3. Flight Standards Services	1
4. Systems Research & Development Service	1
TOTAL	9

SECTION 7. FINAL SITE SELECTION

66. DISCUSSION.

a. In the event that final site selection is still in doubt, use of a mobile siting van should be considered as a means of alleviating any final uncertainty. The final selection of the ASR/ATCRBS site will require the concurrence and approval of a number of regional and local FAA offices. These offices, identified by the distribution list given in the previous section, will be called upon to review the siting report and present their objections, suggestions and/or approval of the findings and recommendations described in the siting report. Conferences and meetings between representatives of these offices and members of the siting team should be held as necessary to present and discuss these views.

b. Once agreement between all cognizant offices has been reached regarding the location and requirements of the ASR/ATCRBS site, an appropriate approval/concurrence memorandum should be signed by a representative of each cognizant office. This memorandum should identify the site selected with reference to the siting report, noting all exceptions or changes made with respect to the findings and recommendations made in the report. It should then be inserted as a permanent addendum to the siting report.

APPENDIX 1

REFERENCES

1. M. I. Skolnik, Radar Handbook, McGraw Hill, 1970.

2. F. E. Nathanson, Radar Design Principles, McGraw Hill, 1969.

3. J. D. Kraus, Antennas, McGraw Hill, 1950.

4. H. Jasik, Antenna Engineering Handbook, McGraw Hill, 1961.

5. G. F. Andrews, Solar Radiation - A Useful Tool for Radar Antenna Orientation, FAA Southern Region Report.

6. L. V. Blake, A Guide to Basic Pulse Radar Maximum Range Calculation, Part I - Equations, Definitions, and Aids to Calculation, Report 6930, Naval Research Laboratory, AD 701-321, December 23, 1969.

7. C. R. Burrows and S. S. Attwood, Radio Wave Propagation, Academic Press, 1949.

8. G. F. Spingler, Experimentation and Analysis of Siting Criteria, Report NA-69-36, FAA/NAFEC, September 1969.

9. F. K. Preikschat, "Screening Fences for Ground Reflection Reduction," Microwave Journal, P. 46, August 1964.

10. M. I. Skoknik, Introduction to Radar Systems, McGraw Hill, 1962.

11. E. K. Smith and S. Weintraub, "The Constants in the Equation for Atmospheric Refractive Index at Radio Frequencies," Proc. IRE, Vol. 41, pp. 1035-1037, August 1953.

12. Handbook of Geophysics, Revised Edition, the Macmillan Co., New York, 1960.

13. N. Murarka, et. al., Secondary En Route Beacon Splits, Report IITRI-E6253-1, IIT Research Institute, July 1973.

14. N. Murarka and D. Lanera, Investigation of False Target Problem at the Las Vegas En Route Radar Beacon Site, Report IITRI-E6253-2, IIT Research Institute, August 1973.

APPENDIX 2

INTERROGATION VERSUS REPLY LINK IN LIMITING ATCBI PERFORMANCE

1. Radar equations governing beacon system performance may be written as follows:

$$R_i^2 = \frac{P_{oi} G_i G_t \lambda_i^2}{(4\pi)^2 P_{rt} L_s} \qquad \text{(interrogation link)} \qquad (2\text{-}1)$$

$$R_r^2 = \frac{P_{ot} G_t G_i \lambda_r^2}{(4\pi)^2 P_{ri} L_s} \qquad \text{(reply link)} \qquad (2\text{-}2)$$

where:

R_i = interrogation range

R_r = reply range

P_{oi} = interrogator transmitter output

P_{ot} = transponder transmitter output

G_i = interrogator antenna gain

G_t = transponder antenna gain

λ_i = interrogation wavelength

λ_r = reply wavelength

P_{rt} = received power at transponder

P_{ri} = received power at interrogator

L_s = system losses

2. Maximum range occurs, for either situation, when the received power is equal to the minimum detectable signal. Calling these parameters $s_{min,t}$ and $s_{min,i}$ for transponder and interrogator, respectively, the maximum range relationships are given by:

$$R_{max,i}^2 = \frac{P_{oi} G_i G_t \lambda_i^2}{(4\pi)^2 L_s S_{min,t}} \qquad \text{(interrogation link)} \qquad (2\text{-}3)$$

$$R^2_{max,r} = \frac{P_{ot} G_t G_i \lambda_r^2}{(4\pi)^2 L_s S_{min,i}} \qquad \text{(reply link)} \qquad (2\text{-}4)$$

3. Comparing the two expressions it may be noted that

$$\frac{S_{min,t} R^2_{max,i}}{P_{oi} \quad \lambda_i^2} = \frac{S_{min,i} R^2_{max,r}}{P_{ot} \quad \lambda_r^2}$$

or that

$$\frac{R^2_{max,r}}{R^2_{max,i}} = \frac{P_{ot} S_{min,t} \quad \lambda_r^2}{P_{oi} S_{min,i} \quad \lambda_i^2} \qquad (2\text{-}5)$$

4. Now the parameters of common beacon systems (table 1-2) are such that in most cases $R_{max,r} > R_{max,i}$. As an example, take

P_{ot} = +51 dBm

$S_{min,t}$ = -74 dBm

P_{oi} = +60 dBm

$S_{min,i}$ = -87 dBm

$(\lambda_r/\lambda_i)^2$ = +.5 dB

$$20 \log \frac{R_{max,r}}{R_{max,i}} = +51 -74 -60 +87 +0.5 = 4.5 \text{ dB}$$

$$R_{max,r} = 1.68 \ R_{max,i}$$

5. Effective beacon system operation, especially in terminal installations where P_{oi} is reduced, is normally limited by the performance of the interrogation link.

APPENDIX 3

SCREENING RELATIONSHIPS

1. DERIVATION OF SCREEN ANGLE RELATIONSHIPS.

a. The geometric relationship between the screen angle (θ_S), range (d), antenna height (h_a), and altitude (h), for a curved earth is shown in figure B-1. To derive the mathematical expression relating the screen angle to these parameters, we see from the figure that

$$\overline{DC} = R \cos \theta_S = (h + ka) \sin \beta \quad (3\text{-}1)$$

and from the relation

$$\overline{DE} = R \sin \theta_s = \overline{OD} - \overline{OA} - h_a \quad (3\text{-}2)$$

we have

$$\overline{DE} = R \sin \theta_s = (k_a + h)\cos\beta - (ka + h_a) \quad (3\text{-}3)$$

where the radius of the equivalent earth is given as ka with

a = actual Earth's radius

k = equivalent earth radius factor

and the angle β is defined by the arc length d between the antenna and the altitude point B.

b. Dividing above equations by 3-3 by 3-1, yields,

$$\tan \theta_s = \frac{(h + ka)\cos\beta - (h_a + ka)}{(h + ka) \sin\beta} \quad (3\text{-}4)$$

c. From geometrical considerations, the angle β is given by

$$\beta = d/ka \quad (3\text{-}5)$$

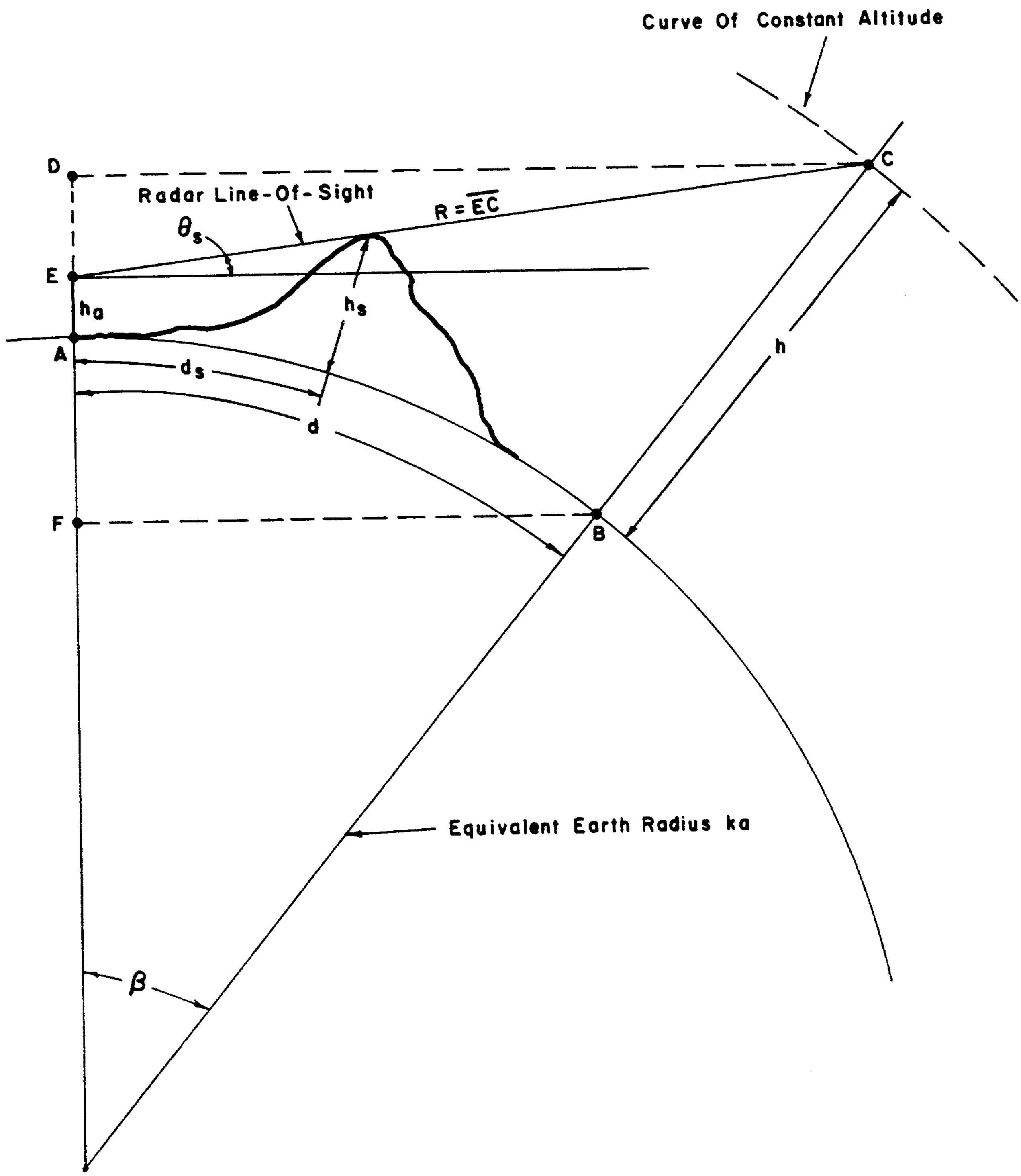
and as long as d << ka, or $\beta \leq 10^\circ$, the approximations

$$\sin \beta \simeq \beta \quad (3\text{-}6)$$

$$\cos \beta \simeq 1 - \beta^2/2 \quad (3\text{-}7)$$

are valid for all practical purposes. Substituting equations 3-5, 3-6, and 3-7 into equation 3-4 gives the desired relationship

FIGURE 1. SCREENING GEOMETRY FOR A CURVED EARTH



$$\tan \theta_s = \frac{h - h_a}{d} - \frac{d}{2ka} \qquad (3\text{-}8)$$

d. In the development of this equation, the units for h_1, h_a, d and a were all assumed to be the same. If h and h_a are given in feet and d and a in nautical miles, equation 3-8 is written as

$$\tan \theta_s = \frac{h - h_a}{6080\ d} - \frac{d}{2ka} \qquad (3\text{-}9)$$

2. SCREEN ANGLE AND COVERAGE CHARTS. Radar vertical coverage charts which provide a graphical solution to equation 3-9 for various values of the equivalent earth radius parameter, k, are plotted in figures 3-2 through 3-8. Four charts (FAA Drawings D-50979-2, 3, 4, 8) are given for k = 4/3. Single charts are provided for k = 1 (FAA Drawing D-50979-5), k = 2/3 (FAA Drawing D-50979-6), and k = 1/2 (FAA Drawing D-50979-7). These charts can be used for location of navigational fixes and assessment of coverage for k-values corresponding to a variety of possible atmospheric conditions.

3. RADAR VS OPTICAL ALTITUDE COVERAGE.

a. Although both radar and optical energy undergo atmospheric refraction, radar refraction is usually more severe. This effect makes it reasonable to expect that radar will provide better low altitude coverage at a given range than will be observed optically. To demonstrate that this is in fact true, consider the case where the angles θ_{os} and θ_{rs} represent the optical and radar screening angles for a given screen object distance, d_s, and height, h_s. Using equation 3-9 the altitude that can be seen optically at the range d ($d \geq d_s$) is expressed as:

$$h_o = 6080\ d \tan \theta_{os} + \frac{3(6080)\ d^2}{7a} : \quad k = 7/6 \qquad (3\text{-}10)$$

where k = 7/6 is the standard earth's radius multiplier for optical refraction. The altitude, h_r, that is within the radar los is given by (for arbitrary k)

$$h_r = 6080\ d \tan \theta_{rs} + \frac{6080\ d^2}{2ka} \qquad (3\text{-}11)$$

b. Taking the difference between h_o and h_r we obtain:

$$h_o - h_r = 6080\ d(\tan \theta_{os} - \tan \theta_{rs}) + \frac{3(k-\frac{7}{6})\ 6080\ d^2}{7ka} \qquad (3\text{-}12)$$

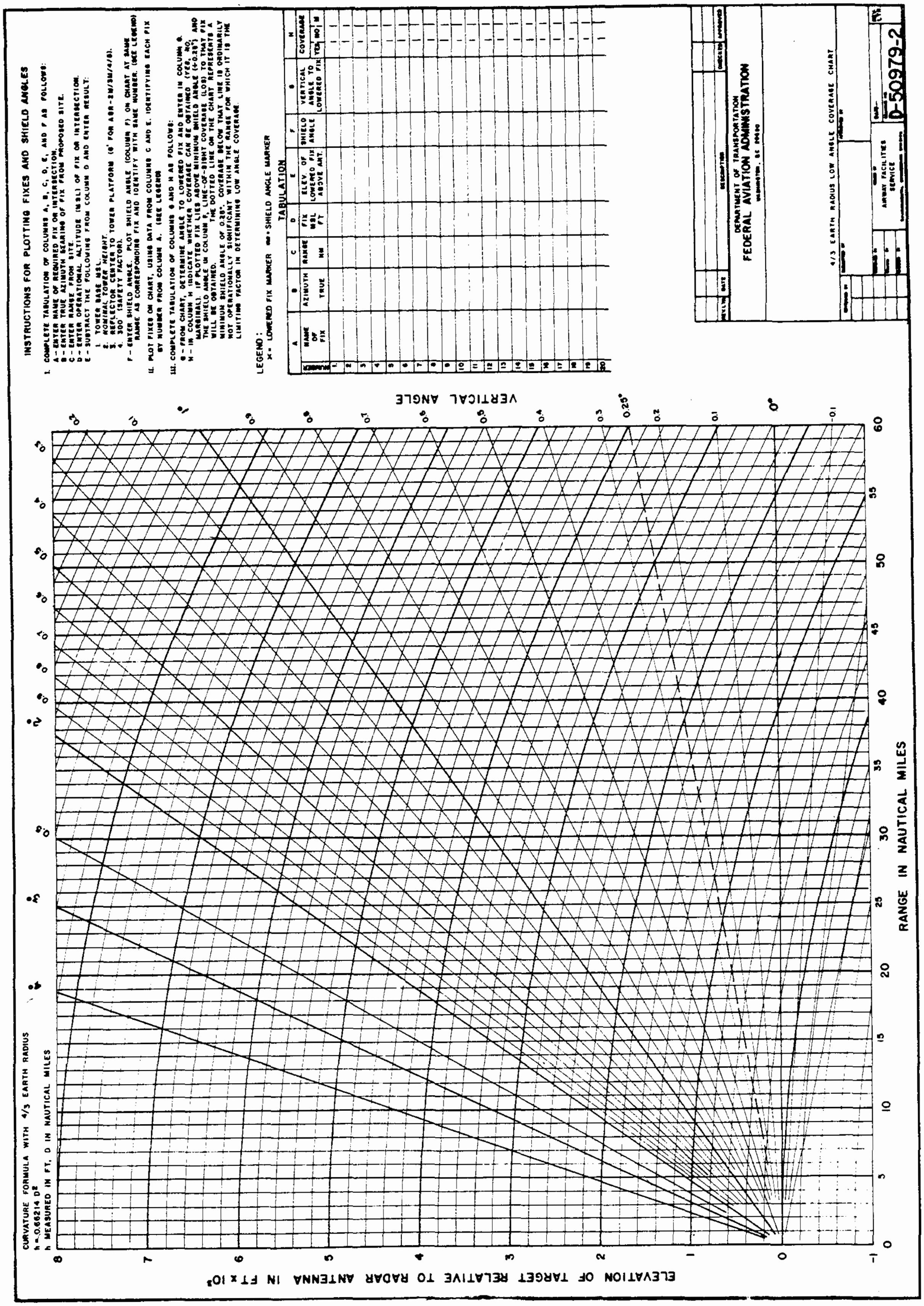


FIGURE 2. 4/3 EARTH RADIUS LOW-ALTITUDE COVERAGE CHART

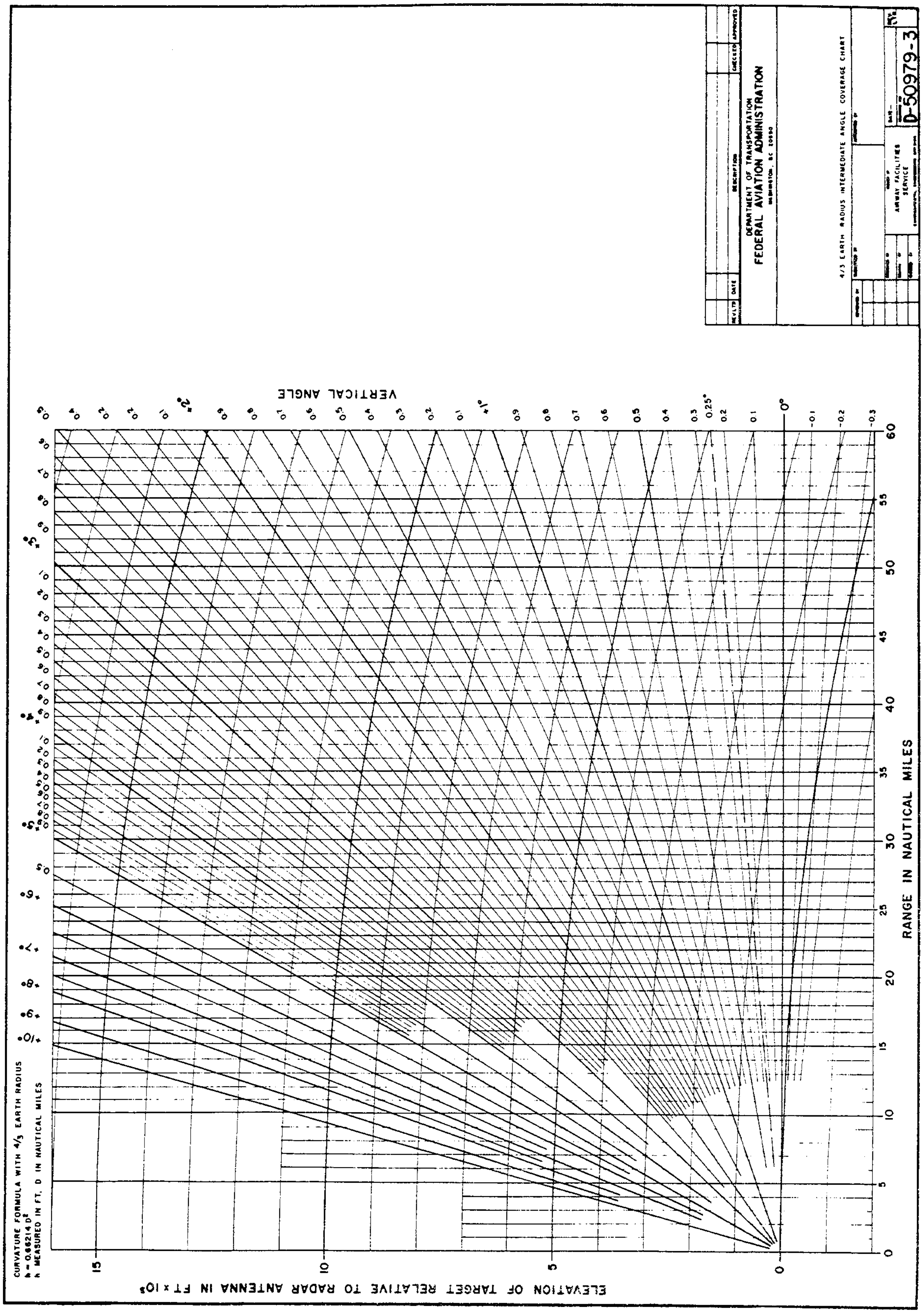


FIGURE 3. 4/3 EARTH RADIUS INTERMEDIATE-ALTITUDE COVERAGE CHART

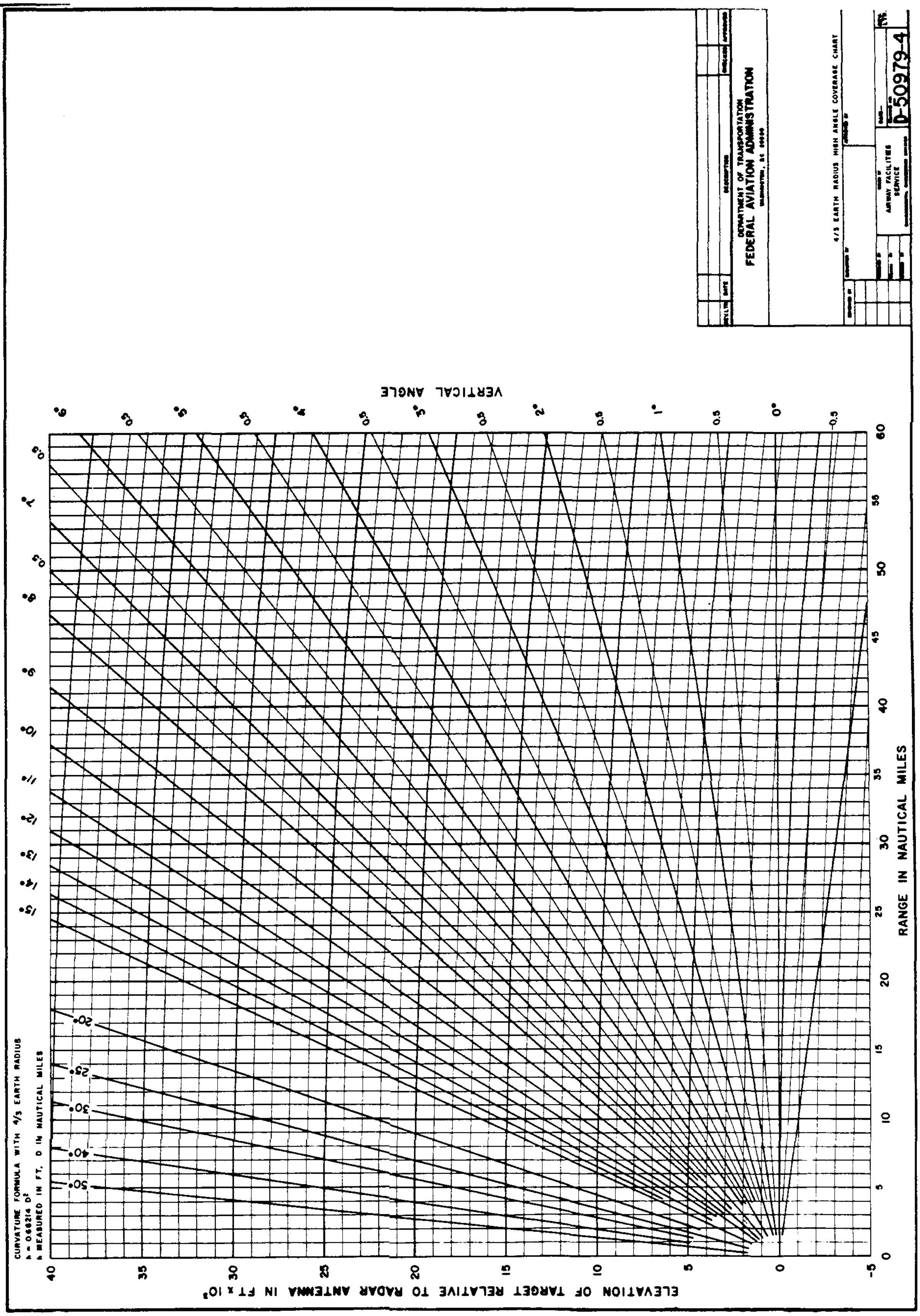


FIGURE 4. 4/3 EARTH RADIUS HIGH-ALTITUDE COVERAGE CHART

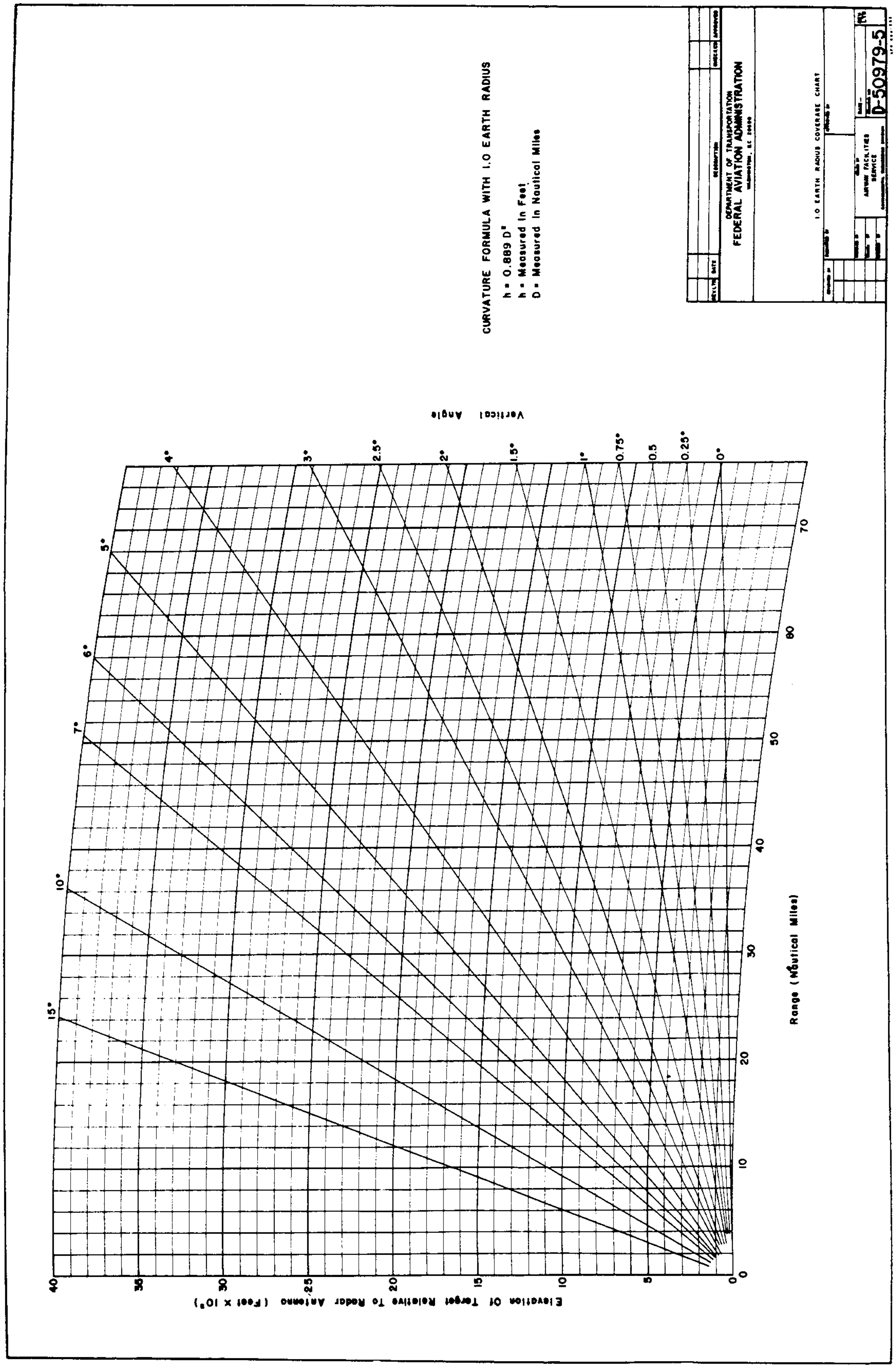


FIGURE 5. 1.0 EARTH RADIUS COVERAGE CHART

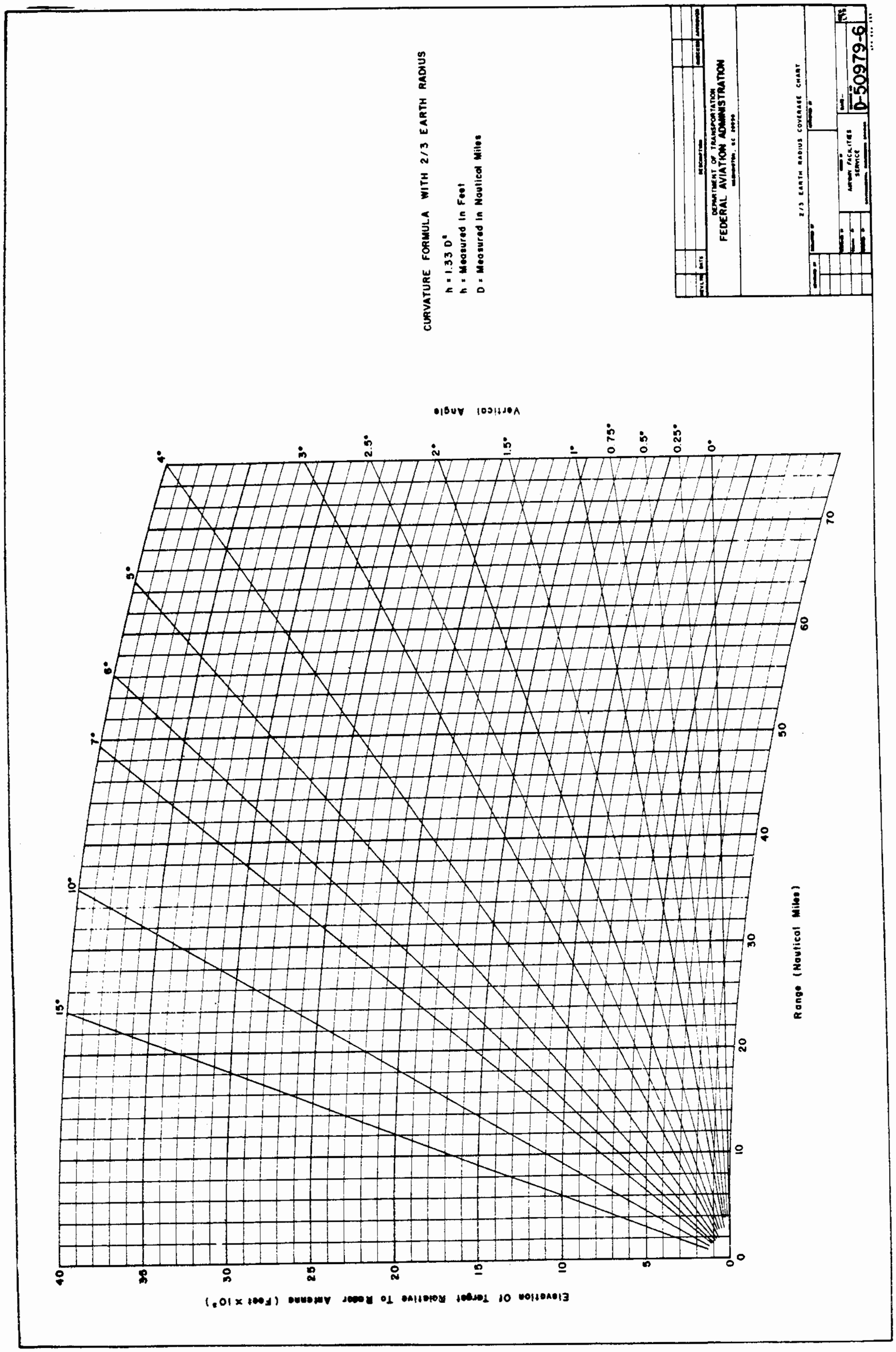


FIGURE 6. 2/3 EARTH RADIUS COVERAGE CHART

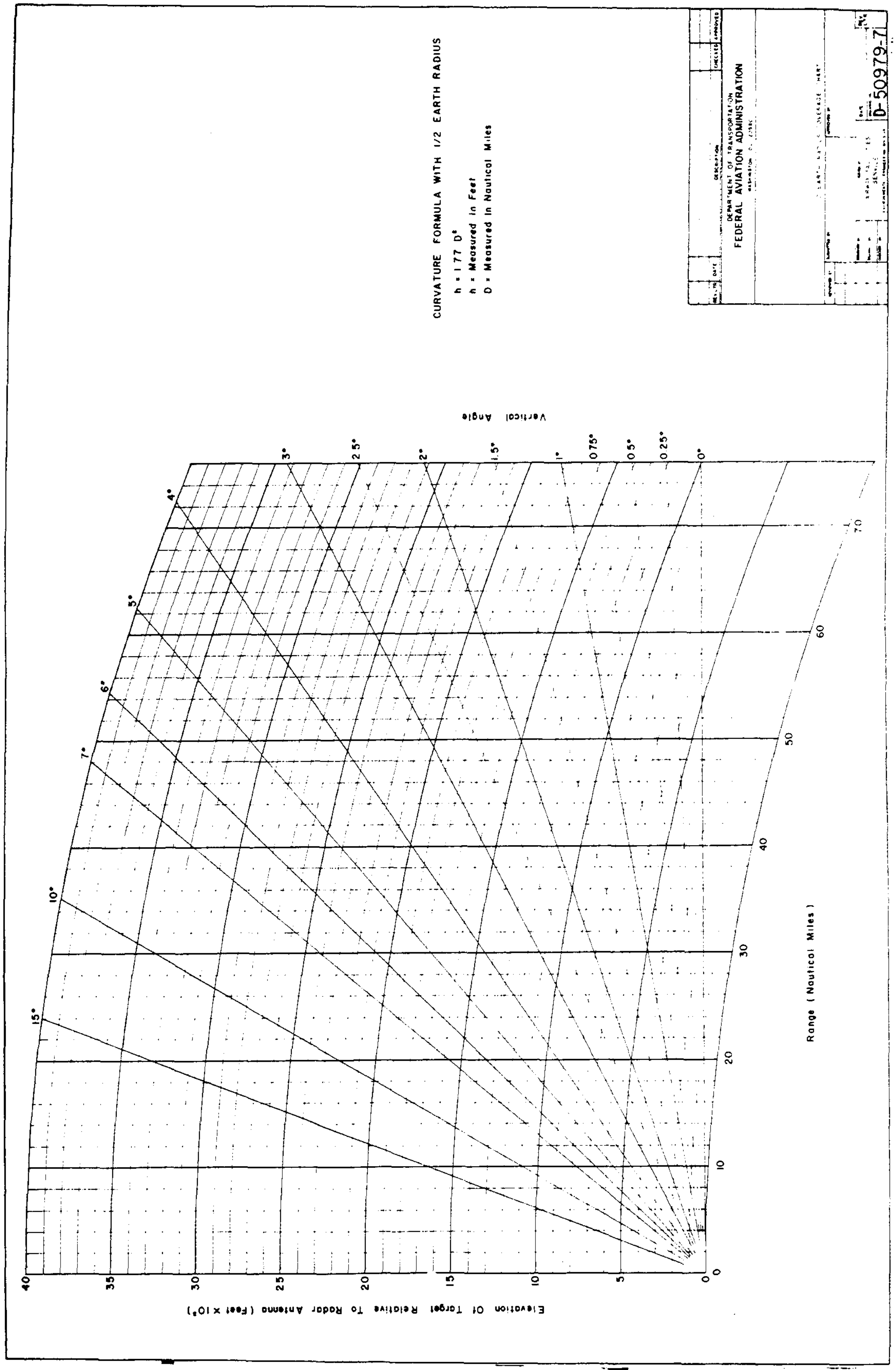


FIGURE 7. 1/2 EARTH RADIUS COVERAGE CHART

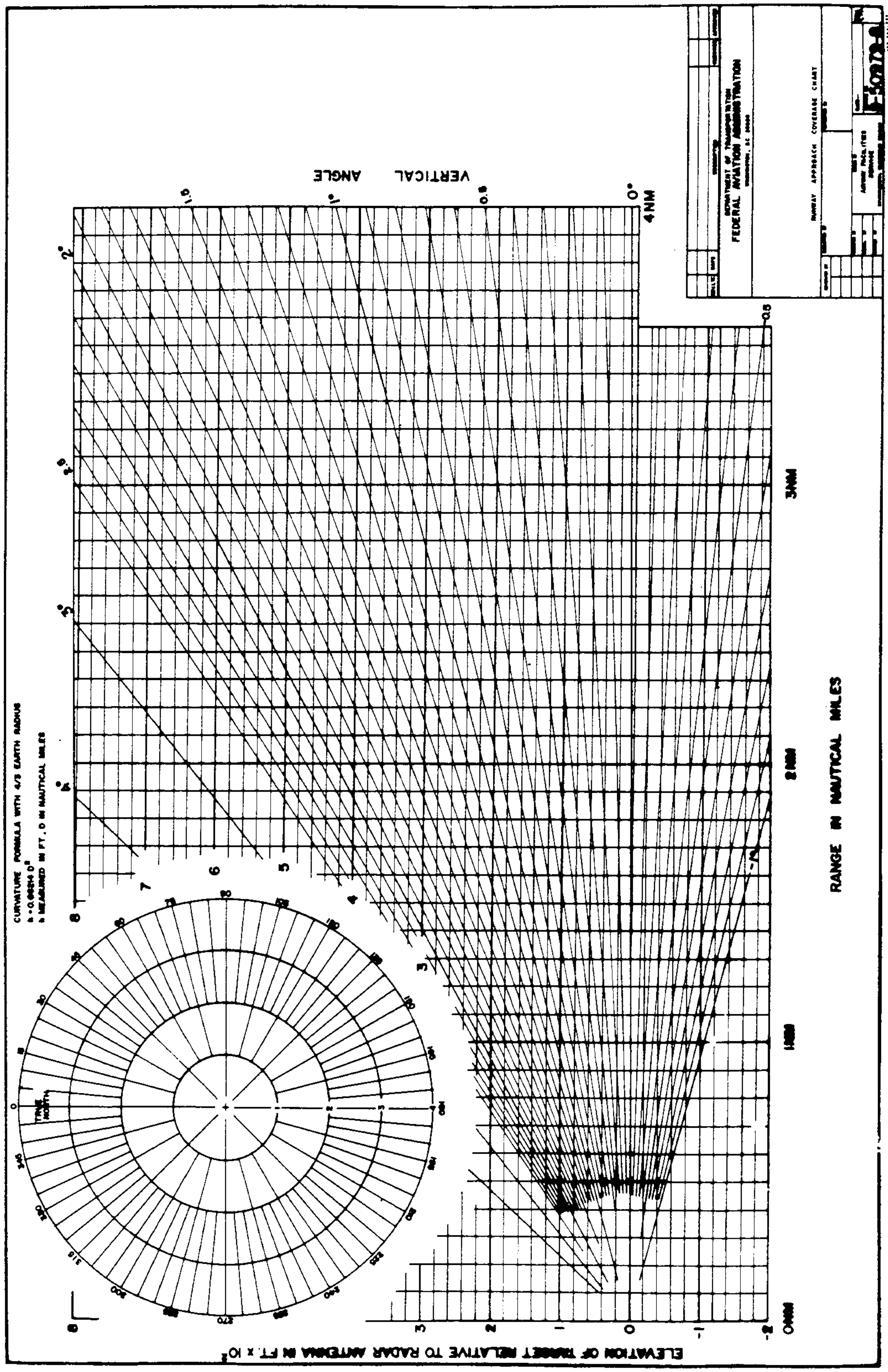


FIGURE 8. RUNWAY APPROACH COVERAGE CHART

c. The difference between the optical and radar screening angles θ_{os} and θ_{sr}, respectively, can be derived by considering each in terms of equation 3-9. For the optical case where k = 7/6, the screen angle is:

$$\tan \theta_{os} = \frac{h_s - h_a}{6080\ d_s} - \frac{3d_s}{7a} \qquad (3\text{-}13)$$

and the radar screen angle for arbitrary k is

$$\tan \theta_{rs} = \frac{h_s - h_a}{6080\ d_s} - \frac{d_s}{2ka} \qquad (3\text{-}14)$$

d. Taking the difference between equations 3-13 and 3-14 yields:

$$\tan \theta_{os} - \tan \theta_{rs} = \frac{-3(k - \frac{7}{6})\ d_s}{7ka} \qquad (3\text{-}15)$$

e. Substituting this relationship in equation 3-12 gives

$$h_o - h_r = \frac{3(6080)\ (k - \frac{7}{6})d(d - d_s)}{7ka} \qquad (3\text{-}16)$$

which for a = 3,437 nautical miles is

$$h_o - h_r = \frac{0.758(k - \frac{7}{6})d(d - d_s)}{k} \qquad (3\text{-}17)$$

f. Hence, for $k > \frac{7}{6}$, equation 3-17 shows that $h_o > h_r$. This states that the radar can "see" to a lower altitude than is visible optically beyond a fixed screening object.

g. For the conventional radar case where k = 4/3, equation 3-15 reduces to

$$\tan \theta_{os} - \tan \theta_{rs} = \frac{-\frac{3}{6}\ d_s}{\frac{28}{3}\ a} = \frac{-\ 3\ d_s}{56a} \qquad (3\text{-}18)$$

where a = 3,437 nautical miles.

h. Now, for small angles

$$\tan \theta = \theta \text{ (in radians)} = \frac{\pi}{(180)\ (60)} \times \theta \text{ (in minutes)}$$

i. Equation 3-18 can therefore be written as

$$\theta_{os} - \theta_{rs} = - \frac{(180)\ (60)}{\pi} \frac{3\ d_s}{56(3437)} = -3437.7 \frac{3\ d_s}{56(3437)}$$

or

$$\theta_{rs} \simeq \theta_{os} + \frac{3\ d_s}{56} \qquad (3\text{-}19)$$

where

θ_{rs} = radar screening angle in minutes

θ_{os} = optical screening angle in minutes

d_s = distance to screen object in nautical miles.

j. Also for the k = 4/3 case with small angles, equation 3-14 can be written as

$$\theta_s = \frac{h-h_a}{6080\ d_s} - \frac{3\ d_s}{8a} \qquad (3\text{-}20)$$

where

h = height of point, in feet

h_a = height of antenna, in feet

d_s = screening distance, in nautical miles

a = earth radius, in nautical miles

θ = radar screening angle, in radians

k. Modifying equation 3-20 to allow angles to be measured in minutes, yields

$$\theta_s = 3438 \left[\frac{h-h_a}{6080\ d_s} - \frac{d_s}{9165} \right] \qquad (3\text{-}21)$$

l. The screen angle θ_{s1} to an object at height h_s, measured from antenna height h_1 is then

$$\theta_{s1} = 3438 \left[\frac{h_s - h_1}{6080\ d_s} - \frac{d_s}{9165} \right] \quad (3\text{-}22)$$

m. If a fix at distance d_f and height h_f is measured from this point to be Δ_1 minutes above the screening point, then

$$\Delta_1 + 3438 \left[\frac{h_s - h_1}{6080\ d_s} - \frac{d_s}{9165} \right] = 3438 \left[\frac{h_f - h_1}{6080\ d_f} - \frac{d_f}{9165} \right] \quad (3\text{-}23)$$

n. Should the antenna height now be adjusted to a new position, h_2, which will cause the fix to be located at the screening angle θ_{s2}

$$\theta_{s2} = 3438 \left[\frac{h_s - h_2}{6080\ d_s} - \frac{d_s}{9165} \right] = 3438 \left[\frac{h_f - h_2}{6080\ d_f} - \frac{d_f}{9165} \right] \quad (3\text{-}24)$$

o. Subtracting equation 3-24 from 3-23 gives

$$\Delta_1 + 3438 \left[\frac{h_2 - h_1}{6080\ d_s} \right] = 3438 \left[\frac{h_2 - h_1}{6080\ d_f} \right] \quad (3\text{-}25)$$

which reduces to

$$h_2 = h_1 - \frac{6080\ d_f d_s}{3438\ (d_f - d_s)} \left| \Delta_1 \right| \quad d_f > d_s \quad (3\text{-}26)$$

or

$$h_2 = h_1 - 1.769 \frac{d_f d_s}{(d_f - d_s)} \left| \Delta_1 \right| \quad d_f > d_s \quad (3\text{-}27)$$

p. A new antenna height, h_2, will thus cause the fix to be seen at the screen angle.

q. Likewise, if the fix lies below the screening profile by an angle of Δ_2 minutes, a new antenna height, h_2, will allow the fix to be seen at the screening angle. In this case

$$h_2 = h_1 + 1.769 \frac{d_f d_s}{(d_f - d_s)} \left| \Delta_1 \right| \quad d_f > d_s \quad (3\text{-}28)$$

APPENDIX 4

OUTLINE OF SITING REPORT

i Title Page

ii Forward (describing authorization for siting, type equipment to be installed, principal airport served, period of study, and names/titles of contributing personnel)

iii Distribution Page

iv Table of Contents

v List of Illustrations

TECHNICAL CONTENT OF REPORT

I. SITING REQUIREMENTS

A. ATC Requirements

1. Primary Airport Served (high, low, intermediate activity)

2. Coverage Requirements

(a) Table of Fixes
(b) Principal/Worst Case Aircraft Type

3. Special Constraints/Requirements

(a) Runway Coverage
(b) No Airport Property Available
(c) Interface with Existing ATC Facilities

B. Equipment/Operational Requirements (Frequency, PRF, etc.)

II. SUMMARY REVIEW OF RESULTS/RECOMMENDATIONS

A. Identification/Description of Sites Surveyed

1. Identification

(a) Name/Number

(1) Percent of Fixes Covered
(2) Identify Fixes not Covered
(3) Reason (i.e., Screen, Lobing, Rangential Course, etc.) for no Coverage

(b) Summary Comparison of Operational Performance

(1) False Targets (Beacon and ASR)
(2) Second-Time-Around
(3) Clutter
(4) Lobing
(5) Tangential Course Problems
(6) Shadowing/Shielding
(7) Interference
(8) Costs

2. Recommended Site

(a) Recommended Installation/Operational Conditions (stc, tilt, antenna height, rag, beacon power, prf)
(b) Coverage Deficiencies/Limitations
(c) Flight-Check Recommendations

III. SITING INVESTIGATIONS/ANALYSIS/DISCUSSION

A. Preliminary Investigations

1. Identification/Description of all Sites Investigated

2. Environmental Impact Assessment

3. Reasons for Rejecting Various Sites

4. Reasons for Selecting Sites for Detailed Survey

5. Meteorological/Climatological Data

B. Site #1 Analysis

1. Site Description

(a) Location (longitude/altitude)
(b) MSL Elevation
(c) Site Terrain/Geological Features (general description of site data to include soil conditions, slope gradients, etc.)
(d) Surrounding Terrain Features (mountain, coastal, etc.)
(e) Complete FAA Form 402
(f) Panoramic Photographs

2. Coverage Analysis

(a) Screening Profile Graph

(1) LOS Coverage to Fixes
(2) Recommended Antenna Height

(b) LOS Boundary Diagram

(1) Air-Route Coverage

(c) Vertical ASR Coverage

(1) Range Coverage to Fixes
(2) Recommended Tilt Angle

(d) Beacon Coverage

(1) Recommended Power

(e) Runway Coverage (if required)

3. Lobing Analysis

4. Beacon False Target Analysis

5. Clutter Analysis

(a) Radar In-Clutter Coverage
(b) Permanent Echoes
(c) Surface Traffic

6. Tangential Course Analysis

7. Second-Time-Around

8. Engineering and Construction Data

(a) Recommended Antenna Tower Height
(b) Requirements for Access Road
(c) UTILITY Requirements

(1) Commercial Power (show route of power lines)
(2) Telephone Installation
(3) Water/Sanitation

(d) Site Improvements

(1) Grading
(2) Clearing
(3) Landscaping
(4) Security Fence

9. Real Estate Data

   (a) Acreage of Land Selected
   (b) Easements and/or Right of Way Requirements for Roads, Utilities, Prevention of Future Construction, etc.
   (c) Name of Owner or Agent
   (d) Is Property Occupied or In Use?
   (e) Can FAA Acquire Land
   (f) Purchase or Leasing Cost

10. Cable Route Survey

   (a) Show Routing and Length of Cable

11. RML Path Survey

   (a) Show RML Path(s)
   (b) Indicate Need for One Path or Multiple Path With Repeater
   (c) Estimated RML Tower Height/Antenna Location
   (d) Recommended Frequencies

12. MTI Reflector Installation

   (a) Number and Location of MTI Reflectors
   (b) Exceptions Taken in Standard Number or Location Desired (i.e., use of permanent echo targets, off runway center-line location, etc.)

13. Recommended Installation/Operation Parameters

   (a) Antenna Height
   (b) Antenna Tilt Angle
   (c) Expected CP and LP Usage
   (d) RAG Recommendations
   (e) STC Recommendations
   (f) Recommended Beacon Power
   (g) Recommended PRF

14. Miscellaneous

   (a) Interference Problems
   (b) Corrosive Environments

15. Cost Estimates

C. Site #2 Analysis

   (repeat for each site surveyed)

IV. CORRESPONDENCE/FINAL SITE APPROVAL

APPENDIX 5

DESCRIPTION OF AVAILABLE COMPUTER PROGRAMS BENEFICIAL TO RADAR SITE SELECTION

1. INTRODUCTION.

a. The selection of sites for FAA terminal radar and beacon control facilities can be thought of as a twofold problem: The geographical location of the site and the performance capability of the equipment at the geographical location. In either case, the engineer is faced with a number of parameters to be evaluated in order to assess the system performance or to choose a particular location for the equipment. Some of the major parameters that an engineer would be concerned about are:

(1) Topographic environment - this would be used to determine radar coverage with respect to detection of incoming and departing targets; to locate equipments in areas where there is a maximum amount of rfi shielding, therefore minimizing interference to and from other equipments.

(2) Round reliability - this is the probability that a given ATCRBS interrogation will elicit a reply from a particular transponder. Low-round reliability results in degradation of azimuth accuracy.

(3) Reflections - reflections from surfaces such as buildings, towers, parked aircraft, etc., can cause false replies which are displayed at the azimuth of the reflecting surface rather than the true azimuth of the aircraft.

(4) Fruit - fruit are asynchronous beacon replies generated by aircraft being interrogated by stations other than the receiving station. Fruit causes false-target generation and valid reply garbling.

(5) Vertical pattern lobing - the vertical radiation patterns displayed peaks and nulls caused by ground reflections. The nulls result in missed reports, thereby creating a degradation in system effectiveness.

b. Recently a survey was conducted to locate and evaluate computer programs which would provide engineers with data regarding these and other parameters important to radar siting analysis. This report is a result of that survey. The report contains resumes of all computer models deemed significant to radar siting. A brief statement of the purpose, application, input data requirements, and output data content is presented for each model. Also provided is a brief summary of the applicable limitations on the use of the model.

2. COMPUTER MODELS.

a. This section contains descriptions of computer automated analysis systems which are applicable to radar siting problems. The computer programs described herein should provide the engineer with assistance in the following areas:

(1) Selecting locations for equipment.

(2) Evaluating potential sites for line-of-sight coverage.

(3) Evaluating potential sites for compatibility with surrounding electronic and topographic environment.

(4) Selecting frequency.

(5) Determining power densities.

(6) Determining effects of placing new systems into present and future environments.

b. In addition to a resume of technical information, the agency or organization in possession of the program is identified for each computer model summarized. Organizations named are:

(1) Electromagnetic Compatibility Analysis Center (ECAC).

(2) Cornell Aeronautical Laboratories.

(3) Transportation Systems Center.

c. User contact with any of these organizations should, of course, be arranged through the appropriate FAA channels.

d. It should be noted that the operational computer models existing at the ECAC can be run with either an existing data base or with user supplied input data. A description of the ECAC data base can be found in paragraph 4 of this appendix.

e. Site Analysis Model (SAM)

(1) Purpose. The sam is a computerized system which determines the areas about one or more sites in which a target can appear without being detected. SAM has been designed to handle the problem of site selectivity and compatibility with surrounding terrain.

(2) Description.

(a) SAM is a sequenced collection of computer programs which utilize a topographic data base to determine areas of protection against detection for specified flight paths within a given geographic problem area. SAM can be considered to have three major phases:

1. Profiling.

2. Line-of-sight calculations.

3. Output formulation.

(b) The problem area is considered to be covered by a grid of variable dimensions. Each intersection point on this grid is considered as a hypothetical target location and is analyzed to determine if it is visible to the increment along the great circle path between the site and each endpoint. Each profile is examined to determine line-of-sight and the elevation of the radar above sea level at the gridpoint. This value is maintained for each profile and forms the basis for the generation of the output display. This program offers the user an option of forming a series of overlays reflecting various combinations for each site in the group which are stored and later recalled and combined on the basis of a master combination list formed from input data. To generate the output overlays, the beam elevations are retrieved and compared in turn to the approach altitude of the target to determine if shielding occurs at that point. The program indicates the status of the target at each point forming the overlay. A mask plot may be produced indicating shielded versus detected areas, or the degree of shielding or vulnerability at each point may be represented.

(3) Inputs.

(a) The input to this program consists of digitized topographic data, site coordinates, target altitude, and a scale for the main overlay. For the overlay, the following parameters are required:

1. Center latitude (degrees).

2. Center longitude (degrees).

3. Grid spacing for overlay.

4. Number of rows for overlay (maximum of 75).

5. Number of columns for overlay (maximum of 123).

6. Number of sites to be processed (maximum of 50).

7. Radius of area covered by overlay (miles).

8. Spacing of elevations along profile.

9. Number of antenna heights.

10. Number of target altitudes.

11. Scale factor for calculating degree of shielding or degree of vulnerability.

12. Combination option (1 = yes, 0 = no).

13. Overlay option (0 = shielding only, 1 = vulnerability only, 2 = both).

(b) The following siting parameters are required for each site to be processed:

1. Latitude (degrees).

2. Longitude (degrees).

3. Range.

4. Site elevation.

5. Antenna height (for each antenna with a maximum of four).

(4) Outputs. A map overlay showing the degree of terrain shielding at radar or communication sites.

(5) Applications.

(a) Used to obtain overlays showing line-of-sight coverage for radar installations.

(b) Used to determine target penetration routes which will provide maximum shielding for aircraft.

(c) Used to show shielding against radiation from high-powered equipment.

(d) Used to locate equipment in areas where there is a maximum amount of shielding.

(6) Limitations.

(a) Masking caused by clutter is not included.

(b) Vertical antenna patterns are not included.

(7) Agency.

Electromagnetic Compatibility Analysis Center (ECAC)
North Severn
Annapolis, Maryland 21402

f. Target Acquisition Model

(1) Purpose. To analyze the effect of topography on the target acquisition capability of an equipment.

(2) Description. The coordinates of the site location, the topographic data for the desired area around the site, and the target altitude are used to generate topographic profiles along radials extending outward from the site and spaced at equi-angular increments about the site. The profiles have been normalized to an earth's radius greater than the true earth's radius to account for bending due to atmospheric refractivity. Points along the profiles may be printed or plotted. These profiles are then used to determine the distances at which targets, approaching the site at a given altitude, will be detected.

(3) Inputs.

(a) Digitized topographic data.

(b) Site coordinates.

(c) Target altitude.

(d) Scale for map overlay.

(4) Outputs.

(a) Map overlay showing line-of-sight contour and contours showing acquisition distance for targets at specified altitudes.

(b) The elevation angle to the radar horizon is provided for each azimuth specified.

(5) Applications.

(a) Used to evaluate radar sites.

(b) Used to determine the line-of-sight contour and target acquisition contour for various target altitudes.

(6) Limitations. Only the limiting line-of-sight along each radial from a site is available. Shielding that may exist at points within the line-of-sight contour is not determined.

(7) Agency.

Electromagnetic Compatibility Analysis Center (ECAC)
North Severn
Annapolis, Maryland 21402

g. Smooth Curve Smooth Earth Propagation Model (SCSE)

(1) Purpose. The scse provides a capability to compute propagation path loss for smooth earth situations.

(2) Description.

(a) The model is based on state-of-the-art propagation theory. Included are the following propagation modes:

1. Reflection.

2. Intermediate.

3. Diffraction.

4. Tropospheric scatter.

(b) This model is used to compute path loss when the frequency is above 1000 MHz. It may, with some restrictions, also be used for propagation frequencies down to 50 MHz.

(3) Inputs.

(a) Frequency.

(b) Path distance.

(c) Effective antenna heights.

(d) Refraction index.

(e) Polarization.

(f) Ground constants.

(4) Outputs. Transmission loss in dB for each path of interest.

(5) Applications.

(a) Used as propagation model for Terrain Integrated Interference Prediction Systems (TIIPS) model B and pulse density model.

(b) Used to compute transmission loss.

(c) Used to perform parameter sensitivity analysis.

(6) Limitations.

(a) Terrain features not included.

(b) Maximum antenna heights are frequency dependent.

(7) Agency.

Electromagnetic Compatibility Analysis Center (ECAC)
North Severn
Annapolis, Maryland 21402

h. Pulse Density Model

(1) Purpose. To determine the distribution of interfering pulses at the input to a receiver.

(2) Description. The transmitter input to the pulse density model can be generated from the E-file or the engineer may generate his own technical characteristics. In either case, a file of equipment records is created. Once the locations of the equipment within the problem area are known there are two variables that may affect the pulse count at a given receiver; the interfering transmitter frequencies and the antenna orientation of the interfering transmitters. In order to do an analysis of the cumulative effect of a pulsed environment on a receiver, the pulse density model assigns operating frequencies to the interfering transmitters. The model then takes into account the effects of antenna motion. This is done by calculating the probability of occurrence of various levels of mutual gain coupling for pairs of rotating or scanning antennas. Each mutual gain level in the distribution results in a corresponding interference level, which yield a

distribution of inner levels. The number of pulses at each inner level is obtained by multiplying the pulse repetition frequency for a given transmitter by the probability of occurrence of that power level. The number of pulses occurring at each level (pulse count) is accumulated for each receiver within the problem area.

(3) Input.

(a) Description of pulsed receivers being analyzed.

(b) Description of transmitter equipment in area and frequency band of interest (ECAC E-file or manual input).

(c) Parameters to define probability density functions to be used for statistically assigning operating frequency.

(4) Output.

(a) Expected number of pulses/second that enter a receiver at specified inner levels. (This output may be obtained for an individual transmitter, for all transmitters, or categorized by pulse width.)

(b) Plot of the number of interfering pulses/second above a specified threshold as a function of frequency.

(5) Applications.

(a) To determine the cumulative interference effect at the input to a pulsed receiver.

(b) To determine if the prf agrees with the required operational prf.

(6) Limitation.

(a) Antenna pattern is statistically based on a limited number of antenna types.

(b) Does not include interference pulses received via reflections from terrain and man-made structures.

(7) Agency.

Electromagnetic Compatibility Analysis Center (ECAC)
North Severn
Annapolis, Maryland 21402

i. Power Density Display Program

(1) Purpose. To generate a map overlay showing power density contours.

(2) Description.

(a) The power, antenna gain, frequency, and location of all equipment within the problem areas are used to compute the power density. The power density is computed by determining the propagation loss value between each transmitter and receiver. The power density display program offers both a rough and a smooth earth case. The terrain profile for the rough earth case is constructed between transmitter and receiver and the propagation loss is calculated by tirem (see par 2j). For the smooth earth case, no profiles are constructed. Here, the elevations at the path end points are retrieved from topographic data, and the Integrated Propagation System (IPS) is used to calculate the propagation loss. The power density at a point is determined by either summing the effects of all emitters or by considering only the most significant contributor.

(b) In addition to the power density overlay, the following overlays are also available: line-of-sight, propagation loss, signal strength at the receiver, and signal-to-noise.

(3) Inputs.

(a) For the overlay, the following parameters are required:

1. Overlay center (latitude and longitude).

2. Map ratio.

3. Number of sites (maximum of 26).

4. Radius about overlay center.

(b) For the site, the following parameters are required:

1. Latitude and longitude.

2. Site elevation.

3. Transmitter tuned frequency (MHz).

4. Transmitter output power (kW).

5. Transmitter antenna height (feet).

6. Transmitter antenna gain (dB).

7. Polarization (vertical or horizontal).

8. Transmitter horizontal beamwidth for directional antennas (degrees).

9. Transmitter pointing azimuth for directional antennas (degrees).

10. Receiver antenna height (feet).

11. Receiver antenna gain (dB).

12. Receiver sensitivity (dBm).

(4) Outputs.

(a) A map overlay showing the power density contours over a specified area of interest.

(b) Propagation path loss.

(c) Power density (dBm/m^2).

(d) Distance from transmitter to line-of-sight (statute miles).

(e) Distance from receiver to line-of-sight (statute miles).

(5) Applications.

(a) Used for performing site analysis. This model may be used to assess the relative merits of a set of proposed sites within a given area. The rating is based on the number of victim systems found within a given power density contour.

(b) Used to generate a map overlay showing power density contours based on one or more specified emitters.

(c) Used to check coverage of communications stations transmitting to mobile receivers.

(d) Used to identify areas where power levels would be sufficient to cause interference with other operating systems within the area.

(6) Limitations.

(a) Not applicable below 40 MHz.

(b) Tropospheric ducting not included.

(7) Agency.

Electromagnetic Compatibility Analysis Center (ECAC)
North Severn
Annapolis, Maryland 21402

j. Terrain Integrated Rough Earth Model (TIREM)

(1) Purpose. The function of tirem is to provide an automatic capability for computing propagation path loss in the frequency range of 40 to 20,000 MHz.

(2) Description.

(a) The model is based on state-of-the-art propagation theory. TIREM incorporates a number of different propagation modes to calculate propagation path loss within the limiting frequency range. Included in tirem are the following rough earth propagation models:

1. Diffraction.

2. Line-of-sight.

3. Tropospheric scatter.

4. Knife-edge diffraction (single, sharp obstacle).

(b) The system includes the capability to automatically generate terrain profiles from an existing digitized terrain data base. The system can also be used with manually input terrain profile data. The system will select the appropriate mode of propagation based upon input parameters and then the various formulae are applied to compute the path loss.

(3) Inputs.

(a) Digitized topographic data.

(b) Coordinates of path and points.

(c) Antenna heights.

(d) Frequency.

(e) Polarization.

(f) Ground constants.

(g) Atmospheric refractivity.

(h) Climate.

(4) Outputs.

(a) Median propagation loss including power fading statistics.

(b) Topographic profile.

(c) Scatter angle, elevation angle, Fresnel reflection coefficient, and effective antenna heights are available from intermediate computations.

(5) Applications.

(a) Used to predict propagation loss over specified paths as a function of terrain and time variations.

(b) TIREM is the propagation model employed in TIIPS model B. It is also used to provide propagation loss calculations for TIPPS second-level analysis.

(6) Limitations.

(a) Not applicable below 40 MHz since skywave, surface wave, and earth ionospheric waveguide modes are not included.

(b) Tropospheric ducting not included.

(7) Agency.

Electromagnetic Compatibility Analysis Center (ECAC)
North Severn
Annapolis, Maryland 21402

k. TIIPS First-Level Analysis

(1) Purpose. TIPPS first-level analysis is a program designed to analyze possible interference cases, using as input, an environmental data base.

(2) Description.

(a) TIIPS consists of the following three computer programs:

1. Input processor program.

2. Environment reduction analyzer program.

3. Output processor program.

(b) The input processor program allows the engineer flexibility in selecting only specific records within an environment, or selecting and modifying items within a given class of records. It also checks to assure that all data needed for calculations exist. When there is missing data, an appropriate value is obtained from tables. The actual analysis performed within the environment reduction analyzer program allows the option for the computation of either the signal-to-interference ratio or required distance separation. The former is employed when the equipment has fixed positions; the latter is used when equipment is mobile. The output processor program provides a flexible general output formatting capability. With this program, the engineer may specify the exact items desired and the precise positioning on the printer output page.

(3) Inputs. Location of equipment (either E-file or manual input); technical and operating characteristics of equipment (either NCF file or manual input).

(4) Outputs.

(a) Signal-to-interference ratio.

(b) Minimum distance separation to avoid interference.

(c) Power density.

(d) Interference-to-noise ratio.

(5) Applications.

(a) To separate equipment which will not cause interference from those equipment that will cause interference in an environment where a large number of signal combinations exist.

(b) Used as input to the model B program.

(6) Limitations.

(a) Treats receiver as a linear system.

(b) Vertical antenna patterns not included.

(7) Agency.

Electromagnetic Compatibility Analysis Center (ECAC)
North Severn
Annapolis, Maryland 21402

1. TIIPS Second-Level Analysis

(1) Purpose. The purpose of the TIIPS second-level analysis is to perform calculations of signal-to-interference ratios and required distance separations.

(2) Description. This program uses either equipment characteristics or a point set description of emission spectrum and receiver selectivity. It then employs the modulation oriented transmitter synthesis (mots) to estimate the emission spectra as a function of modulation type for all modulation codes. Then the off-frequency rejection is calculated from either synthesized spectra and selectivity curves of measured spectra or selectivity curves. A numerical integration technique is used to obtain the off-frequency rejection curve. Then either the frequency distance separation curves or signal-to-interference ratios are computed using the off-frequency rejection.

(3) Inputs.

(a) Location of equipment (either E-file or manual input).

(b) Equipment characteristics (NCF file or manual input).

(c) Point set description of emission spectrum and receiver selectivity using NCF file.

(4) Outputs.

(a) Signal-to-interference ratio.

(b) Off-frequency rejection curves.

(c) Frequency distance separation curves.

(5) Applications.

(a) Used to separate equipment which will not cause interference from the equipment that will cause interference in an environment where a large number of interference combinations exist.

(b) Used to generate frequency distance separation curves to be used as input to the model B system.

(6) Limitations.

(a) Treats receiver as a linear system.

(b) Vertical antenna patterns not included.

(c) High power effects not considered.

(7) Agency.

Electromagnetic Compatibility Analysis Center (ECAC)
North Severn
Annapolis, Maryland 21402

m. Model B

(1) Purpose. The purpose of the model B program is to perform analysis between all combinations of environmental records.

(2) Description. The model B program utilizes two separate analysis techniques. In those cases where an interfering transmitter and victim receiver are within the same frequency separation (from a specific frequency assignment) they are compared with an appropriate point on a frequency distance curve to determine if a possibility for interference exists. For an interfering transmitter and victim receiver that are not within the same frequency band, a rapid cull type technique has been devised to determine if a potential interference situation exists.

(3) Inputs. Same inputs as TIIPS first-level and tirem models.

(4) Outputs.

(a) Signal-to-interference ratio using rough earth propagation.

(b) Equipment selected using frequency constraints.

(c) Equipment selected using distance constraints.

(d) Power density.

(e) Interference-to-noise ratio.

(5) Applications.

(a) Used to perform a frequency and distance selection of all equipment within a given range of proposed sites. Selected transmitters are analyzed against card input receivers, or selected receivers are analyzed against card input transmitters. Terrain dependent propagation is used where data exists.

(b) Used in combination with TIIPS first-level analysis and tirem to perform environment analysis for site selection and evaluation. This model permits the user to perform a frequency and distance selection of all equipment meeting the selection criteria within the vicinity of a proposed site. Selected equipment is analyzed using terrain dependent propagation models.

(6) Limitations. Same limitations as TIIPS first-level analysis and tirem.

(7) Agency.

Electromagnetic Compatibility Analysis Center (ECAC)
North Severn
Annapolis, Maryland 21402

n. IFF Mark X (SIF) Air Traffic Control Radar Beacon System Performance Prediction Model.

(1) Purpose. The ATCRBS performance prediction model is used to perform a sensitivity analysis of the system.

(2) Description.

(a) The basic program can be considered to contain three major subprograms: the transponder processor, the transponder model, and the victim interrogator model. The transponder processor computes the average interrogator rate for each interrogator transponder based on mode interlace and the probability that antenna orientation will be such that the interrogator will illuminate the transponder. The transponder model predicts the action of each transponder under these input conditions. The inputs from interfering interrogators to the transponder are treated statistically. The basic outputs are round reliability and fruit rate. The computations are made from the following cases:

1. Victim interrogator interrogating on its mainbeam.

2. Victim interrogator interrogating on its side-lobe.

3. Victim interrogator interrogating on its back-lobe.

(b) The victim interrogator model predicts the average fruit replies per scan received by the victim interrogator from the transponders. This is accomplished by computing the total fruit received on the mainbeam, side-lobe, and back-lobe separately and summing the products of each total multiplied by the probability of having a particular orientation of the interrogator antenna.

(3) Inputs.

(a) Interrogator.

1. Antenna beamwidth.

2. Antenna gain (dB).

3. Mode.

4. Interrogator receiver sensitivity.

5. Side-lobe suppression (on or off).

(b) Transponder.

1. Power output (watts).

2. Sensitivity.

3. Antenna gain (dB).

4. Reply rate limited threshold (number/second).

(4) Outputs.

(a) Total detected interrogations.

(b) Total transponder suppressions.

(c) Synchronous reply rate.

(d) Probability of reply rate limiting.

(e) Round reliability.

(f) Mainbeam fruit rate.

(g) Side-lobe fruit rate.

(h) Back-lobe fruit rate.

(i) Final transponder sensitivity.

(j) Total fruit per scan at interrogator of interest.

(5) Applications.

(a) To determine how interrogators affect the ability of each transponder to reply to an interrogation from one particular interrogator.

(b) To determine how replies to interrogations from other interrogators degrade the ability of a given interrogator to detect desired replies.

(c) To determine how changes in system parameters affect the system performance.

(6) Limitations.

(a) Interrogation garbling and transponder-code garbling not included.

(b) Time-on factors for maximum and minimum interrogator environments are not considered.

(7) Agency.

Electromagnetic Compatibility Analysis Center (ECAC)
North Severn
Annapolis, Maryland 21402

o. Fresnel Diffraction of RF Wavefronts.

(1) Purpose. To predict and define the limit of the rf and geometrical shadow of any proposed obstruction.

(2) Description.

(a) The objective of this computer program is to predict and define the limit of the rf and geometrical shadow of an obstruction in the coverage volume of airspace of radar facilities considering the effects of Fresnel diffraction. The program enables the user to enter such pertinent data as latitude and longitude of the facility and the obstruction, operating frequency (between 50 MHz and 40 GHz), polarization, obstruction dimensions, and orientation. In addition, one may select a vertical plane or series of planes at any combination of distances behind the obstruction, and obtain data regarding the projection of the shadow of the obstruction on the given plane or planes.

(b) The basic obstacle shape considered is a finite, perfectly conducting rectangle. Both line-of-sight (geometrical-optic) shadowing and Fresnel diffraction effects are determined. Geometrical diffraction theory is applied for arbitrary incidence and observation angles. Signal degradation, relative to the obstacle-free field, is described by providing plots of arbitrarily chosen dB levels at chosen planes behind the obstacle.

(c) Cylindrical, spherical, and convex polyhedron obstacles can be considered, but only for the geometrical mode.

(3) Inputs.

(a) The following input parameters are required of the radar:

1. Latitude.

2. Longitude.

3. Height above mean sea level.

4. Height above ground.

5. Frequency.

6. Polarization (vertical, horizontal, right circular, left circular).

7. Minimum elevation angle.

(b) The following input parameters are required of the obstacle:

1. Latitude.

2. Longitude.

3. Height above mean sea level.

4. Height above ground.

5. Length of building.

6. Width of building.

7. Orientation of long axis of building.

(c) In addition, the following parameters are required:

1. Number of object planes.

2. Distance from source to first object plane (nmi).

3. Distance increment to the next plane (nmi).

4. Plot scale.

(4) Outputs.

(a) Maximum height of rf shadow in feet above ground level.

(b) Maximum height of rf shadow in feet above mean sea level.

(c) Elevation angle above horizon of the top of rf shadow in degrees.

(d) Maximum width of rf shadow in feet.

(e) Printer plot of geometric pattern.

(f) Printer plot of diffraction contours (rectangular obstacle only).

(g) Printer plot of diffraction density (rectangular obstacle only).

(h) Calcomp plot of geometric contours.

(5) Applications. To determine the rf shadowing effects on the coverage volume of radar or ATCRBS sites caused by the construction of large obstructions near the site.

(6) Limitations.

(a) Fresnel diffraction patterns can only be computed for rectangular structures.

(b) Only one obstacle can be treated at a time.

(c) Climatic conditions not included.

(7) Agency.

CALSPAN
Buffalo, New York

p. Simulation of the Air Traffic Control Radar Beacon System

(1) Purpose. The intent of this simulation is to provide a capability of calculating the effectiveness of an interrogator or interrogators with any realistic deployment of aircraft.

(2) Description. The first step in this simulation is to obtain the information necessary to describe the problem situation. This is done by reading in particular values of the input parameters for interrogator/receivers and the aircraft within the problem area. Cartesian coordinates of the interrogators, effective cross section of the ground receiver antennas, and interrogation repetition period (sweep time) are calculated. At each instant of simulated time, the following aircraft parameters are obtained by means of linear interpolation: aircraft position (Cartesian coordinates), velocity, heading, roll, pitch, azimuth, and elevation, with respect to the interrogator/receiver of interest. Those aircraft which would be sensed by the main receiver if it were at maximum sensitivity are then identified. The power level of the transponder transmission at the ground receiver is determined. If the resulting signal power exceeds the smallest signal detectable by the ground receiver, the aircraft in question is labeled. This is done for all aircraft within the problem area. The power level and arrival time of interrogation pulses for each interrogator to the aircraft of interest is computed. For those pulses which fall within the range of the transponder receiver, the arrival time and the corresponding signal power are stored in an array. At this point the side-lobe suppression option is checked to determine if a P_2 pulse should be transmitted. The array of pulse arrival times and signal levels for the subject aircraft are sorted into chronological order. This chronological array of pulses is operated upon in the same manner as a transponder. The particular features that are included in the transponder model are: desensitization, reply rate limiting, delay, dead time, side-lobe suppression, and a choice of passive delay line or active gate-type decoding. (It is noteworthy that any additional transponder features may be readily incorporated. Thus, the model can be used to evaluate operational modifications.) When a proper interrogation is received, the time of arrival at the ground receiver and the power level of all reply pulses are computed and stored in an array. Then the interrogator/receiver portion of the simulation treats the array of reply

pulses in the same manner as the ground receiver. Every detectable and properly spaced pair of pulses with amplitudes within one dB of each other is considered a valid reply and the slant range corresponding to the time of arrival of the first framing pulse is calculated and stored in an array. Then those hits which have moved too far between successive sweeps to represent valid targets are determined. These hits are considered fruit and are eliminated from those hits displayed on the plan-position indicator (ATC display).

(3) Inputs.

(a) Input to the simulation.

1. Simulation run time.

2. Number of interrogators.

3. Maximum number of aircraft.

(b) For each interrogator specified, the following data is required:

1. Rotation rate (rpm).

2. Interrogation repetition frequency.

3. Peak radiated power (watts).

4. Latitude and longitude.

5. Site elevation.

6. Antenna height (feet).

7. Initial azimuth.

8. Initial interrogation time.

9. Mode interlace.

(c) For the receiver the following information is required:

1. Side-lobe suppression (on or off).

2. Maximum sensitivity of the main ground receiver (dBm).

3. Initial reduction in sensitivity of the sensitivity time control.

4. Interrogator/receiver antenna gain.

5. Maximum and minimum ranges to be displayed.

(d) For the aircraft the following information is required for the transponder:

1. Sensitivity (dBm).

2. Reply rate limit setting (replies/second).

3. Antenna gain (dB).

4. Peak radiated power.

5. Transponder dead time.

6. Transponder delay.

7. Decoder option (specify either passive delay line or active gate-type processor).

(4) Outputs.

(a) Time of reply.

(b) Average rate of reply.

(c) Reply probability.

(d) Fruit per scan.

(e) Average fruit per scan.

(f) Suppression probability.

(g) ATC display.

(5) Applications.

(a) To determine how the replies to interrogations from other ATCRB equipment interferes with the ability of the interrogator of interest to detect desired replies. This result can be used to evaluate whether a selected site provides satisfactory performance.

(b) To determine how the array of relevant interrogators affect the ability of transponders to reply to an interrogation from one particular interrogator.

(c) To evaluate proposed hardware and operational modifications.

(6) Agency.

Transportation System Center
Cambridge, Massachusetts

3. SUMMARY AND CONCLUSIONS

a. Summary. In this brief survey a number of automated computational techniques having application to radar siting have been identified. A group of these techniques (see paragraphs 2e, 2f, 2g, 2j, 2o) may be useful to FAA siting engineers for evaluation of radar/beacon coverage resulting from a particular site selection, and in determining the shadowing effect of nearby reflecting objects. A second group of computer programs analyze interference situations and may find utility among FAA Frequency Management personnel engaged in selection of frequencies, prf's etc., for ASR and ATCBI equipment. Two other programs (see paragraphs 2n and 2p) contain simulations of the ATCRBS system. They may be used to evaluate the interference implications of a new ATCBI site in terms of the impact on transponder suppression and reply rate and fruit presented to existing interrogation equipment. It would appear useful to employ one of these latter programs as a regular part of siting analysis to provide assurance that the increased coverage expected through establishment of a new ATCBI site is not achieved at the expense of intolerable transponder reply rate limiting and/or interrogator fruit in the affected area.

b. Conclusions. The computer models located in this brief survey represent a significant achievement in enabling the engineer to directly utilize an environmental data base in analyzing problems. Furthermore, with the development of new mathematical models and the upgrading of existing models, the type of problems that can be treated will doubtlessly be expanded in the future. In order to keep FAA engineers abreast in the expanding computer analysis capabilities which are available, it is recommended that surveys of useful computer modeling activities be continued as a regular FAA activity. It is additionally recommended that a convenient means be established for collecting, cataloging, abstracting, and disseminating the surveyed computer information to FAA personnel on a continuing basis.

4. SUPPLEMENT - ECAC DATA BASE.

a. The data base existing at ECAC consists of many different files. This section will briefly describe the contents of those files used in conjunction with the computer programs described within this document.

b. The Environmental File (E-file) contains the nomenclature of the equipment, its location, and technical and operating characteristics of equipment. The major parameters that are contained in the E-file are:

(1) Latitude.

(2) Longitude.

(3) Site elevation.

(4) Terrain type.

(5) Antenna Height.

(6) Antenna elevation angle.

(7) Antenna azimuth.

(8) Modulation types.

(9) Emission bandwidth.

(10) Frequency.

(11) Pulse width.

(12) Antenna beamwidth.

(13) Mainbeam gain.

c. The Nominal Characteristic File (NCF) supports the E-file by providing the detailed equipment characteristics of each nomenclature equipment. The major parameters that are contained in the NCF file are:

(1) Average power output.

(2) Peak power output.

(3) Frequency range.

(4) Pulse width capability.

(5) PRF capability.

(6) Rise time.

(7) Decay time.

Appendix 5

(8) Sensitivity.

(9) Antenna type.

(10) Antenna lead type.

(11) Fundamental antenna gain.

(12) Horizontal beamwidth.

(13) Vertical beamwidth.

(14) Number of mainbeams.

(15) Sector scan limits.

(16) Horizontal scan rate.

(17) Image rejection level.

(18) Polarization.

(19) Special circuitry remark.

APPENDIX 6

SAMPLE SITING ANALYSIS

1. INTRODUCTION. In this appendix some important aspects of the siting analysis are described with the aid of an example. The discussion is limited to a single prospective site in the vicinity of the Robert Gray AAF, Ft. Hood, Texas.

2. SITING REQUIREMENTS.

   a. Airports. Robert Gray AAF is the primary airfield to be served by a proposed ASR-8/ATCBI-5 installation. Approach/departure control to three secondary airports within the Gray Approach Control area is also desired. The location and the msl elevation of the runways at each of these airfields is given in table 6-1.

   b. Coverage. The terminal airspace to be covered by the proposed ASR-8/ATCBI-5 includes, but is not limited to, the 8,000 foot msl area of jurisdiction over about a 30 nmi radius. The principal fixes to be covered within this airspace are given in table 6-2.

   c. Runway Approach/Departure Control. The fundamental requirement for approach/departure coverage is to provide ASR-8/ATCBI-5 coverage at distances 1 nautical mile and beyond, from the edges of all runways at an altitude 300 feet above the extended runway surface. This is an essential requirement for the primary airfield (Gray AAF), and is important for secondary airports as well. Since each airport has one runway, there are two approach/departure points for each airport.

   d. Airway Coverage. Another ATC requirement is for full ASR-8/ATCBI-5 coverage of the V-17 air route as shown in table 6-2.

3. SITING INVESTIGATIONS/ANALYSIS/DISCUSSION. As a result of preliminary site investigations, three candidate site locations within a 20,000 foot radius of the Robert Gray AAF Control Tower were identified for detailed survey and analysis. A brief analysis for only one site, "A", is presented here.

   a. Site Description. Site A is situated on the westernmost edge of a mountain ridge located just east of the runway at Gray AAF. This ridge rises approximately 130 to 150 feet above the msl elevation of the airfield and surrounding terrain. In the vicinity of the site, the slopes of this ridge average about 20%. The terrain of the site area is relatively flat and measures approximately 250' x 250'. The soil throughout the site is sandy and heavily rock-laden, and will support very little vegetation. In certain sections of the site area, continuous lines of rock formations are visible, indicating that the subsurface consists of rock over a large portion of the site area.

Appendix 6

TABLE 1

AIRFIELD DATA

Airfield Name	Location	MSL Elevation of Runway
Robert Gray AAF	31 04' N 97 50' W	1015 feet
Hood AAF	31°09' N 97°43' W	923 feet
Killeen Municipal	31°05' N 97°41' W	846 feet
Draughon-Miller Municipal	31°09' N 97°24' W	682 feet

TABLE 2

LIST OF FIXES

Fix No.	Name of Fix	Location	Desired Min. Altitude (MSL)
	Fixes:		
1	Coke	Int. 80° MTA/150° GRK	1800 feet
2	Arnett	Int. 240° ACT/150° FRK	3000 feet
3	Bandy	Int. 240° ACT/310° TPL	2500 feet
4	Gerell	Int. 202° ACT/338° TPL	2500 feet
5	Barge	Int. V17/93° HLR	2400 feet
6	Belton	Int. V17/116° HLR	2400 feet
7	Walburg	Int. V17/146° HLR	2400 feet
8	Pendleton	Int. V17/60° HLR	2400 feet
9	Hollow	Int. 93° HLR/205° TPL	2500 feet
10	Little	Int. 60° HLR/195° ACT	2500 feet
11	Still	Int. 146° HLR/200° TPL	2500 feet
12	Salado	Int. 116° HLR/205° TPL	2500 feet
13	Sparks	Int. 81° HLR/155° TPL	1500 feet
14	Moody	Int. 205° ACT/154° Temple Localizer	2500 feet
	VOR/VORTAC's:		
15	Temple TPL	31° 12' 33" N, 97° 25' 29" W	4000 feet
16	Gray GRK	31° 07' 18" N, 97° 51' 02" W	1800 feet
17	Ft. Hood HLR	31° 03' 54" N, 97° 42' 05" W	2500 feet
	Approach/Departure Points:		
18	Robert Gray AAF Runway Approach/ Departure Points	1 nmi from the edges of the runway.	1315 feet
19	Hood AAF Runway Approach/Departure Points	1 nmi from the edges of the runway.	1223 feet

TABLE 2 (continued)

LIST OF FIXES

Fix No.	Name of Fix	Location	Desired Min. Altitude (MSL)
20	Killeen Municipal Runway Approach/ Departure Points	1 nmi from the edges of the runway.	1146 feet
21	Draughon-Miller Municipal Runway Approach/Departure Points	1 nmi from the edges of the runway.	982 feet
	Air Routes:		
22	V-17	6° AUS-186° ACT	2400 feet

b. LOS Coverage Analysis.

(1) Screening Profile Graph.

(a) The optical screening angles were measured using a surveyor's transit to determine the elevation angle of all screening objects through 360° in azimuth, as viewed from 30 feet and 43 feet, respectively, above the msl height (1141 feet) of the site. The optical screening angles were then converted into radar screen angles to take into account the ray bending effects. Plots of the radar screen angles are given in figure 6-1 for the two heights, respectively.

(b) On the radar acreen angle graphs, the adjusted elevation angles of each navigational fix have also been marked. The azimuth-elevation angle data used in plotting these fixes are shown in columns C and H of the los coverage worksheets corresponding to each height given in tables 6-3 and 6-4. These tables were prepared in accordance with the procedure outlined in chapter 3, paragraph 53a.

(2) LOS Coverage of Fixes. Examination of column J of tables 6-3 and 6-4 shows that there is complete los coverage for each of the fixes numbered 1 through 17 at antenna heights of 30 feet or more. In fact, examination of figure 6-1 shows that the angular displacement, between the adjusted fix elevation angle and the screen angle along the azimuth of each fix, is of sufficient magnitude to provide los visibility even if the antenna height is lowered from 30 feet to 25 feet, which is the minimum standard antenna height. In any case, the required minimum antenna height is not governed by the los visibility of the fixes, but is dependent on the los visibility of the approach/departure points at the airports as discussed below.

(3) LOS Coverage of Approach/Departure Points.

(a) Examination of column J of tables 6-3 and 6-4 for fixes numbered 18 through 21 shows that there is complete los coverage of the approach/departure points corresponding to three out of the four airfields at their respective desired minimum altitudes. As mentioned above, the desired minimum altitudes are 300 feet above the msl altitude of the runway. As the data shows, approach/departure points at Robert Gray AAF and the two secondary airfields, Ft. Hood AAF and Killeen Municipal, have los coverage even for an antenna height of 30 feet. In fact, these airfields will receive full coverage even if the antenna height is lowered to 25 feet.

FIGURE 1. SCREENING PROFILE GRAPH (SITE A, FT. HOOD, TEXAS)

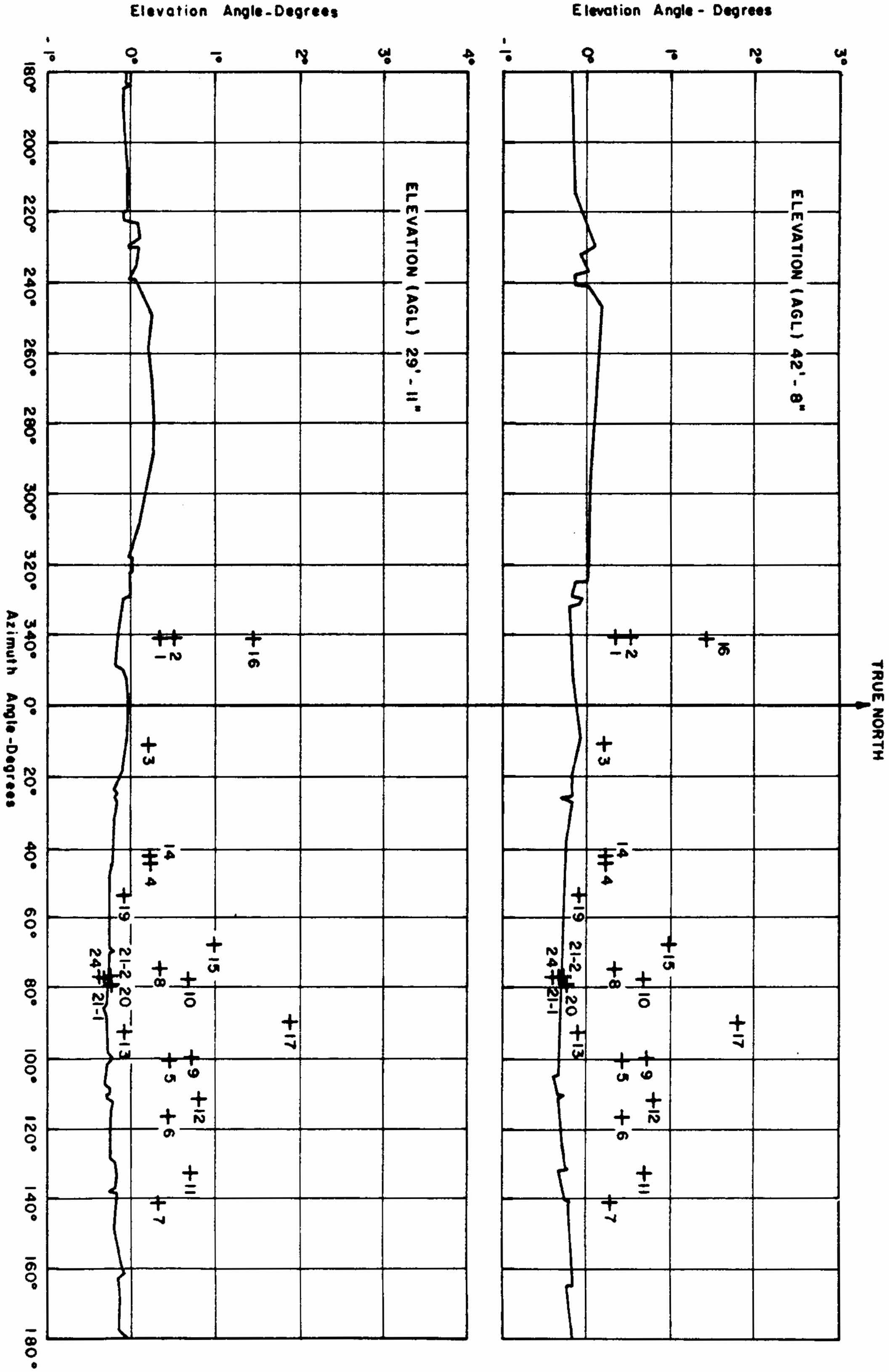


TABLE 3.
LOS COVERAGE EXAMPLE

SITE: A -- MOUNTAIN RIDGE, GRAY AAF, FT. HOOD, TEXAS | RADAR TYPE: ASR-8/ATCBI-5 | CONDITION: [ ] LP-FAIR [X] CP-HVY PRECIP

SITE LOCATION: 97° 49' 23.797" W LATITUDE, 31° 03' 53.365" N LONGITUDE | SITE ALTITUDE: 1141.45 FT MSL | ANTENNA HEIGHT: 43 FT AGL, 1184 FT MSL

A	B	C	D	E	F	G	H	I	J			K	
Fix No.	Name of Fix	Fix Azimuth (Deg. True)	Fix Range (nmi)	Fix Height (Ft.MSL)	Fix Ht. Above Antenna (Ft.)	Fix Elevation (Deg.)	Adj.Fix Elevation (G -0°5') (Deg.)	Measured Screen Angle (Deg.)	LOS Coverage			Radar Coverage for 2.5° Tilt	
									Yes	No	Marg	Yes	No
1	COKE	341.0	11.6	1800	629	26.3'	21.3'	-10.0'	X			X	
2	ARNETT	341.0	23.2	3000	1829	35.9'	30.9'	-10.0	X			X	
3	BANDY	11.0	27.1	2500	1329	17.6'	12.6'	-03.0'	X			X	
4	GERELL	45.0	26.0	2500	1329	19.1'	14.1'	-13.0'	X			X	
5	BARGE	101.0	18.0	2400	1229	31.9'	26.9'	-15.0	X			X	
6	BELTON	117.0	18.1	2400	1229	31.6'	[illegible].6'	-15.0	X			X	
7	WALBURG	141.5	21.8	2400	1229	23.7'	18.7'	-10.5	X			X	
8	PENDLETON	75.0	20.8	2400	1229	25.6'	20.6'	-15.5'	X			X	
9	HOLLOW	100.0	14.0	2500	1329	48.4'	43.4'	-13.0'	X			X	
10	LITTLE	78.0	14.5	2500	1329	46.4'	41.4'	-15.5'	X			X	
11	STILL	133.0	14.2	2500	1329	47.6'	42.6'	-11.0'	X			X	
12	SALADO	112.0	12.8	2500	1329	53.9'	48.9'	-16.5'	X			X	
13	SPARKS	93.0	22.9	1500	329	-00.5'	-05.5'	-17.5'	X			X	
14	MOODY	43.0	25.75	2500	1329	19.5'	14.5'	-12.5'	X			X	
15	TEMPLE TPL	68.0	22.0	4000	2829	1°04.4'	59.4'	-15.0'	X			X	
16	GRAY GRK	341.0	3.8	1800	629	1°32.1'	1°27.1'	-10.0'	X			X	
17	FT. HOOD HLR	90.0	6.2	2500	1329	1°58.8'	1°53.8'	-17.5'	X			X	
18	ROBERT GRAY AAF	120.0	1.5	1300	129	04.8'	-00.2'	-30.0'	X			X	
19	FT. HOOD AAF	54.0	7.0	1200	29	-0°0.3'	-05.3'	-15.0'	X			X	
20	KILLEEN	79.5	7.3	1100	-71	-08.3'	-13.3'	-16.0	X			X	
21-1	DRAUGHON MILLER	77.0	22.0	1000	-171	-12.6'	-17.6'	-15.0'			X	X*	
21-2	DRAUGHON MILLER	77.0	22.0	1100	-71	-10.1'	-15.1'	-15.0'			X	X*	
21-3	DRAUGHON MILLER	77.0	22.0	1200	29	-7.5'	-12.5'	-15.0'	X			X	

* Assumes LOS Coverage

TABLE 4.4

LOS COVERAGE EXAMPLE

SITE: A -- MOUNTAIN RIDGE, GRAY AAF, FT. HOOD, TEXAS | RADAR TYPE: ASR-8/ATCBI-5 | CONDITION: /_/ LP-FAIR /X/ CP-HVY PRECIP

SITE LOCATION: 97° 49' 23.797" W LATITUDE, 31° 03' 53.365" N LONGITUDE | SITE ALTITUDE: 1141.45 FT MSL | ANTENNA HEIGHT: 30 FT AGL, 1171 FT MSL

A	B	C	D	E	F	G	H	I	J			K Radar Coverage for 2.5° Tilt	
Fix No.	Name of Fix	Fix Azimuth (Deg. True)	Fix Range (n.m.)	Fix Height (Ft.MSL)	Fix Ht. Above Antenna (Ft.)	Fix Elevation (Deg.)	Adj.Fix Elevation (G -0°5') (Deg.)	Measured Screen Angle (Deg.)	LOS Coverage Yes	No	Marg	Yes	No
1	COKE	341.0	11.6	1800	616	25.7'	20.7'	-11'	X			X	
2	ARNETT	341.0	23.2	3000	1816	35.6'	30.6'	-11'	X			X	
3	BANDY	11.0	27.1	2500	1316	17.3'	12.3'	-05'	X			X	
4	GERELL	45.0	26.0	2500	1316	18.9'	13.9'	-15'	X			X	
5	BARGE	101.0	18.0	2400	1216	31.4'	26.4'	-19'	X			X	
6	BELTON	117.0	13.1	2400	1216	31.2'	26.2'	-18'	X			X	
7	WALBURG	141.5	21.8	2400	1216	23.4'	18.4'	-11'	X			X	
8	PENDLETON	75.0	20.8	2400	1216	25.3'	20.3'	-17.5'	X			X	
9	HOLLOW	100.0	14.0	2500	1316	47.9'	42.9'	-19.0'	X			X	
10	LITTLE	78.0	14.5	2500	1316	45.9'	40.9'	-17.5'	X			X	
11	STILL	133.0	14.2	2500	1316	47.1'	42.1'	-19.0'	X			X	
12	SALADO	112.0	12.8	2500	1316	53.3'	48.3'	-20.0'	X			X	
13	SPARKS	93.0	22.9	1500	316	00.8'	-05.8'	-18.0'	X			X	
14	MOODY	43.0	25.75	2500	1316	19.2'	14.2'	-14.5'	X			X	
15	TEMPLE TPL	68.0	22.0	4000	2816	1°04.1'	59.1'	-17.0'	X			X	
16	GRAY GRK	341.0	3.8	1800	616	1°30.2'	1°25.2'	-11.0'	X			X	
17	FT. HOOD HLR	90.0	6.2	2500	1316	1°57.6'	1°52.6'	-18.0'	X			X	
18	ROBERT GRAY AAF	120.0	1.5	1300	116	04.3'	-00.7'	-31.5'	X			X	
19	FT. HOOD AAF	54.0	7.0	1200	16	1.3'	-06.3'	-15.0'	X			X	
20	KILLEEN	79.5	7.25	1100	-84	9.3'	-14.3'	-17.5'	X			X	
21-1	DRAUGHON MILLER	77.0	22.0	1000	-184	-12.9'	-17.9'	-17.0'			X	X*	
21-2	DRAUGHON MILLER	77.0	22.0	1100	-84	-10.4'	-15.4'	-17.0'	X			X	
21-3	DRAUGHON MILLER	77.0	22.0	1200	16	-07.8'	-12.8'	-17.0'	X			X	

*Assumes LOS Coverage

(b) However, the los coverage of approach/departure points for Draughon Miller Municipal airfield at the desired minimum msl altitude of 982 feet is marginal even for a 43 foot antenna height. The range of the screen object along the azimuth of this airfield is about 22 nmi from site A. Consequently, for full coverage, the antenna height would have to be raised to over 100 feet. Since this is impractical, the requirements for Draughon Miller airfield must be relaxed somewhat for this site to be acceptable. Tables 6-3 and 6-4 also show calculations for the case when the minimum coverage altitude for Draughon Miller airport is raised from 1,000 feet to 1,100 and 1,200 feet. Column J of these tables shows that for an antenna height of 30 feet, the coverage is marginal at msl heights of 1,000 and 1,100 feet, but full coverage occurs at 1,200 feet. At an antenna height of 43 feet, good coverage is possible at altitudes of 1,100 feet or above. Thus, the required minimum antenna height has to be chosen on the basis of acceptable minimum altitude for coverage.

(c) As a compromise, an antenna height of 35 feet is recommended. The minimum altitude of coverage to be expected at Draughon Miller for this antenna height is about 1,100 feet, which is about 400 feet above the runway elevation.

(4) <u>LOS Boundary Diagram/Air Route Coverage</u>.

(a) Figure 6-2 shows a radar los boundary diagram about site A. The msl altitudes for each contour are marked in the diagram. These altitudes correspond to 300 feet, 600 feet, 1,000 feet, 2,000 feet, and 3,000 feet above the msl antenna height (1,171 feet). All of the navigational fixes, airfields of interest, and relevant air routes are also marked on this boundary diagram.

(b) Examination of figure 6-2 shows that full los coverage occurs for air route V-17. Further, the other air routes in the airspace of interest also have los coverage.

(5) <u>LOS Analysis Results</u>. Site A offers full los coverage of all navigational fixes, VOR/VORTAC's, air routes, and the approach/departure points for all airfields with the exception of Draughon Miller Municipal. For the recommended 35-foot antenna height, los coverage at Draughon Miller is possible only to an msl altitude of 1,100 feet. If coverage below 1,100 feet is required at this airport, then the antenna height must be raised accordingly. This is not recommended because of the increase in visible clutter area that will result with a higher antenna.

Appendix 6

c. Primary Radar Coverage Assessment. Initially, the ASR coverage analysis is based on the radar range equation to determine free-space radar coverage under ideal conditions. This is then modified to take into account the effects of clutter and to define those sectors where the use of mti is necessary to overcome clutter effects. Finally, analysis is made to identify all tangential course problems that may develop as a result of mti operation.

(1) ASR Free-Space Coverage Analysis. The locations of the critical fixes have been marked on the rci chart of figure 6-3 using the range and adjusted elevation angle information from the los coverage example of table 6-3. The rci overlay chart (figure 3-21) corresponding to the ASR-8 radar under conditions of heavy rain and cp was applied over the rci chart and adjusted for proper alinement and a nominal tilt angle of 2.5° for the nose of the main beam. It was noticed that all the fix locations were within the boundary of the contour for the main-beam, implying that free-space radar coverage will be possible if los coverage is available. This information has also been recorded in column K of tables 6-3 and 6-4. Finally, by rotating the overlay, the maximum tilt angle (of the nose of the main beam), which will allow coverage of all fixes, was determined to be 2.9°.

(2) Clutter Analysis.

(a) The first step in the clutter analysis involved determination of the range along various azimuths over which clutter could be a potential problem. The maximum possible range of the clutter zone along a certain azimuth is simply the range to the horizon or to the screening object, whichever is smaller. An outline of the clutter region about site A is shown in figure 6-2. The range extremities shown were estimated during screening angle measurements and by reference to maps. The plot indicates that the range of the clutter region extends up to a maximum of 25 nmi along certain azimuths.

(b) The next step in the clutter analysis involved determination of signal-to-clutter ratio for the worst case conditions. This ratio was then used to determine target detectability with or without mti. Since measured values of clutter power were not available, s/c was computed in accordance with the procedure described in chapter 3, paragraph 59d.

(c) The s/c given by equation 2-38 (p. 136) is reproduced here in decibel form.

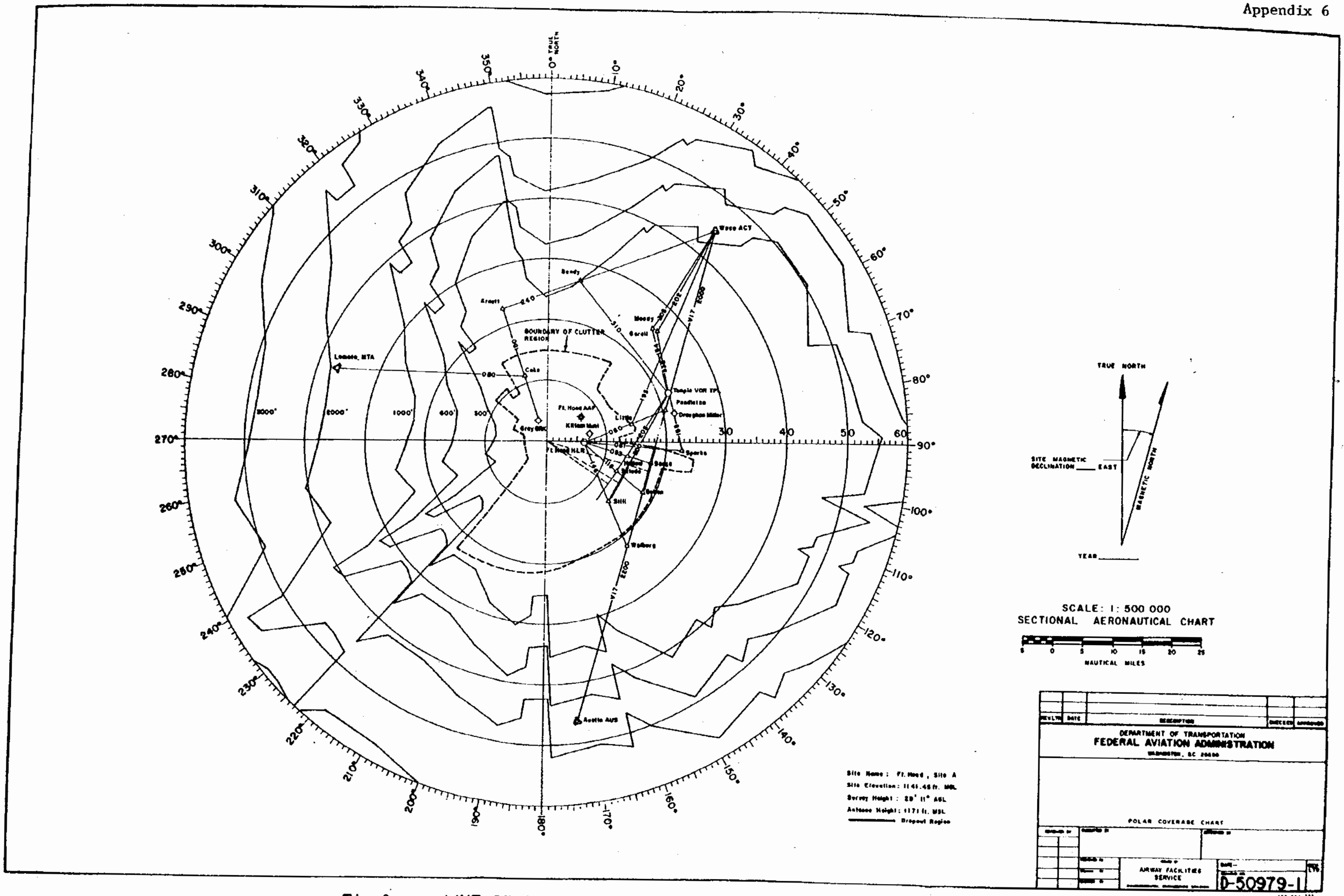
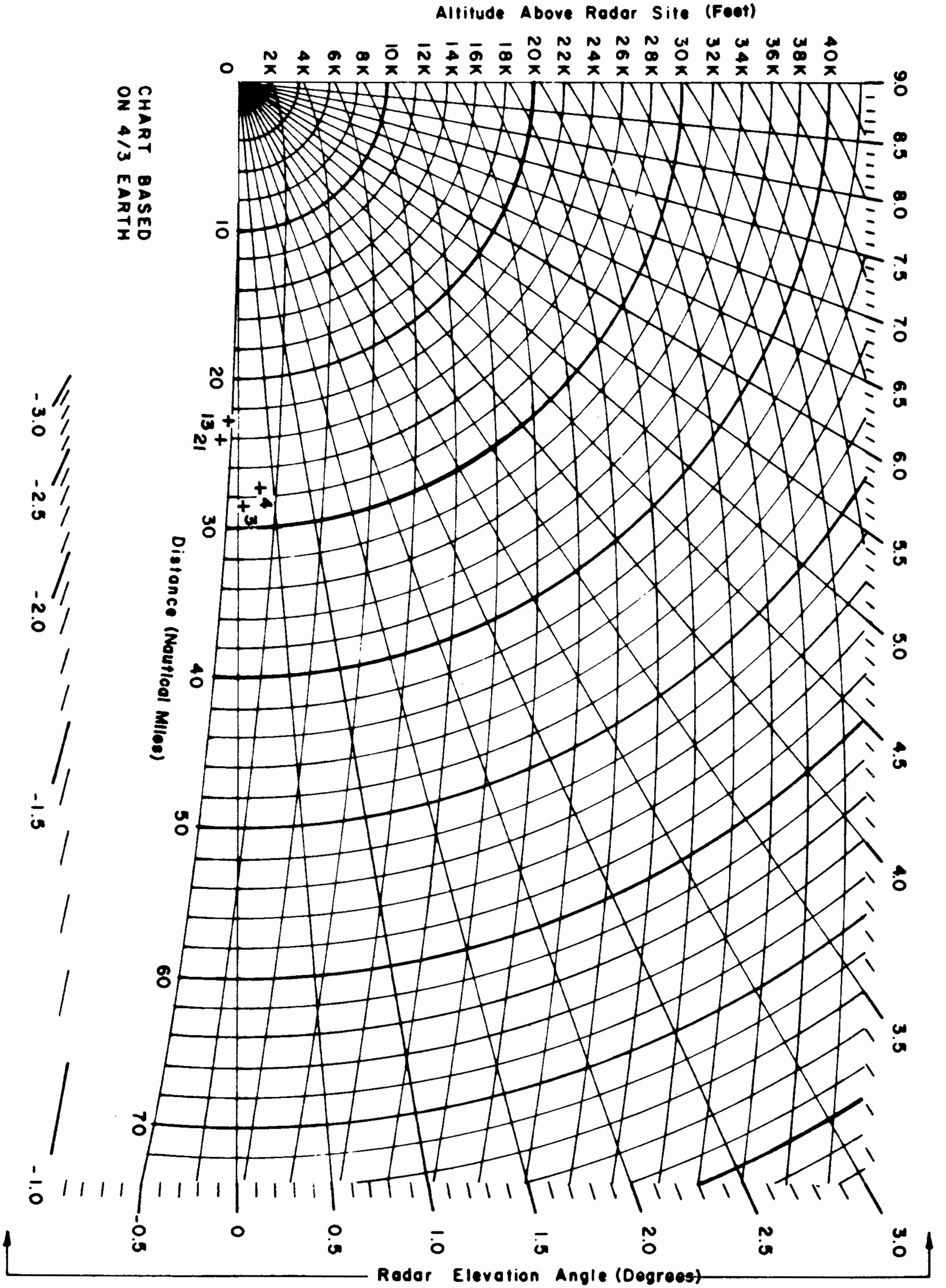


Fig. 2. LINE OF SIGHT BOUNDARY DIAGRAM

Figure 3. RADAR COVERAGE INDICATOR (RCI) CHART, SITE A



$$s/c = 10 \log \sigma_t/\sigma_c + 10 \log G_t + 10 \log G_r \; 7 \qquad (6\text{-}1)$$
$$-10 \log G_{tc} - 10 \log G_{rc}$$

where for the ASR-8 (equation 2-42 (p. 137))

$$\sigma_c = 3927.4 \; R\sigma_o \; \text{Sec}\psi$$

(d) The value of clutter cross-section σ_c was calculated to be 15.92 dB assuming R = 25 nmi, σ_o = -34 dBm, and ψ = -0.18°.

(e) Further, assuming σ_t = -1.5 dB, the value of s/c was determined for different antenna tilt angles by substituting appropriate values of antenna gains in the above equation. Values of -18.1 dB, -11.8 dB, and -3.5 dB were obtained for s/c for tilt angles of 1.5°, 2.0°, and 2.9°, respectively.

(f) Examination of these values of s/c shows that radar coverage in the clutter zone is possible only if mti is used. However, in order to have reduced clutter intensity, a higher antenna tilt angle should be used. Consequently, the maximum acceptable tilt angle of 2.9° is recommended. It should also be noted that the parameters of the range azimuth gate unit associated with the mti are also defined by the clutter region of figure 6-2.

(g) Finally, for the recommended tilt angle of 2.9°, the beams of the ASR-8 antenna should be switched at a range of 12 nmi as given in table 3-1 of chapter 3, paragraph 59b.

(3) Tangential Course Analysis. The previous analysis showed that mti usage is required for ranges up to the radar horizon or to the screening objects, whichever is smaller. In order to identify the air routes with potential tangential course problems, a perpendicular is drawn from the site to different airways (or their extensions) wherever possible. In figure 6-2, these perpendiculars are shown by dotted lines. The extent of the tangential course problem along each of these airways is determined in accordance with the procedure described in chapter 3, paragraph 60. Results are tabulated below.

TABLE 5

TANGENTIAL COURSE ANALYSIS EXAMPLE

No.	Ⓐ Airway Name	Ⓑ d	Ⓒ L_{dm}	Ⓓ L_d	Ⓔ Dropout Time T_d
1	205° TPL	12.3 nmi	5.02 nmi	0.00 nmi	0.0 sec.
2	200° TPL	13.6 nmi	5.55 nmi	5.55 nmi	3.3 min.
3	V-17	17.6 nmi	7.20 nmi	7.20 nmi	4.3 min.

(4) Summary of ASR Analysis Results. The ASR coverage analysis provides the following conclusions:

(a) The maximum acceptable antenna tilt angle is 2.9°, measured with respect to the nose of the main beam. Use of this maximum tilt angle is recommended to provide the desired coverage and minimize clutter intensity.

(b) For a tilt angle of 2.9°, the main and passive beams of the ASR-8 antenna should be switched at 12 nmi.

(c) The parameters of the rag circuitry associated with the mti should follow the contours of the clutter region given in figure 6-2.

(d) Tangential course problems exist along certain sectors of airways V-17 and 205, tpl if mti operation is limited to the clutter region as recommended. The appropriate sectors are marked by heavy lines in figure 6-2.

d. Beacon Coverage Analysis. This analysis makes use of the beacon overlay chart of figure 3-23, together with the radar coverage indicator chart of figure 6-3. The beacon overlay chart is applied over the rci chart and is adjusted for the recommended 2.9° tilt angle. The smallest beacon power required to cover all fixes and the maximum range of 30 nmi is noted to be 39 dBm. This minimum required power level is increased by 3 dB to account for substandard propagation conditions. Thus, a total 42 dBm power output is required from the antenna. To obtain the transmitter power output, the two-way transmission line and plumbing losses for the particular installation must be added to 42 dBm.

Appendix 6

e. Lobing Analysis. Referring to site A photographic data, it was noted that, for the most part, the terrain about the site consists of gradual slopes, mountain rises, ridgelines, and hills that are heavily populated with trees, shrubbery, etc. In general, these are not smooth or flat terrain characteristics necessary to produce lobing. However, it was noted in the photograph that there are two relatively flat portions of real estate that appear to extend to the distant horizon. These two regions are: (1) the region beginning with the exposed end of runway 15 at 290° to 360° in azimuth, and (2) the region of terrain between 70° and 100° in azimuth. Because of the appearance of flatness in these two regions, a lobing analysis was carried out using the procedures outlined in chapter 3, paragraph 57.

(1) Existence of Lobing.

(a) To establish if lobing will occur in either or both of the suspect sectors, analysis of the field data together with map studies were carried out to determine:

1. MSL elevation of the terrain in each sector.

2. The extent of land area in each of these sectors that will be illuminated by a radar/beacon antenna located at site A.

3. The distances to near reflection and far points of the first Fresnel zone.

4. Estimates of the surface roughness or irregularities over the land area contained in each section.

(b) As a first approximation, the extent of the land area illuminated or visible in each sector was determined by computing the range to the radar horizon using the following relationship (from equation 2-6 (p. 84) with k = 4/3):

$$d = 1.23 \sqrt{h_a} \qquad (6\text{-}2)$$

where

d = the ground range to the horizon in nautical miles.

h_a = the effective height of the antenna in feet.

(c) To obtain the proper values for h_a, map studies were made to estimate the average elevation of the terrain in each of the two sectors of interest.

(d) In the sector between 295° and 360° in azimuth, the elevation of the terrain fluctuates between 1,000 and 1,100 feet msl out to a range of approximately 20 miles. The up and down nature of the terrain results in surface irregularities that vary between 15 and 100 feet. Taking the average elevation of this land area to be 1,050 feet msl, the effective height of the antenna becomes 125 feet (1,175-1,050) where 1,175 feet is msl elevation of antenna. Using this value for h in the above equation, a range of 13.75 nmi to the radar horizon was obtained. This defines the extent of land area illuminated by the radar and beacon in this sector.

(e) In the region between 70° and 100° in azimuth, the terrain recedes almost uniformly from an elevation of 1,000 feet to an elevation of approximately 700 feet msl at 25 nmi from the site. Surface irregularities along this receding terrain vary from 10-30 feet. As a first approximation, the average between these two is assumed to be 850 feet msl. Therefore, in this sector the effective antenna height is 325 feet (1,175-850) and the range to the horizon is 22.17 nmi.

(f) Knowing the extent of terrain illumination and surface roughness in the two regions of interest, the question of whether vertical lobing will occur can be answered by invoking the criteria based on the Fresnel theory outlined in chapter 2, paragraph 22b(3).

(g) Values defining the length of the first Fresnel zone and the critical height, Δh_c, for each sector were computed for a number of nulls, and are tabulated in table 6-6 and 6-7 for the ASR-8 and the beacon, respectively. For ASR-8, the calculations are based on the effective antenna heights of 125 feet and 325 feet in each respective region of interest. For beacon, the corresponding effective antenna heights were taken to be 130 feet and 325 feet.

(2) Lobing for ASR.

(a) Examination of table 6-6 shows that for sector 1, the surface roughness of the terrain exceeds the critical height, Δh_c, for all lobe nulls except the first. Therefore, no lobing beyond the first null can occur. In the case of the first null, we note from the table that only about 20% of the Fresnel zone is illuminated. Although theory doesn't provide a clear answer in such cases of partial illumination, it is reasonable to expect that the

TABLE 6

ASR LOBING ANALYSIS EXAMPLE

	Order of null	Fresnel Zone Parameters - nautical miles -			Horizon Range (nmi)	Grazing Angle, Ψ (deg.)	Critical Ht. of Surface Irregularity Δh_c, (ft.)	Measured Ht. of Surface Irregularity Δh, (ft.)
		Near Point	Reflection Point	Far Point				
Sector 1 (Effective Antenna Height = 125')	1	3.9	14.6	54.6	13.75	.081	15.56	15 - 100
	2	2.8	7.3	19.2	13.75	.161	7.83	15 - 100
	3	2.2	4.9	10.8	13.75	.241	6.21	15 - 100
	4	1.8	3.7	7.3	13.75	.319	3.95	15 - 100
	5	1.7	2.9	5.5	13.75	.406	3.10	15 - 100
	10	.9	1.5	2.3	13.75	.786	1.60	15 - 100
	15	.7	.8	1.4	13.75	1.47	0.86	15 - 100
	20	.5	.7	1.0	13.75	1.68	0.75	15 - 100
Sector 2 (Effective Antenna Height = 325')	1	26.5	98.9	369	22.17	.031	40.64	15 - 30
	2	18.9	49.3	129	22.17	.062	20.32	15 - 30
	3	14.9	33.0	73	22.17	.093	13.55	15 - 30
	4	12.4	24.7	49.5	22.17	.124	10.16	15 - 30
	5	10.6	19.8	36.8	22.17	.155	8.13	15 - 30
	10	6.3	9.9	15.4	22.17	.31	4.06	15 - 30
	15	4.6	5.1	9.5	22.17	.60	2.10	15 - 30
	20	3.6	4.9	6.8	22.17	.63	2.0	15 - 30

TABLE 7

BEACON LOBING ANALYSIS EXAMPLE

	Order of null	Fresnel Zone Parameters - nautical miles - Near Point	Reflection Point	Far Point	Horizon Range (nmi)	Grazing Angle, Ψ (deg.)	Critical Ht. of Surface Irregularity Δh_c, (ft.)	Measured Ht. of Surface Irregularity Δh, (ft.)
Sector 1 (Effective Antenna Height=130')	1	1.56	5.82	21.72	14.02	0.21	15.63	15 - 100
	2	1.16	2.92	7.62	14.02	0.42	7.69	15 - 100
	3	0.88	1.94	4.30	14.02	0.62	5.22	15 - 100
	4	0.73	1.45	2.91	14.02	0.84	3.84	15 - 100
	5	0.58	1.16	2.17	14.02	1.03	3.13	15 - 100
	10	0.37	0.58	0.91	14.02	2.07	1.56	15 - 100
	15	0.27	0.39	0.56	14.02	3.93	0.82	15 - 100
	20	0.21	0.29	0.40	14.02	4.21	0.77	15 - 100
Sector 2 (Effective Antenna Height=330')	1	10.05	37.50	139.95	22.34	0.08	40.45	10 - 30
	2	7.45	18.75	49.09	22.34	0.16	20.23	10 - 30
	3	5.64	12.50	27.69	22.34	0.24	13.48	10 - 30
	4	4.69	9.37	18.74	22.34	0.32	10.11	10 - 30
	5	3.77	7.50	13.97	22.34	0.40	8.09	10 - 30
	10	2.41	3.75	5.84	22.34	0.81	4.0	10 - 30
	15	1.74	2.50	3.59	22.34	1.53	2.1	10 - 30
	20	1.39	1.87	2.57	22.34	1.61	2.0	10 - 30

depth of the resulting null will be reduced proportionally. Combining this with the fact that the critical height of 15.56 feet falls within the lower end of the actual 15-100 foot irregularities in this region, it is suggested that the first order null would be a very weak one, if it does exist at all.

(b) An evaluation of the results shown in table 6-6 for sector 2 also leads to the conclusion that lobing will not be troublesome. The reasoning here is that for the first four nulls, the absence or partial nature of the illumination (less than 30% of the Fresnel zone) negates the possibility of significant lobing problems. For all higher order nulls, the surface irregularities exceed the critical heights necessary to sustain lobing.

(3) Lobing for Beacon.

(a) In table 6-7 it can be seen for sector 1 that the critical height, Δh_c, is much smaller than the actual surface irregularities for all nulls except the first. Hence, no beacon lobing beyond the first null can be expected. Also, the fact that the critical height, Δh_c, for the first null (15.63' in table 6-7) is just above the lower bound of estimated surface irregularities in sector 1 tends to make the possibility of a first order null highly unlikely.

(b) For sector 2, the fact that the actual surface irregularities exceed the critical height, Δh_c, for all nulls above the fourth, suggests that no vertical lobing of the beacon will occur above 0.32° (the angle of the fourth null). For all practical purposes, this argument applies to the fourth null also, since the critical height, Δh_c, for this null just barely exceeds the lower bound of the actual surface irregularities.

(c) The Fresnel zones for the first and second nulls are only partially illuminated (less than 30%), and it is therefore concluded that no significant first or second lobing nulls will occur. There are indications that a third order null in the beacon pattern may develop, however, because of the fact that the Fresnel zone for this null is illuminated to a considerable extent (∿75%). Since the upper bound of surface irregularities (∿30 feet) exceeds the critical height, Δh_c, for this null, a strong null is not expected, but it is recommended that this airspace sector be investigated during flight checks for the existence and impact of a third order beacon lobing null. The null, if it exists, will occur at an angle of 0.24° with respect to the local horizontal at the beacon antenna.

APPENDIX 7

SAMPLE ASR COVERAGE RANGE COMPUTATION

1. INTRODUCTION. The detailed coverage range calculations for an ASR radar are presented in this appendix as an example. The case considered here is that of the ASR-7E where it is desired to calculate the maximum range of coverage at the elevation angle corresponding to the main beam maximum gain.

2. COMPUTATIONAL CONDITIONS. The calculations are done for the following conditions:

Detection Probability = 0.75

False Alarm Probability = 10^{-6}

Target Cross Section = 2.2 m^2 (T-33 Aircraft)

Polarization = Linear.

3. EQUATIONS. Equation 2-1 is used for the range calculation and is repeated here for convenience:

$$R(\text{naut. miles}) = 129.2 \left[\frac{P_t(\text{kW})\ \tau(\mu s)\ G_t G_r\ \sigma(m^2)}{f^2(\text{MHz})\ T_s(K^o)\ S/N\ C_B\ L}\right]^{1/4} \quad (7\text{-}1)$$

where the units in parentheses represent the correct ones to obtain the range in nautical miles. Equation 7-1 is cumbersome to use in that form because many of those parameters are specified in decibels. It is convenient, therefore, to change it into the form of equation 7-2.

$$10 \log R = 21.11 + \frac{1}{4}\Big[10 \log P_t(\text{kW}) + 10 \log \tau(\mu s) + -20 \log f(\text{MHz}) - 10 \log T_s(K^o) - S/N(\text{dB}) + -C_B(\text{dB}) - L(\text{dB})\Big] + \frac{1}{4}\Big[G_t(\text{dB}) + G_r(\text{dB}) + 10 \log \sigma(m^2)\Big] \quad (7\text{-}2)$$

The terms in the first set of brackets are independent of the antenna gain or the target cross section. Equation 7-2 can be rewritten in the following form:

$$R = 10^{\left[2.111 + \frac{K(\text{dB}) + G_t(\text{dB}) + G_r(\text{dB}) + 10 \log \sigma(m^2)}{40}\right]} \quad (7\text{-}3)$$

where the constant K is defined as follows:

$$K = 10 \log P_t(kW) + 10 \text{ long } \tau(\mu sec) - 20 \log F(MHz)$$
$$+ -10 \log T_s(K^o) - S/N(dB) - C_B(dB) - L(dB) \quad (7-4)$$

4. PARAMETERS. The radar parameters for the ASR-7E necessary for the range calculation are repeated here from Table 1-1:

Peak Power (P_t) = 425 kW

Pulse Length (τ) = 0.833 μsec

Frequency (f) = 2800 MHz

Scan Rate (W_r) = 12.75 rpm

MTI RF Bandwidth = 5 MHz

Receiver Noise Figure (F_n) = 5.1 dB

PRF (f_r) = 1030 Hz

Antenna Azimuth Beamwidth (θ_a) = ~1.35°.

The other parameters for equation 7-4 are determined as follows:

a. Noise Temperature - T_s. The noise temperature is determined using equation 2-2.

F_n = 5.1 dB

T_a = 124 k (assumption as for paragraph 19.b)

$$T_s = 290 \left[F_n - 1)\right] + T_a = 290 \left[10^{\frac{5.1}{10}} - 1\right] + 124 = 772.42 \ K^o$$

b. Signal to Noise Ratio - S/N. This parameter is determined using the Swerling Case 1 fluctuation curves as given in reference 6. The curve corresponding to 0.75% probability of detection and 10^{-6} probability of false alarm is selected. The number of integrated pulses is calculated using equation 1-4 as follows:

$$M = \frac{a \ f_r}{6 \ W_r} = \frac{1.45^o \times \frac{710 + 1200}{2}}{6 \times 12.75} = 18.1 \text{ hits/scan.}$$

The value of S/N read from the Swerling curve is approximately 7.4 dB.

c. Bandwidth Correction Factor - C_B. Using equation 2-3 and the mti receiver bandwidth value, the bandwidth correction factor is calculated as follows:

$$C_B = \frac{B(MHz)\ \tau(\mu sec)}{4}\left[1 + \frac{1}{B(MHz)\ \tau(\mu sec)}\right]^2$$

$$= \frac{5 \times 0.833}{4}\left[1 + \frac{1}{5 \times 0.833}\right]^2 = 1.60 = 2.04 \text{ dB}$$

d. Losses - L. Plumbing losses for the ASR-7E are calculated to be 3.2 dB as shown in paragraph 19.f. of Section 2. The antenna pattern beam shape losses are 1.6 dB, as for reference 6, and the propagation absorption losses are assumed to be zero dB. The total losses are calculated to be 5.8 dB using equation 2-4:

$$L = L_\alpha(dB) + L_p(dB) + L_{tr}(dB)$$

$$= 0 + 1.6 + 4.2 = 5.8 \text{ dB}.$$

5. RANGE CALCULATIONS. The value of the constant K, using equation 7-4, is -85.84 dB.

$$K = 10 \log 425 + 10 \log 0.833 - 20 \log 2800$$

$$-10 \log 772.42 - 7.4 - 2.04 - 5.8 = 87.57 \text{ dB}.$$

The antenna gains for the upper and lower beams at the angle where the main beam reaches its maximum are determined from figure 1-6A:

Gain of Lower Beam (G_{LB}) = 33.85 dB

Gain of Upper Beam (G_{UB}) = 25.45 dB.

Finally, the target cross section of 2.2 m^2 for a T-33 aircraft is 3.424 dB. The last step in the range calculation is to use equation 7-3. In the following paragraphs two cases are considered for the ASR-7E depending on which beam is used for reception.

a. Main Beam Reception. The maximum coverage range in the case where the main beam is used for both transmitting and receiving is 50.1 n.m. as calculated below:

$$R = 10^{\left[2.111 + \frac{K + G_{LB} + G_{LB} + \sigma}{40}\right]}$$

$$= 10^{\left[2.111 + \frac{-87.57 + 33.85 + 33.85 + 3.424}{40}\right]} = 50.1 \text{ n.m.}$$

This range value can be cross referenced with both figures 2-4A and 3-18A.

b. Upper Beam Reception. The maximum coverage range in the case where the passive beam is used for receiving and the main beam for transmitting only is 30.9 n.m. as calculated below:

$$R = 10^{\left[2.111 + \frac{K + G_{LB} + G_{UB} + \sigma}{40}\right]}$$

$$= 10^{\left[2.111 + \frac{-87.57 + 33.85 + 25.45 + 3.424}{40}\right]} = 30.9 \text{ n.m.}$$

This range value can be cross referenced with figure 3-18A.

INDEX

* U.S. GOVERNMENT PRINTING OFFICE : 1982 O - 386-138