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Mode S Installation and Siting Criteria

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16. Abstract

This paper provides information on site-associated phenomena that affect the proper operation of a Mode S sensor and therefore warrant serious consideration when siting a sensor. The Mode S related discussion is intended to be a supplement to the ATCRBS siting criteria presented in the FAA Primary/Secondary Terminal Radar Siting Handbook. The paper discusses siting criteria as they relate to the Mode S sensor antenna system, as opposed to the ATCRBS hogtrough antenna, and importantly, addresses those characteristics of the surrounding environment that are crucial to proper Mode S surveillance.

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1.0 INTRODUCTION

This paper provides insight into site-associated phenomena that affect the operation of a Mode S sensor and which warrant serious consideration in any Mode S siting exercise. The Mode S-related discussion is intended to be a supplement to the ATRCBS siting criteria presented in the FAA Primary/Secondary Terminal Radar Siting Handbook[1]. The paper discusses siting criteria as related to the Mode S sensor antenna system, as opposed to the ATCRBS hogtrough antenna, and most importantly it describes features of the surrounding environment that are crucial to proper Mode S surveillance and what can be done in siting the Mode S sensor to mitigate them.

2.0 OVERVIEW

The most common site characteristics affecting Mode S performance and which will be discussed in greater detail are:

a. Signal shadowing and diffraction induced azimuth errors from man-made obstructions and natural terrain.

b. In-beam vertical lobing fades caused by specular reflections from smooth flat terrain surrounding the sensor.

c. Man-made and natural reflective surfaces that cause generation of false targets.

In general most of the siting criteria discussed in the Siting Handbook for ATCRBS apply equally well to Mode S with few exceptions. The vertical pattern lower edge roll-off of the Mode S open array antenna will minimize the sensitivity of the vertical pattern to ground reflections. This in turn will provide ModeS with improved coverage capability and will afford greater freedom in site selection as far as in-beam multipath is concerned.

The fact that Mode S has the capability of flagging false target reports together with its lower edge cutoff will also lessen the importance of location with respect to man-made reflecting surfaces.

One area of considerable importance to Mode S which is not covered in the Siting Handbook, is the impact of obstructions (towers, buildings, smokestacks, etc.) on Mode S surveillance accuracy. The inherently greater resolution of the Mode S azimuth position estimator will result in noticeable cross range and cross track velocity errors due to the diffraction effects of shadowing obstruction. Depending on size and distance of the obstruction, the azimuth error may greatly exceed the surveillance accuracy requirement specified in paragraph 3.3.2.8 of the Mode S sensor specification, FAA-E-2716.

3.0 SHADOWING AND DIFFRACTION

3.1 Obstructions

Man-made and natural obstacles surrounding the Mode S site can cause both a serious fade in the link signal strength resulting in noise-induced errors and a sizeable azimuth error in the position estimate of aircraft flying behind the obstruction. Signal blockage on both the uplink and downlink can result in either marginal or no coverage for several scans and seriously impair the capability of the Mode S sensor. In addition to shadowing, the obstruction will cause diffraction of the downlink signal wavefront from aircraft whose line-of-sight is in close proximity to it. Serious diffraction can cause a sizeable error in the Mode S azimuth position and cross track velocity estimate of the aircraft.

3.2 Signal Fades Due to Man-Made Obstructions

The primary cause of blockage in a terminal enviroment are man-made obstructions such as towers, buildings and smokestacks. In heavily populated urban areas the proximity of these structures to an airport-located sensor could provide destructive interference to Mode S surveillance of aircraft up to a few degrees elevation. As an example Figs. 1a and 1b illustrates the Boston skyline (typical of many terminal locations) as seen from the ASR at Logan Airport. Most of the buildings in one particular 11 degree azimuth sector exceed 1 degree elevation and some extend to 2.5 degrees. Fig. 2 typifies the character of signal fading caused by an obstruction, in this case the Prudential building in Boston, in which the aircraft is below the top of and at considerably greater range than the structure[2]. The building is 220 feet wide, 22000 feet from the sensor and extends to 2 degrees elevation. The variation of the fade pattern as a function of aircraft offset from the midpoint of the obstruction as illustrated in Fig. 2 (i.e., a midpoint lobe surrounded by deep nulls) is characteristic of all isolated and geometrically simple structures except that the width of the structure will determine the frequency and number of fade nulls. Fig. 3 is a plot of the approximate relationship between the deepest null value and the obstacle range for different obstacle widths. Generally the fade at midpoint is one-half the value of the deepest fade.

The following general comments relative to the Prudential example can be made concerning the relationship of signal fade to the obstacle dimension and to the obstacle and the aircraft range.

a. An increase in obstacle width for a given range will result in deeper fades and will increase the number and frequency of fade nulls.

b. A decrease in obstacle range for a given width will increase the amount of fade.

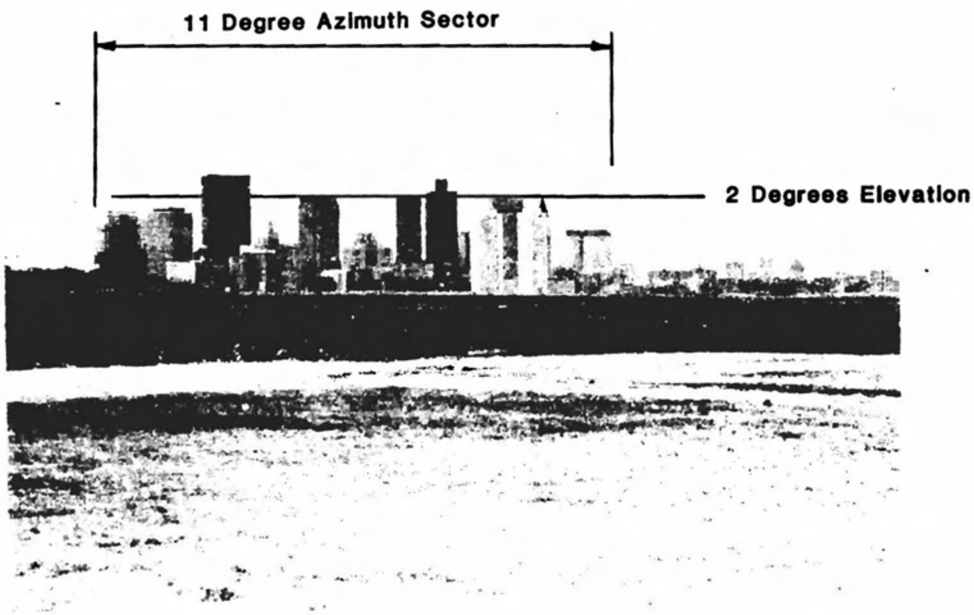


Fig. 1a. Highrise Buildings (Part of Boston Skyline As Seen From Logan Airport).

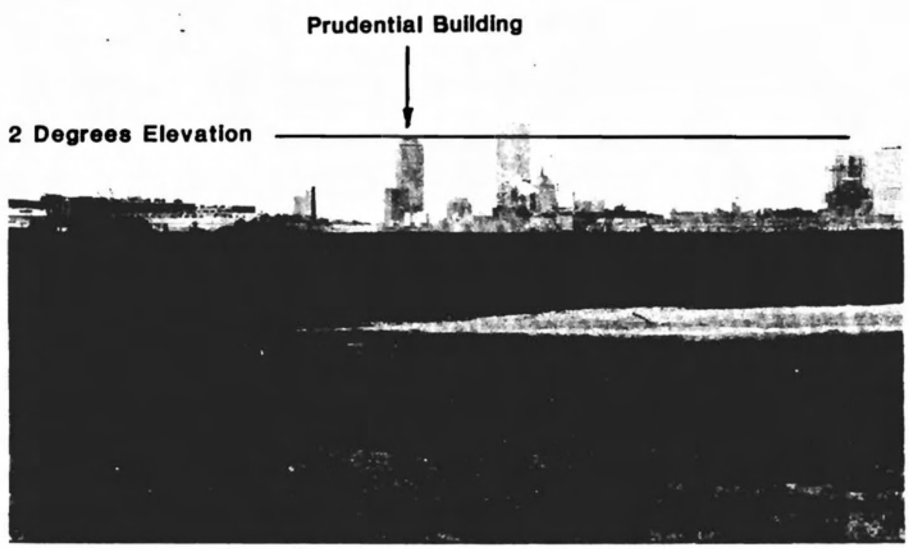


Fig. 1b. Highrise Buildings (A Second View of Part of Boston Skyline As Seen From Logan Airport).

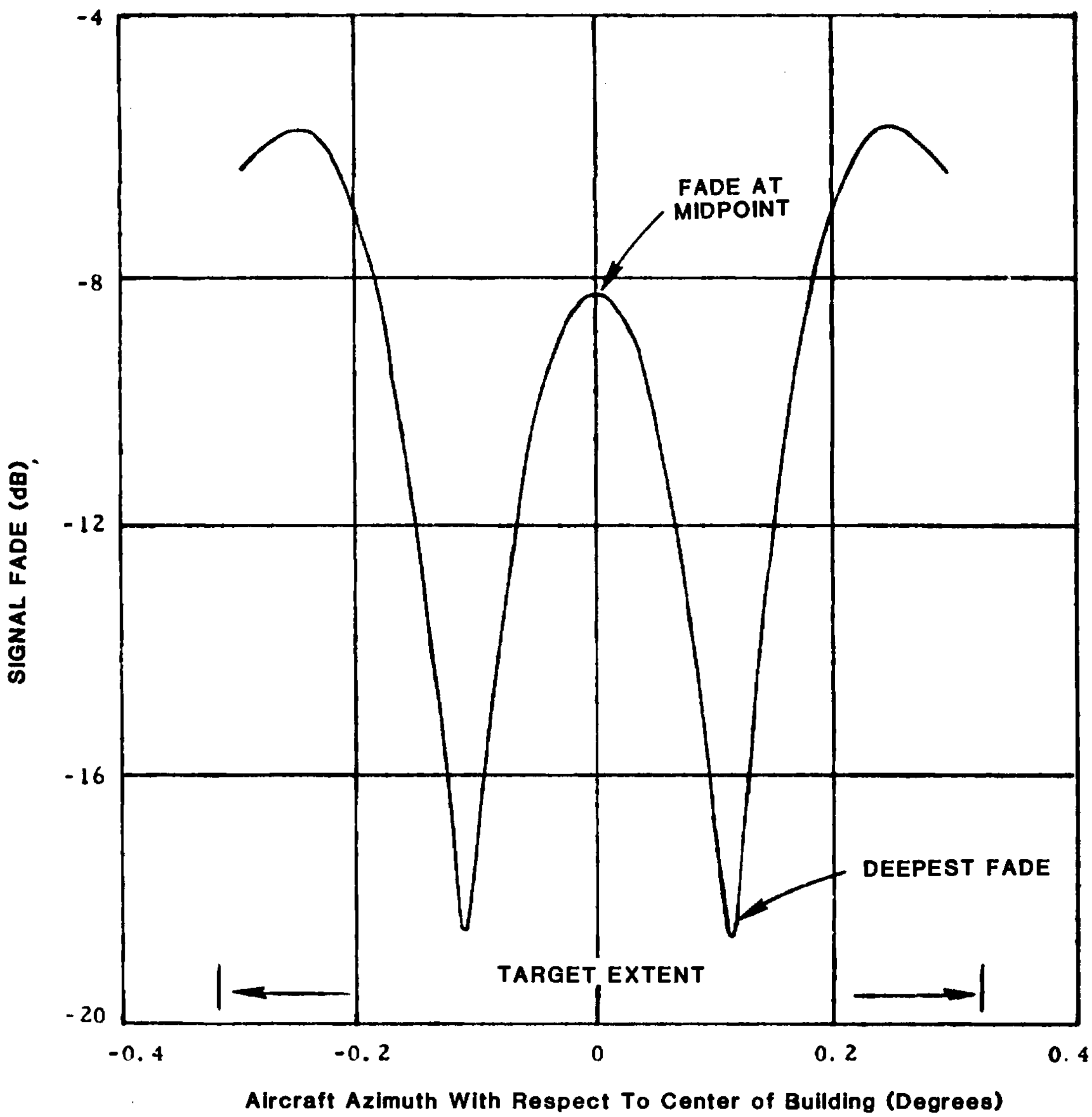


Fig. 2. Fade Cast by the Shadow of the Prudential Building As Seen From Logan Airport. Obstacle Width and Range Are 220 Feet and 22000 Feet Respectively

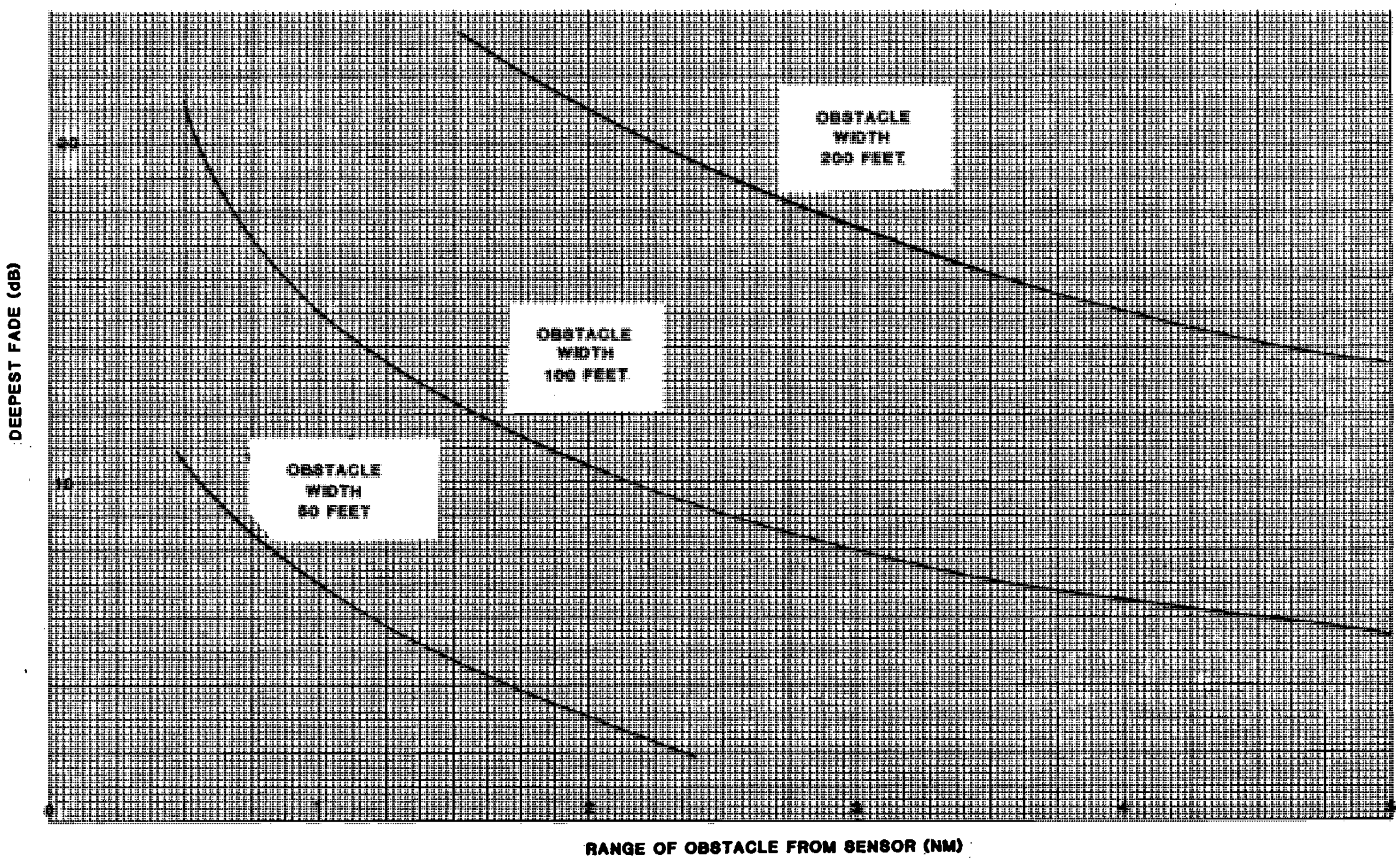


Fig. 3. Envelope of Deepest Fade Nulls Caused by an Obstacle As a Function of Obstacle Range.

c. A decrease in aircraft range will result in deeper fades. As an example an aircraft at twice the obstacle range will result in fades 4 dB larger than that due to an aircraft at much greater range.

In a typical metropolitan environment the ideal location of a Mode S sensor, in order to eliminate low altitude shadowing, would be one that is either sufficiently removed from the obstruction (at least 5 nm for a 200 foot width) or at a height comparable to the obstruction. Unfortunately an ideal location is not always possible in an urban area and therefore consideration should be given to minimizing shadowing effects for a majority of aircraft in predominantly used airspace. A simple and approximate criteria for the distance to an obstruction of given width in order to maintain an "acceptable" level of fade is given in Reference 3. Assuming that the midpoint fade value is a good representation of the likely fade encountered over the azimuth extent of the obstacle then in order to maintain this value to -6 dB or less the range to the obstacle should be at least the square of its width.

3.3 Azimuth Error Due to Man-Made Obstructions

Diffraction of the wavefront from an aircraft whose line-of-sight is either through the obstacle or in close proximity to it can cause an appreciable error in the estimate of the aircraft azimuth. The diffracted signal will have approximately the same effect on the azimuth position estimate regardless of whether the estimate is generated by a Mode S monopulse processor or by the beam splitting technique currently employed in ATCRBS sensors.

Current ATCRBS sensors use a sliding window detection process that has an internal quantization error comparable in magnitude to the errors generated by typical obstructions surrounding an airport. This fact has tended to mask the effect of diffraction errors in present ATCRBS sensors. Mode S, on the other hand, employs a surveillance processor of inherently greater resolution.

The magnitude of the error and the azimuthal extent or wedge over which a position estimate is seriously affected depends on the dimensions of the obstacle as well as on the range of both the obstacle and the aircraft. Figs. 4 and 5 illustrate the typical nature of the azimuth estimation error as a function of aircraft position relative to the obstacle midpoint. The error values in the plots are based on a single Mode S interrogation of an aircraft that is either at or very close to the antenna boresight. An interrogation at the leading (trailing) edge of a clockwise rotating beam would produce a smaller (larger) error if the target azimuth preceeded the obstacle azimuth. The resultant error associated with a large number of interrogations per dwell such as for ATCRBS would tend to average out to a value equivalent to the error from a single interrogation at boresight.

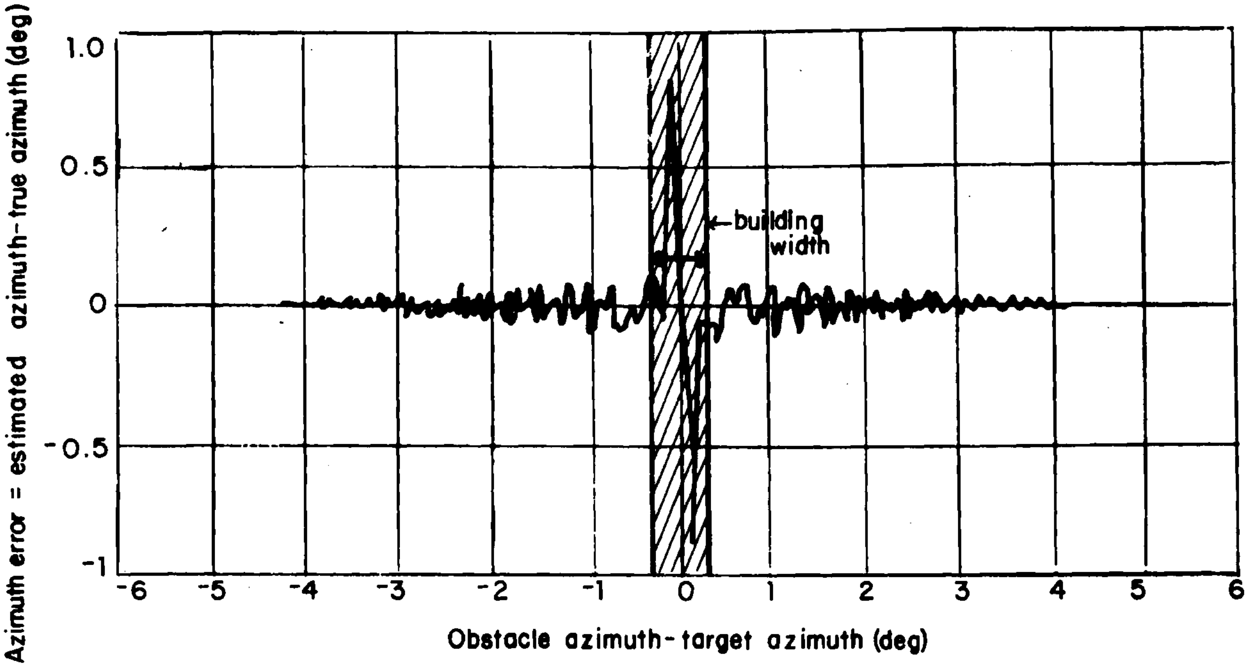


Fig. 4. Azimuth Estimation Error vs. Obstacle Position. Obstacle, Which Corresponds to Prudential Building As Seen From Logan Airport, is 220 Feet Wide and at a 22000 Foot Range.

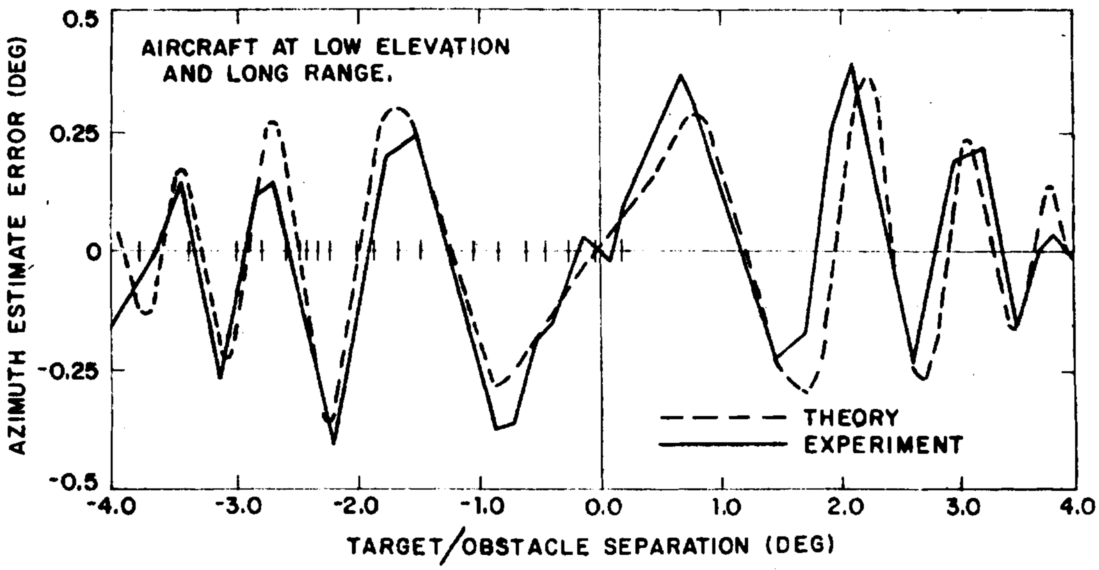


Fig. 5. Azimuth Estimation Error vs. Aircraft Position Relative to Obstacle Midpoint. Obstacle, Which Corresponds to Hanscom AFB Smokestack, is 10 Feet Wide and at a 1500 Foot Range.

Fig. 4 is the computed perturbation caused by the Prudential building in Boston as viewed from the Logan ATCRBS site. The Prudential building is 222 feet wide and at 22000 feet range. Fig. 5 is the Hanscom AFB smokestack as viewed by the Mode S Experimental Facility (DABSEF) in Lexington, MA and illustrates the comparison between the azimuth error function as computed from theory and one derived from actual measurement using a controlled aircraft. The smokestack is 10 feet wide and at a range of 1500 feet. In both cases the aircraft is well below the top of the obstruction and at a much greater range. The azimuth error is zero for an aircraft position directly behind the center of the obstacle and varies in an oscillatory manner as a result of con-structive and destructive interference between the direct and diffracted signals as the aircraft moves away from the obstacle. The important characteristics of this error function, in terms of Mode S performance, are the maximum peak error value, its location relative to the obstacle midpoint and the azimuth wedge over which succeeding peak values are large enough to affect the position estimate. The plots indicate that a single scan azimuth surveillance report on an aircraft which happens to be located in one of the peak error regions can be in excess of surveillance requirements. Additionally this error could persist for many scans depending on the aircraft flight path and then change abruptly due to a maneuver.

The severity of diffraction induced errors are dramatically illustrated during flight testing at the Lincoln Laboratory Mode S Experimental Facility (MODSEF) in August 1975. Fig. 6 is an X-Y plot showing the track history of two test aircraft flying a planned near-miss encounter behind and below the top of the Hanscom AFB smokestack. The target reports are shown as asterisks. The beginning and end points of the line segment associated with each report represents respectively the current smoothed position and a predicted 4-second advanced position based on monopulse inputs. The actual aircraft flight paths are shown by dashed lines and the optical shadowing extent of the smokestack is illustrated by the cross-hatched area. The actual azimuth position of aircraft 1 and 2 with respect to the smokestack midpoint varied from +0.8 degrees to +1.7 degrees and from +2.4 degrees to +1.7 degrees respectively.

The oscillatory nature of the position estimate with respect to the true position is seen to reflect the same kind of azimuth error behavior observed in Fig. 5 in the region of +0.8 to +2.4 degrees offset. Diffraction in this instance was severe enough to seriously degrade the azimuth estimate.

In an analysis of the impact of diffraction on azimuth estimation Reference 4 provides several basic criteria relating obstacle dimension and range to the size and extent of the azimuth error. A completely accurate prediction of the effect of a complex grouping of structures, such as found in a typical metropolitan skyline, would involve a lengthy process, particularly

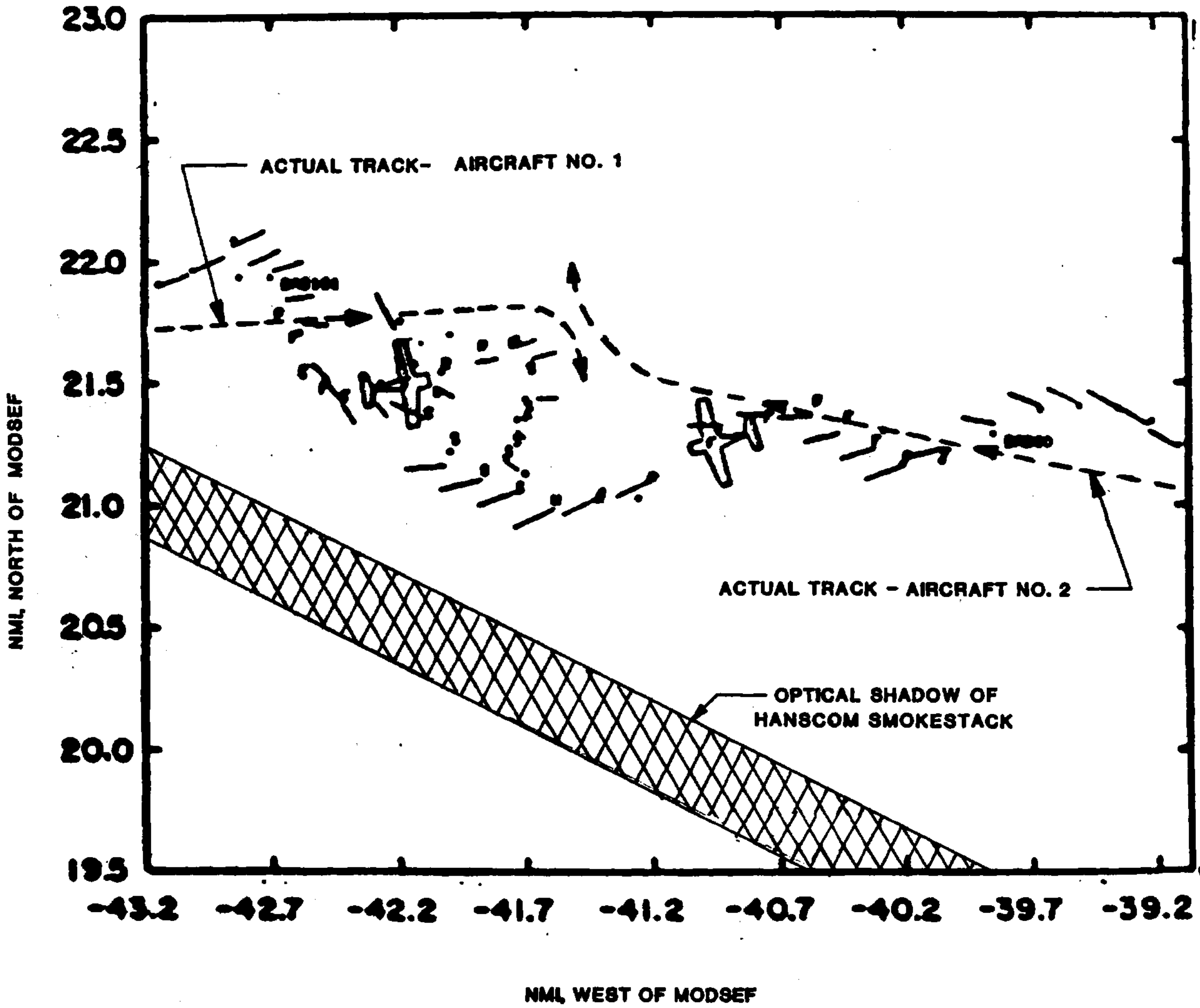


Fig. 6. Plot of an Encounter Exercise Showing the Effect of Diffraction From a Vertical Obstacle on Aircraft Surveillance.

if a large number of site locations were evaluated. However, Reference 4 offers some generalized observations based on relatively simple and isolated geometric shapes that should be sufficient in providing a fairly accurate and practical guideline for siting Mode S to minimize diffraction induced error.

Fig. 7 illustrates the general relationship between obstacle width as observed by the sensor and obstacle range for three different values of maximum peak azimuth error. The aircraft is assumed to be well below the top of the obstacle and at much greater range. The plots show that the maximum peak error is reduced the narrower the obstacle and the further away it is from the sensor. The location of the maximum peak with respect to the midpoint of the obstacle depends primarily on the width of the obstacle (see Figure 8) and is represented by the following approximation:

$$\text{Azimuth of Maximum Peak Error (DEG.)} \approx \frac{20}{\text{obstacle width (feet)}}$$

An important consideration to Mode S is not only the maximum peak error and its position but also the total angular region of destructive error about a given obstacle. As seen in Fig. 5 additional azimuth error peaks occur in an oscillatory fashion as the aircraft line-of-sight moves away from the center of the obstacle. The total azimuth extent of corruptible errors (error wedge) is a more complicated function of obstacle range and particularly width than is the value and position of the maximum peak error. Generally, for any given obstacle width, the azimuth extent of corruptible errors decreases as the obstacle range is increased until it become non-existent, i.e., zero error contribution. Table 1 lists the approximate maximum range for a number of obstacle widths at which the azimuth error wedge becomes zero and the obstacle is no longer a corrupting influence on Mode S. Also shown is the range at which the maximum peak error does not exceed 0.25 degrees. Note that the narrower the obstacle is the shorter the range at which the error wedge becomes insignificant. As the range is decreased both the azimuth wedge and the maximum peak azimuth error (Fig. 7) increase in value.

TABLE 1

Values of Obstacle Range for Zero Azimuth Error Extent (Zero Error) and for 0.25 Degree Peak Error. Aircraft Well Below Top of Obstacle and at Much Greater Range

Obstacle Width (Feet)	Approximate Obstacle Range (Feet) For: Zero Wedge-Zero Error	Approximate Obstacle Range (Feet) For: 0.25 Degree Error
100	32000	20000
40	16000	7000
20	8000	3000
10	4000	1300

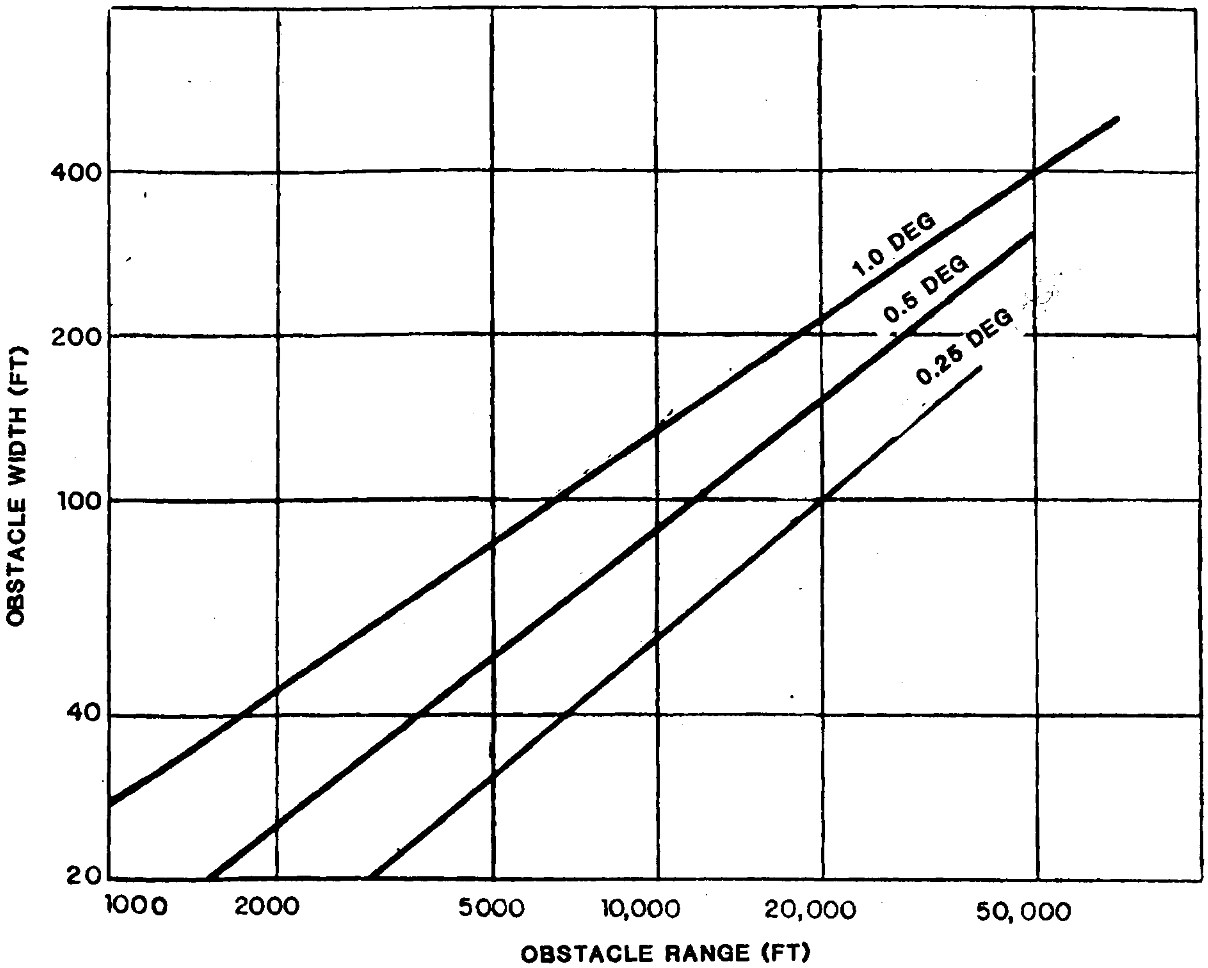


Fig. 7. Maximum Azimuth Error (Deg) As a Function of Obstacle Width (ft) and Range (ft).

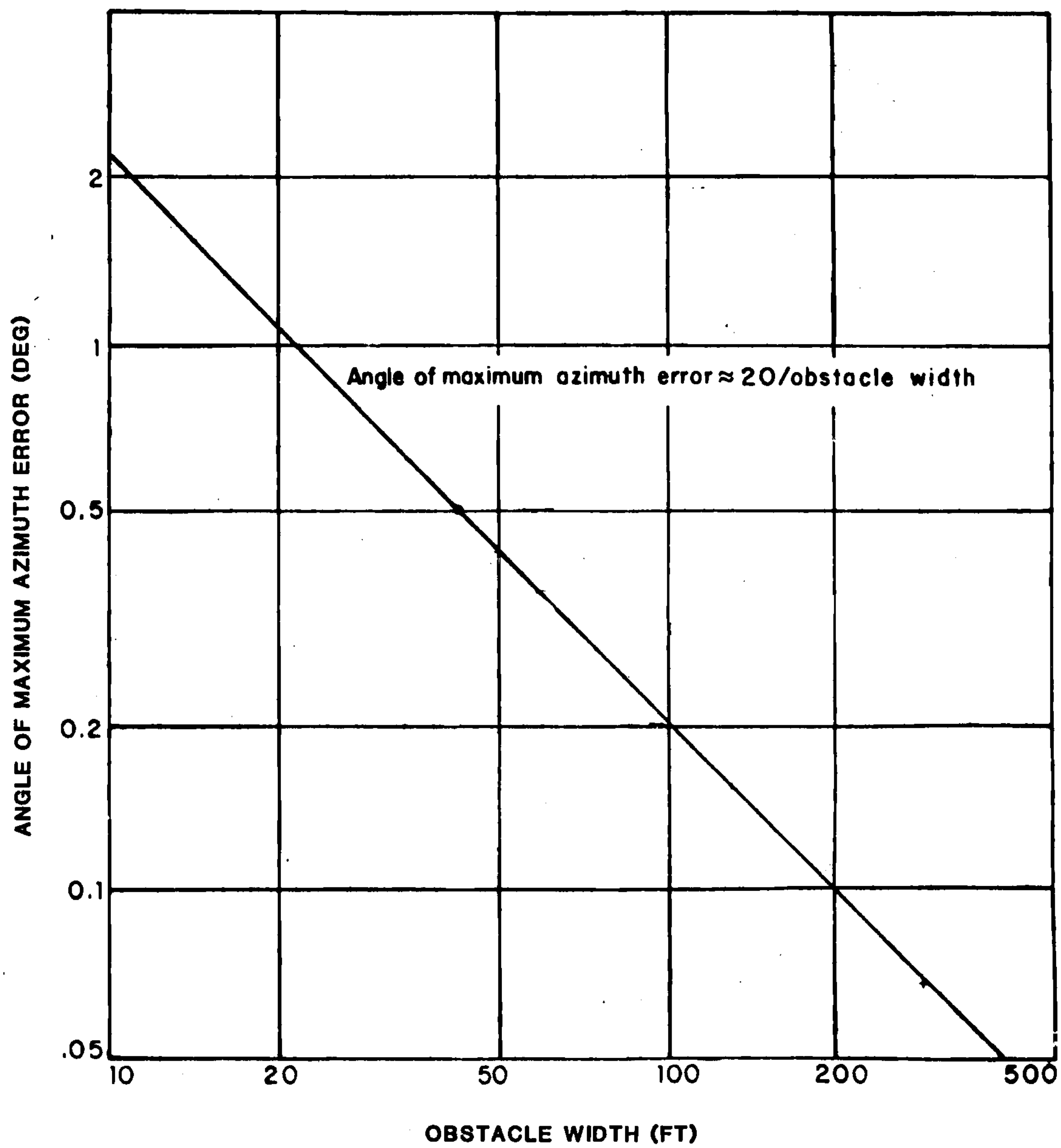


Fig. 8. Angle at Off-the-Center of Obstacle Where Peak Azimuth Error Occurs vs. Obstacle Width (ft).

The dependence of error wedge (i.e., the angle over which the diffraction induced error is non zero) on obstacle width is more complex. Fig. 9 shows the behavior of the error wedge as a function of width for four values of obstacle range. The error wedge exhibits an oscillatory behavior as a function of obstacle width that is more pronounced for narrower obstacles at shorter ranges. Note also that the angular extent of the azimuth error introduced by short range, narrow obstacles can be much larger than the angle subtended by the obstacle. This serves to illustrate that short range obstacles which appear to an observer to be of insignificant width can nevertheless be a decisive influence on the ability of Mode S to meet surveillance requirements (witness the effect of the 10 foot wide Hanscom smokestack with its 6.4 degree error wedge on the encounter mentioned earlier).

In all of considerations of impact of obstacle diffraction on Mode S, the aircraft was assumed to be at a range much greater than the obstacle. If the aircraft range is shortened the errors increase. As an example Reference 4 points out that, for an obstacle range of 32000 feet, the maximum peak azimuth error will increase from 0.25 degrees to 0.55 degrees as the aircraft range is reduced to 64000 feet.

The basic relationships between the important characteristics of the azimuth error and the parameters of the obstacle producing them can be summarized by the following comments.

a. If the peak azimuth error introduced into the Mode S position estimate by diffraction is to be confined to less than 0.25 degrees, the Mode S sensor should be located at least 2000 feet from narrow (10 foot or less) obstructions such as towers and smokestacks, at least 5000 feet down control towers no wider than 30 feet and at least 50000 feet from buildings no wider than 200 feet.

b. The peak azimuth error will decrease, its location will move away from obstacle midpoint and the error wedge will generally increase as the obstacle width is made narrower. At some minimum width the peak error becomes inconsequential and the obstacle is no longer a corrupting influence.

c. The peak azimuth error and the error wedge will decrease as the sensor is moved further from the obstacle. The location of the peak error is relatively insensitive to range. At some maximum range the error wedge disappears and the obstacle is no longer a corrupting influence.

d. The peak azimuth error from obstacles maintaining the same angular width in degrees will increase as the sensor is moved away from the obstacle.

e. Aircraft close to the obstacle in range will experience a larger peak error than aircraft at long ranges.

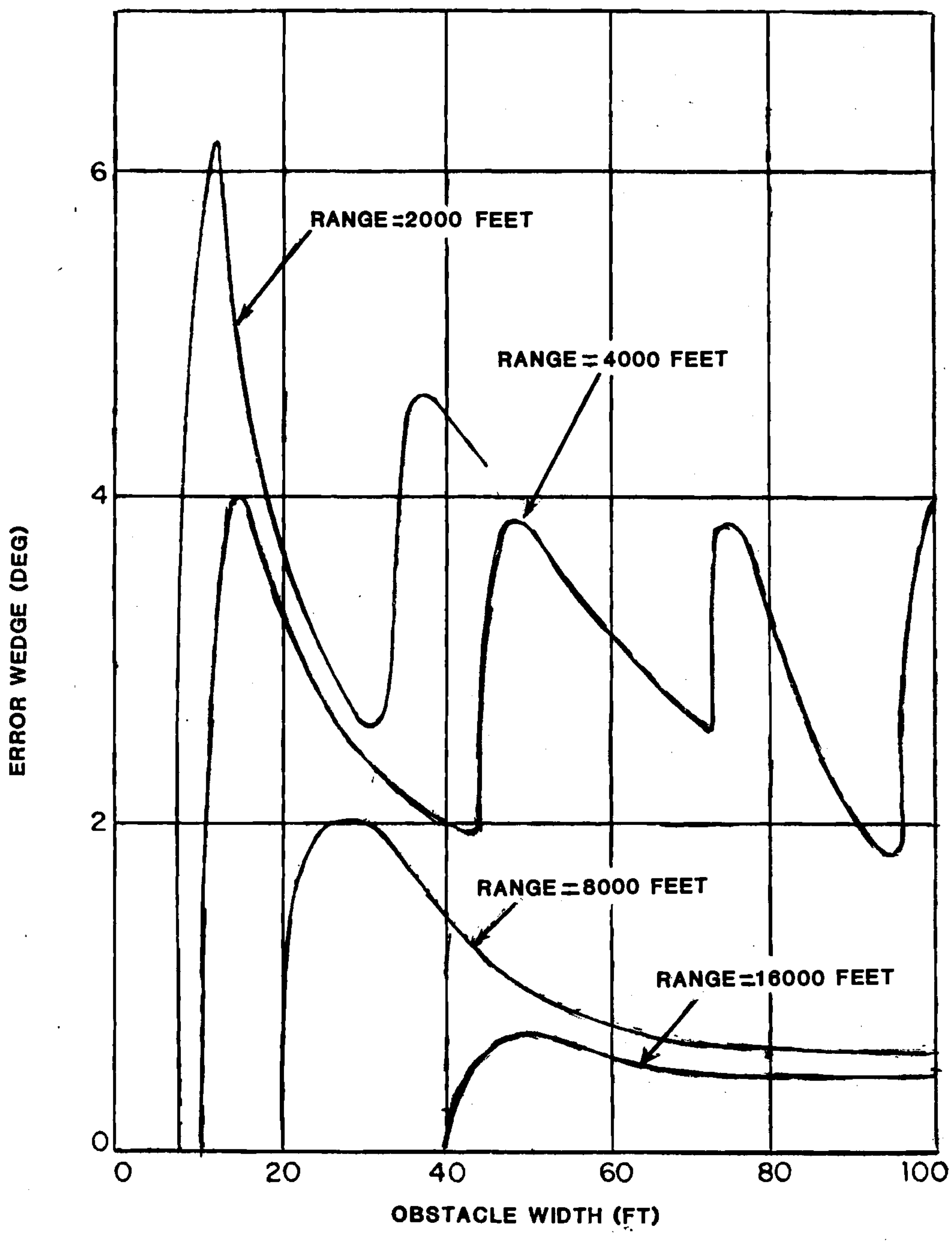


Fig. 9. Error Azimuth Extent vs. Obstacle Parameters: Range and Width.

f. An aircraft whose line-of-sight skims the top of the obstacle will experience a peak error one-half that of an aircraft well below the top. In most cases error influences disappear as the aircraft is elevated 0.5 degrees or more above the obstacle.

In order to ensure that the Mode S sensor will meet its surveillance requirements, any siting exercise involving a Mode S sensor should take into consideration the above influences on the accuracy of position estimation. The freedom of site selection in a terminal location is very often severely restricted particularly with respect to distances from obstructions. One viable option that seems to be available in a large number of urban locations is to elevate Mode S by siting either on top of a nearby hill or on one of the taller buildings. A high Mode S elevation, in addition to providing an improved position estimate for low aircraft, would eliminate many of the coverage problems that ordinarily force a sensor to be located on or close to the airport surface, i.e., unrestricted coverage of approaches, departures, navigational fixes, airways and surface traffic. Historically beacon sensor siting has been dictated in large part by the requirement to reduce the intensity and extent of ground clutter in a co-located surveillance radar. Minimizing the extent of ground clutter has generally imposed a limitation on the height of the antenna above the surrounding terrain.

The siting of the Philadelphia terminal Mode S engineering model at Clementon, NJ provides an example of the quality of performance obtainable from a high elevation site that has a clear horizon in all directions. Clementon is located 260 feet above and approximately 15 miles from Philadelphia International Airport. Comparative data was taken on controlled flight tests by the Transportable Measurements Facility[5] at the Clementon location and at Philadelphia airport. The data was then processed at Lincoln Laboratory to provide a measure of the monopulse error encountered at each site[6]. Figs. 10 and 11 show the monopulse error at each site as a function of azimuth and for six values of aircraft elevation angle. The monopulse accuracy at the Clementon site is seen to be uniformly good over all azimuths and all elevation angles tested. On the other hand, the Philadelphia airport site, which is surrounded by obstructions, is seen to exhibit substantial monopulse errors, particularly at the low elevation angles.

3.4 The Effect of Natural Terrain on Signal Fade and Azimuth Error

In the case of en route sensor locations obstacles which contribute to signal fades and azimuth estimation errors are predominantly major hills surrounding the en route site. Fading is the result of diffraction of the direct signal as it skirts the hilltop at low grazing angles. A succession of a line of hills orthogonal to the signal path causes multiple edge diffraction resulting in even deeper fades. The amount of fade loss possibly due to multiple edge diffraction is illustrated in Reference 3 in which the effect of a series of 4 spaced hilltops lying on a particular radial from the Mode S

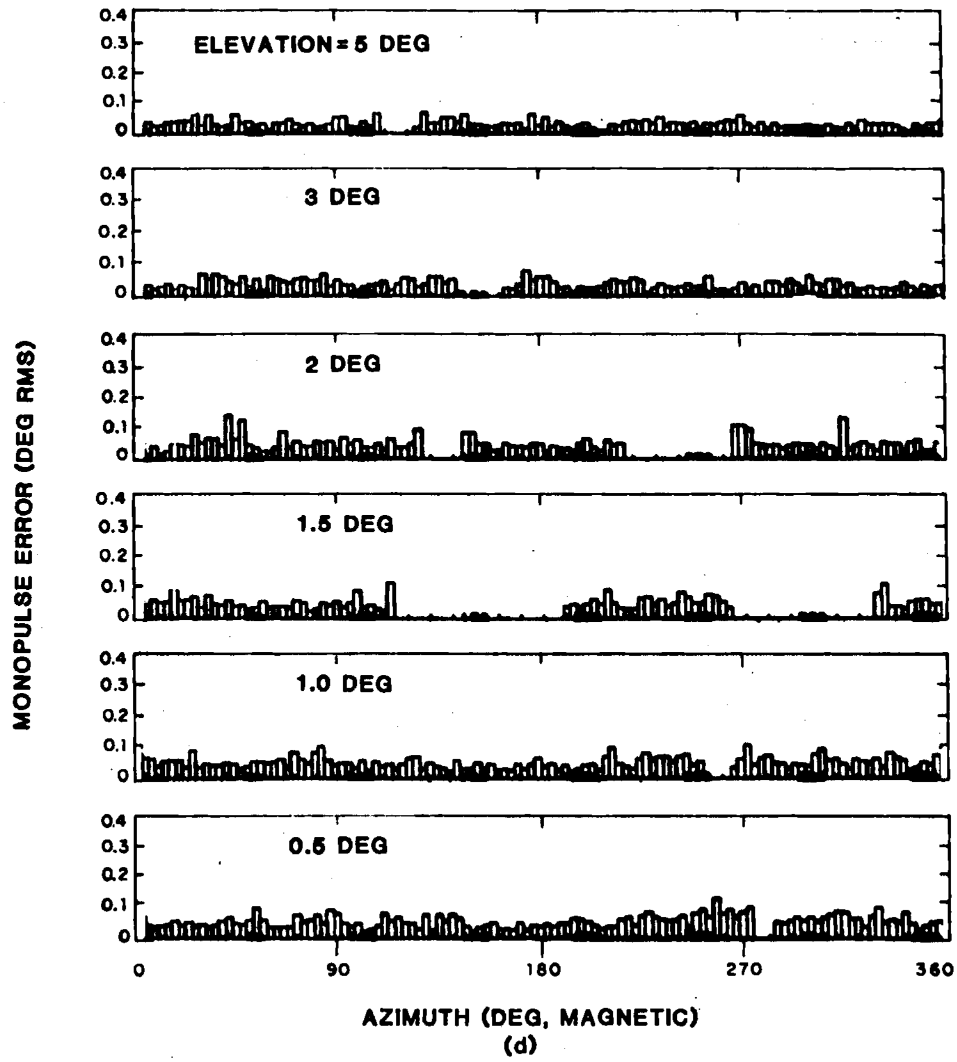
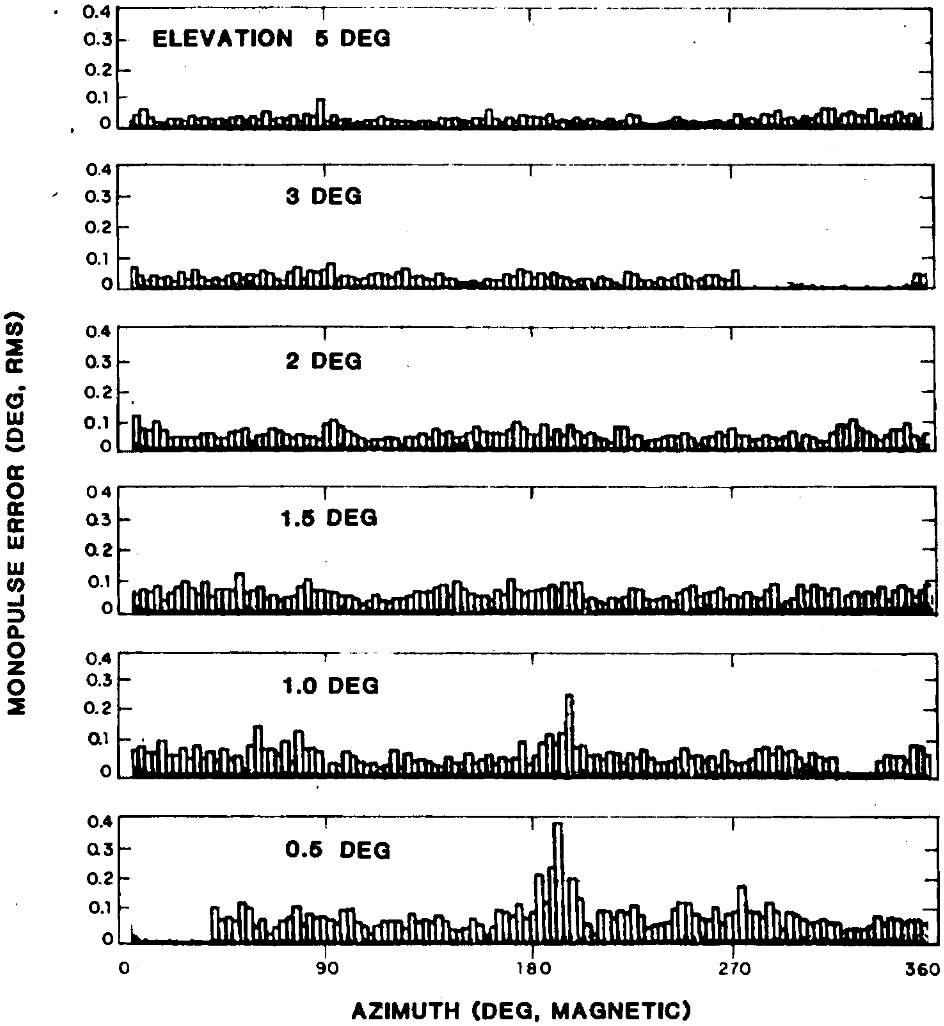


Fig. 10. Monopulse Error vs. Azimuth: Clementon, NJ



(b)

Fig. 11. Monopulse Error vs. Azimuth: Philadelphia Airport

experimental facility at Lexington, MA is evaluated. Fig. 12 is a comparison between the measured fade from flight tests along this radial (solid line) and a calculated maximum grazing fade using topographical data (dotted line). They show good agreement and indicate a fade of 20 dB at an elevation angle equal to the optical line-of-sight. Computed fade values for other groups of diffracting hills of various ranges and heights[3] verify that fading on the order of 20 dB at the optical line-of-sight is not uncommon in a hilly environment. Fig. 12 also shows the location of an effective RF line-of-sight (for this topography) above which fading is insignificant. Reference 3 offers a simple criteria for determining this angle which is defined by the following expression:

$$\text{Effective LOS Grazing Angle} = \text{Tan}^{-1} \left(\frac{1}{R} + \frac{h}{R} \right)$$

for h << R, and where R and h are the range and height of the most critical hill in a multiple hill environment (i.e., the hill determining the optical LOS).

In the fade investigations conducted for Reference 3, the effective LOS did not exceed 0.5 degrees for a variety of hill ranges and heights relative to the sensor. This implies that a proper siting of an en route Mode S sensor in a hilly region (on one of the higher hills for instance) would be sufficient to provide adequate low angle coverage to at least 0.5 degrees elevation.

The impact of hills on the Mode S sensor azimuth estimation is not as clear cut as the situation involving relatively simple and isolated structures such as buildings, smokestacks, etc. In general siting a Mode S sensor to reduce fading from hills (i.e., at a high elevation) will adequately minimize diffraction-induced azimuth errors as well.

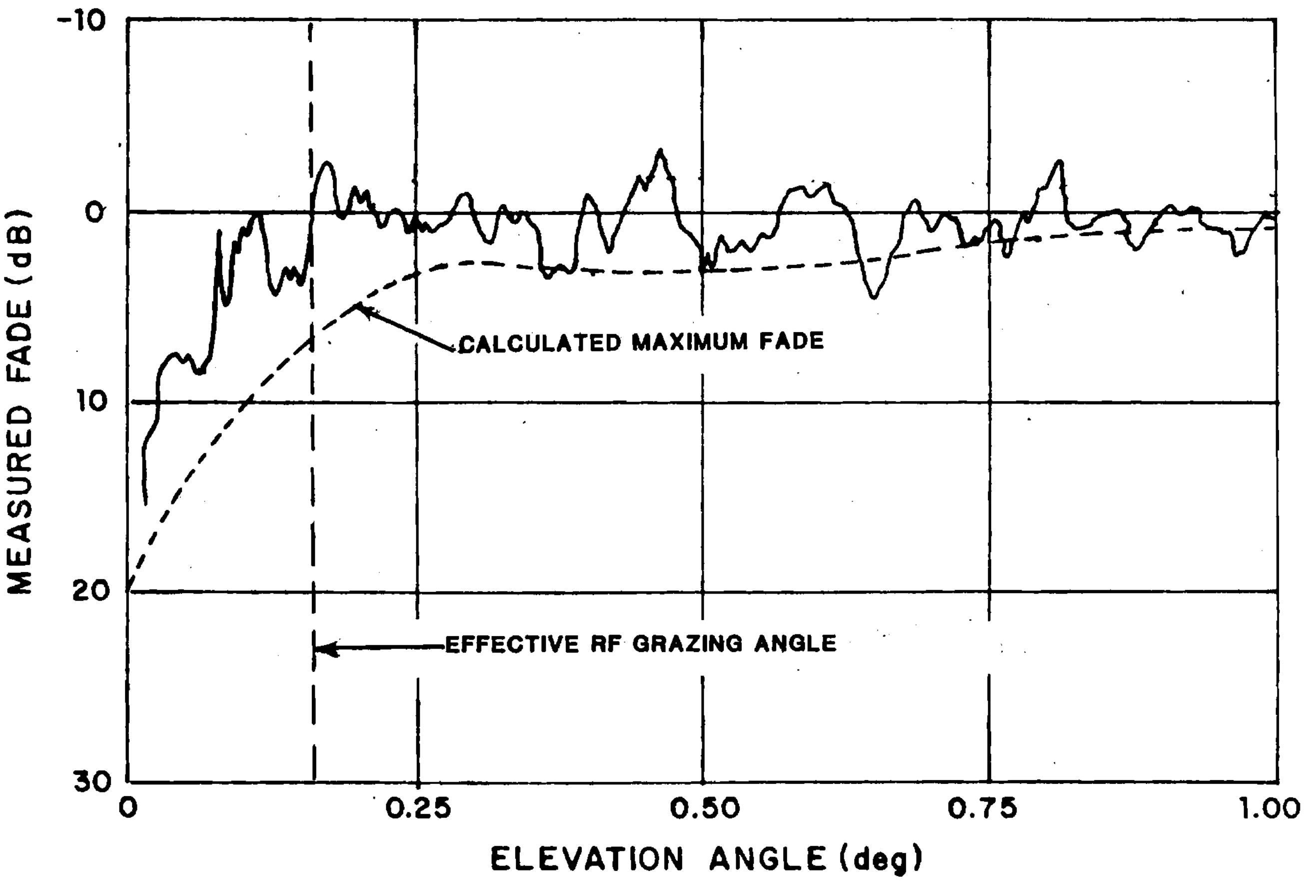


Fig. 12. Signal Fade Due to a Series of Four Hills as Measured from an Aircraft at 4300 Foot Altitude. Optical Line-of-Sight is at 0 Degrees Elevation.

4.0 VERTICAL LOBING

Flat surfaces surrounding the terminal or enroute sensor give rise to in-beam reflections which result in lobing nulls in the antenna elevation pattern and causing serious link fading in the direction of the resulting nulls. The current hogtrough antenna with its broad elevation pattern at horizon is particuarly susceptible to ground reflection and, in this regard, should be sited with extreme care. On the other hand the Mode S five foot open array has an improved lower edge cutoff that makes it less sensitive to the reflecting surface. Fig. 13, which illustrates the advantage of the open array in this regard, is a plot of the envelope of gain minima (lobing nulls) for each antenna as a function of elevation angle and for the following two extremes of surface condition; a flat grass surface of infinite extent which is relatively reflective (causing deep nulls) and, a smooth water surface of infinite extent which is relatively absorptive (causing shallow nulls). The remaining surface conditions found around most terminal and "flat" enroute sites generally fall somewhere between these two extremes. For the simplifying assumption of a flat surface of infinite extent the plots in Fig. 13 indicate that the open array has a 7 dB to 15 dB advantage in lobing minima with respect to the hogtrough antenna. Most airports however do not have surrounding flat surfaces of unlimited extent. A study[3] indicates that for a good fraction of the bearings around several large airports, flat earth extends to 5000 to 20000 feet. A limited reflecting surface produces diffraction that further modifies the effective gain of the antenna. The impact of this limited surface on lobing minima is generally favorable at elevation angles above 0.5 to 1 degree, i.e., the lobing nulls are not as deep, especially for antennas with underside cutoff. Below 0.5 to 1 degree elevation the effect of limited surface diffraction may in some instances produce lobing minima deeper than those associated with a reflecting surface of unlimited extent, particularly so for antennas with small or no underside cutoff. This further reinforces the advantage of the open array over the hogtrough antenna. Siting of the Mode S sensor at a high elevation in order to reduce obstacle shadowing and diffraction induced azimuth errors will also have a desirable advantage with regard to the lobing minima. Reference 3 points out that in a limited surface environment and for antenna heights above 50 to 80 ft., the minimum gain of the antenna will tend to increase (improve) as the antenna height is further increased. A hilly en route site or a terminal site with rough terrain or narrow small obstructions immediately surrounding the sensor will experience appreciable shadowing and scattering of the reflected field. At these locations vertical lobing should not be a significant factor in the coverage or performance of the sensor.

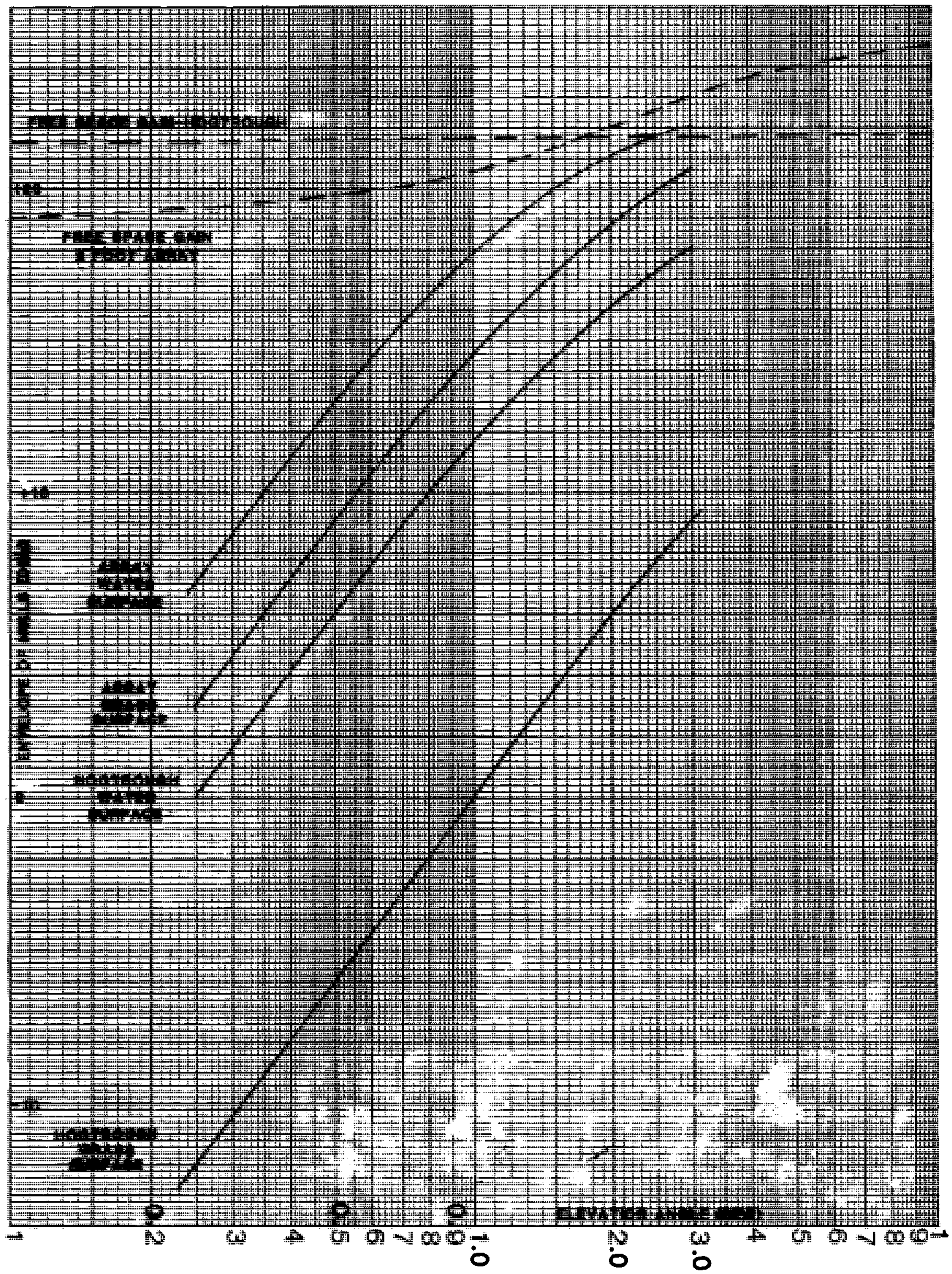


Fig. 13. Envelopes of 5 Foot Open Array and Hogtrough Antenna Lobing Nulls for Flat Grass and Water Surfaces of Infinite Extent.

5.0 FALSE TARGET REFLECTIONS

Specular in-beam reflections from man-made objects (buildings and fences) and inclined terrain (hillsides etc.) tend to produce false target reports which are often many degrees offset from the actual target position. In most terminal environments the predominant reflecting surfaces are man-made and generally oriented in a vertical plane. In such a situation the reported position of a false image can be many sectors removed from the real target and in the case of extended surfaces such as fences and long hangers can persist for many scans. For en route and terminal locations in hilly or mountainous regions, inclined terrain surfaces are an additional factor in producing false targets. For these situations the reported false position is very often close to or within a beamwidth of the actual target thus resulting in "beam splits".

The underside cutoff of the open array will mitigate to some extent the severity of false target generation particularly for reflectors close to or below horizon. Additionally a large number of the false targets can be processed out of the disseminated target reports by the Mode S processor. Even though the above factors will lessen the problem for Mode S sensors, terminal siting should continue to take into consideration reflective locations if only to reduce the false target processing load. In particular, sensor location should minimize the probability of reflections from aircraft in heavy and critical traffic areas such as approach, departure and airway routes. En route site locations (i.e., high elevations) that satisfy fading and azimuth error criteria would also reduce the probability of false target generation.

6.0 SUMMARY AND SITING RECOMMENDATION

Siting requirements for a Mode S sensor will generally coincide with the basic ATCRBS criteria presented in the FAA siting handbook. Most of the environmentally induced phenomena destructive to Mode S surveillance (i.e., diffraction errors, signal blockage, ground lobing and false target reflections) can be minimized or eliminated by positioning the Mode S sensor at an appropriate distance and/or height with respect to the perturbing influence. The following summarizes the particular environmental phenomena discussed in this paper and the generalized siting criteria associated with each.

a. Signal fade due to shadowing man-made obstructions:

   - o Locate the sensor at the appropriate distance. Signal fade is inversely related to sensor to obstruction range. A likely fade on the order of 6 dB will be caused by either a 200 foot wide building at 5 nm or a 100 foot wide building at 1.5 nm.

   - o Locate sensor at the appropriate height to prevent shadowing of low angle aircraft.

   - o Locate sensor to minimize shadowing of navigational intersectionsd, airways and heavy traffic areas.

b. Azimuth error due to diffracting man-made obstructions:

   - o Locate the sensor at the appropriate distance to confine azimuth errors to an acceptable level. For peak errors less than 0.25 degrees, the sensor should be at least 2000 feet from towers and smokestacks, 1 nm from control towers and 8 nm from wide buildings.

   - o Locate the sensor at the appropriate height to reduce diffraction of low angle aircraft. The peak error will be reduced by a factor of two for an aircraft whose line-of-sight grazes the top of the obstacle instead of being below it.

   - o Locate sensor to minimize the occurrence of traffic patterns behind obstacles.

c. Signal fade and azimuth error due to diffracting hills:

- o Locate the sensor as high as possible, preferably on one of the taller hills. Multiple diffraction can cause a 20 dB fade in signal at the horizon.

d. Vertical lobing from in-beam ground reflections:

- o The low angle cutoff of the Mode S sensor five foot open array antenna makes it less sensitive to ground reflections. Further improvement in lobing minima will generally occur for antenna heights greater than 50 to 80 feet above the reflecting surface. Locating the sensor such that a preponderance of the reflections occur over water or broken terrain will further reduce or eliminate lobing.

e. False targets:

- o A high elevation coupled with the antenna underside cutoff will tend to reduce the severity of false target reflections.

- o Locate the sensor to minimize false targets from aircraft in heavy traffic areas such as approach, departure and airway routes.

In problem areas such as heavily populated metropolitan terminal locations which are close to tall skylines and surrounded by various obstructions, an ideal solution would be to locate the sensor at an elevation comparable to the height of the tallest obstruction. Siting possibilities include the tops of the taller structures or an elevated terrain in the vicinity of the airport. The same solution is applicable to non-metropolitan terminal and en route locations in a hilly or a mountainous region. In this situation the sensor could be appropriately sited on one of the more prominent hills. It should be noted that any terminal siting exercise involving a potential location away from the airport should keep in mind the coverage requirements associated with low level approaches and departures as well as airport surface traffic.

In rural terminal and en route locations surrounded by relatively flat terrain the only solution to a diffraction and blockage problem (aside from perhaps a high antenna tower) is to locate the sensor either at an appropriate distance from the obstruction or at a bearing relative to the obstruction that minimizes shadowing of important intersections and airways.

Of the two variables (height and distance) it would appear that an elevated sensor height is more easily accomplished in a metropolitan or hilly location and would have the greater influence on reducing environmentally induced phenomena. In a flat rural region the only alternatives generally are distance and bearing to the obstructions.

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