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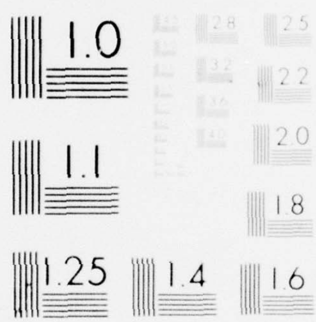

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PREDICTION OF AIRBORNE TARGET DETECTION

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The visibility of a uniformly luminous object depends on the apparent contrast between the object and its background, the angular subtense of the object, the contrast threshold of the observer at the level of luminance to which the eyes are adapted, the conditions and technique of observing and the shape of the object. Techniques for combining the influence of the various factors have been applied to the problem of predicting airborne target detectability. Recommendations for achieving the desired detectability are made.

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LIST OF ABBREVIATIONS

α = Visual Angle in Minutes of Arc

B_0 = Inherent Luminance of Background

B_R = Apparent Luminance of Background

B_S = Surface Illumination

B_T = Luminance of Object

C_0 = Inherent Contrast

C_R = Apparent Contrast

R = Object Distance

$\bar{R}$ = Optical Slant Range

T_R = Surface Reflectance

V = Meteorological Range

BACKGROUND

Targets which simulate aircraft are often used for training purposes. In some types of training, it is necessary that the simulated aircraft be detectable at the same distance that an aircraft would be detected. To design the desired detectability into a simulator, it is necessary to be able to predict airborne target detectability.

The visibility of a uniformly luminous object depends on the apparent contrast between the object and its background, the angular size of the object, the contrast threshold of the observer at the level of luminance to which the eyes are adapted, the conditions and techniques of observing, and the shape of the object. A number of studies of the visibility of distant objects have been made, and techniques for combining knowledge of the influence of the various factors have been developed to permit prediction of the visibility of distant objects. Those techniques have been applied to the problem of predicting the visibility of aircraft and aircraft simulators, and to the development of recommendations for achieving a desired level of visibility of a target.

PROBLEM DEFINITION

Both the apparent contrast and the angular size of an object depend on the distance between the object and the observer. However, the laws which govern the variations in apparent contrast and angular size differ. At a distance R yd, a circular object of area A square ft, subtends an angle, α, minutes of arc given by:

$$\alpha = 1293\ A\ 1/2\ R \text{ minutes of arc} \qquad (1)^{1}$$

The apparent contrast, C_R, of an object at a distance R, has been shown to be related to its inherent contrast, C_0, by the function

$$C_R = (B_0/B_R)\ C_0 e^{-3.912\bar{R}/v} \qquad (2)^{2}$$

when B_0 is the inherent luminance of the background, B_R is the apparent luminance of the background, $\bar{R}$ is the optical slant range and v is the meteorological range. The meteorological range is defined as the distance at which the contrast transmittance of the atmosphere is two percent. The inherent contrast is defined as:

$$C_0 = B_T - B_0/B_0 \qquad (3)$$

where B_T is the luminance of the object.

The contrast threshold of an observer has been shown by Blackwell[3] to depend simultaneously on α and C_R. Calculation of the sighting range of an object requires a series of successive approximations. To avoid the successive approximation method, Duntley and others have devised a nomographic method of predicting sighting range which takes into account the simultaneous operation of α and C_R[1]. If the inherent contrast and size of an object, the meteorological range, and the background brightness are known, the sighting distance can be determined from the nomograph. For example, assume that an object of an area of 20 square ft and a luminance of 10 ft lamberts is viewed on a day when the meteorological range is 20,000 yd against a full daylight sky of 1000 ft lamberts. The inherent contrast of the object is:

$$C_0 = 10\text{-}1000/1000 = -0.99$$

If we go then, to figure 2 and place a straight edge between 0.99 on the contrast scale and 20,000 on the meteorological scale, the left most curve which is the curve for a 1000 ft lambert sky brightness is intersected at a point which corresponds to 6000 yd on the sighting range scale. The nomograph is constructed from the data relating sighting range to background luminance, target luminance, target size, and atmospheric contrast reduction.[1]

The inherent contrast of an object is determined by equation (3). The luminance of the object (B_T) can be approximated from the reflectance of the object and the illuminating source by:

$$B_T = B_S T_R \qquad (4)$$

where B_S is the illumination falling on a surface and T_R is the reflectance of the surface. If B_S is expressed in ft candles, B_T is ft lamberts. The luminance of the sky has been measured at various places by different methods. An approximation of sky brightness at different times of day is shown in table I.

Figures 1 through 6 have been developed from the nomographs reported by Duntley[1] for application to the specific case of predicting the detectability of aircraft and aircraft simulators.

Several assumptions have been made in developing the following solution and recommendations. The first set of assumptions are that the aircraft simulator is the AQM-37B target, that it is painted aircraft orange and that it has the dimensions shown in figure 7. The second set of assumptions are that the aircraft under consideration are painted "aircraft white", that they are the MIG-25 and the MIG-21 and that the dimensions are as shown in table II.[4]

The measured reflectances of samples of international orange and aircraft white and aircraft grey are shown in table III.

The third set of assumptions deals with the geometry of the observation environment and the sample illuminations. The observer is assumed to be on the ground, the target, either aircraft or AQM-37B, is assumed to be airborne and at a distance such that it is seen slightly above the horizon sky, and that it is illuminated by either direct sunlight or sky light. In full daylight, the illumination is direct sunlight. In each of the other conditions shown in table I, the illumination is sky light.

The estimated vehicle illumination provided by the sun when the sky brightness is 1000 ft lamberts is 8300 ft candles.[5] The other vehicle illuminations shown in table I are estimated values based on surface illumination when the sky brightness is as shown. Illumination, E, by an infinite source such as the sky is expressed as:

$$E = B \qquad (5)$$

TABLE I

SKY BRIGHTNESS

Time of Day	Sky Brightness (Ft Lamberts)	Vehicle Illumination (Ft Candles)
Full Daylight	1000	8300[5]
Overcast Day	100	100
Dark Day	10	10
Twilight	1	1
Deep Twilight	10^{-1}	
Full Moon	10^{-2}	
Quarter Moon	10^{-3}	
Starlight	10^{-4}	
Overcast Starlight	10^{-5}	

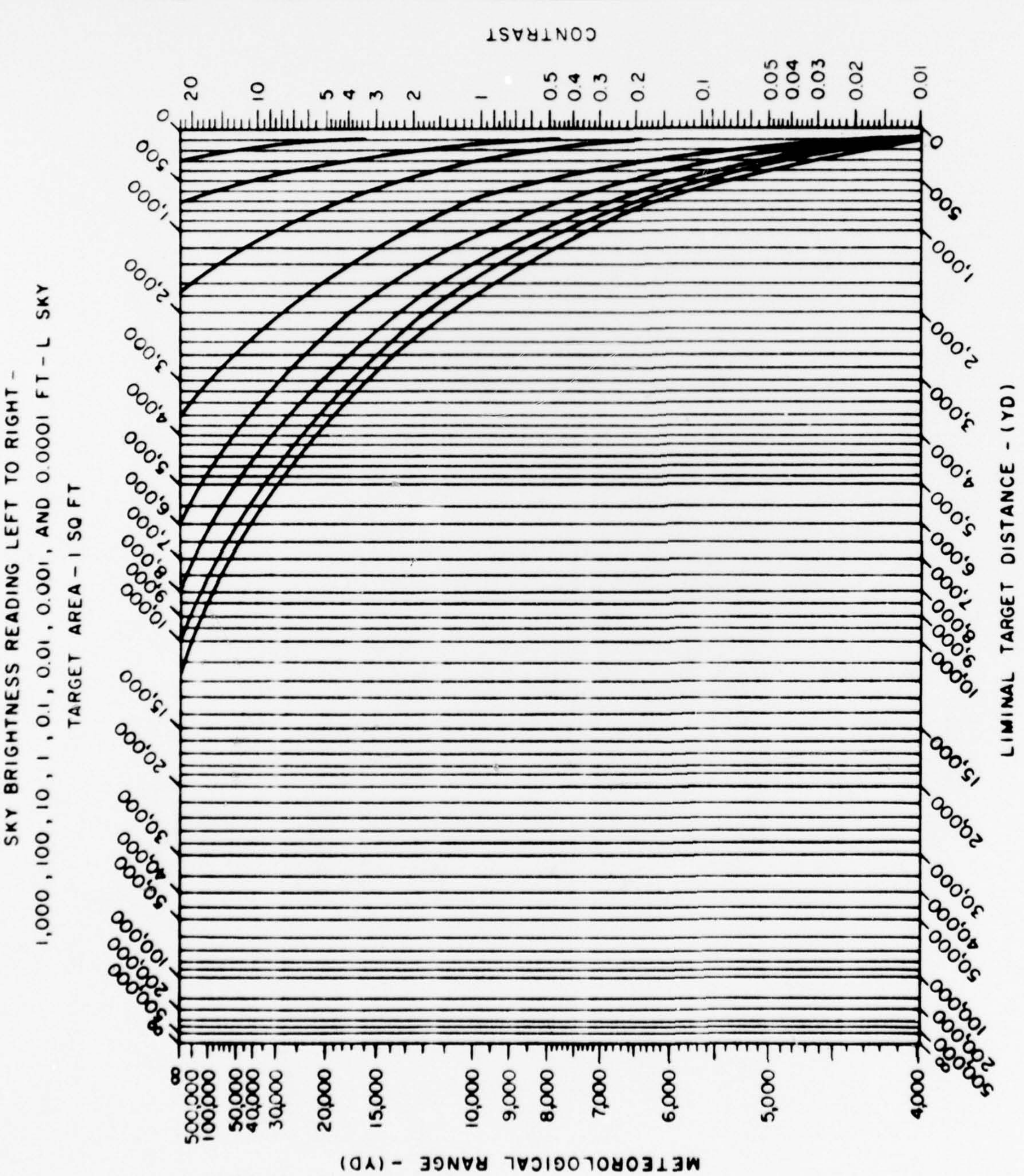

FIGURE 1 - Target Detection Distance; Target Area 1 Sq Ft.

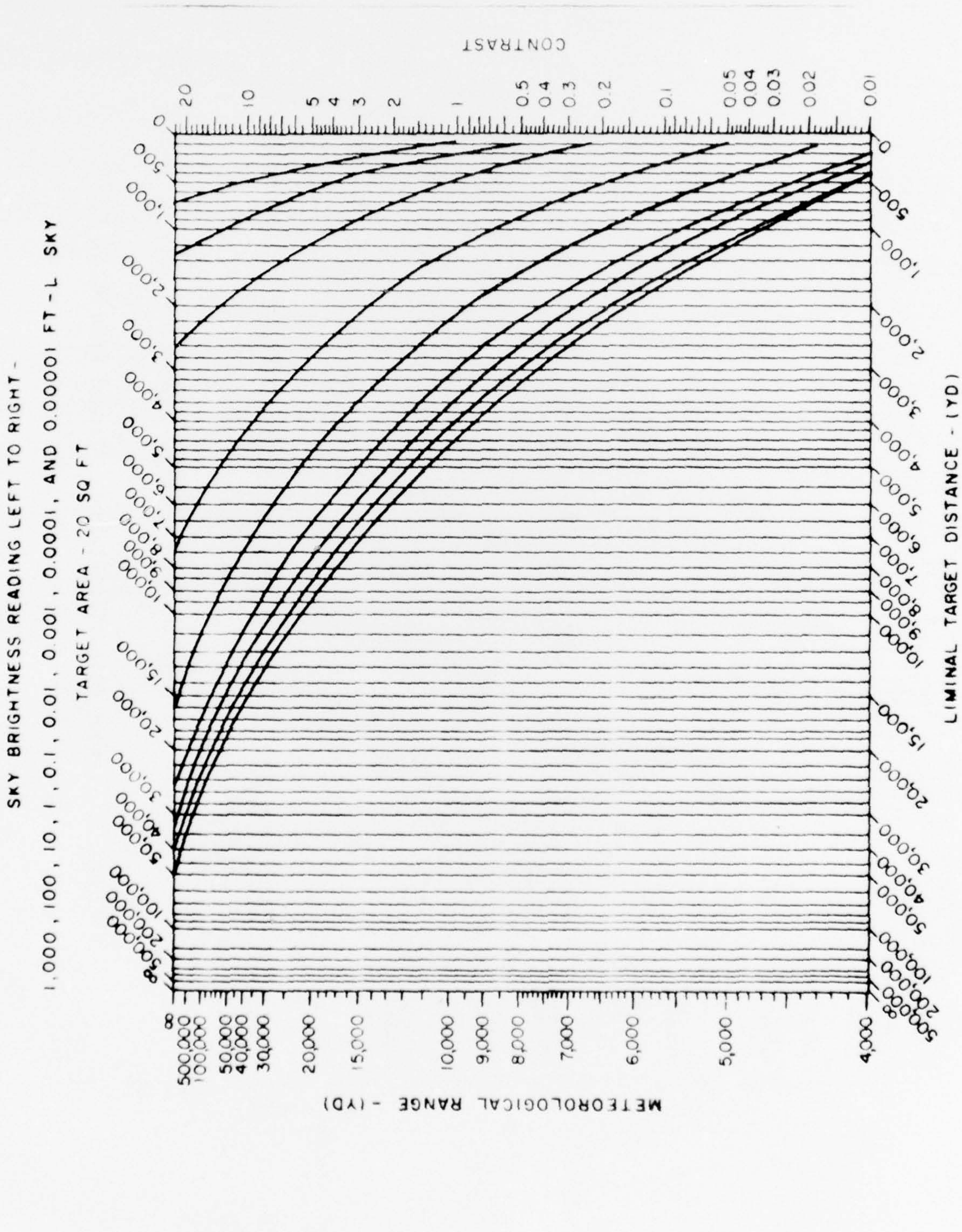

FIGURE 2 - Target Detection Distance; Target Area 20 Sq Ft.

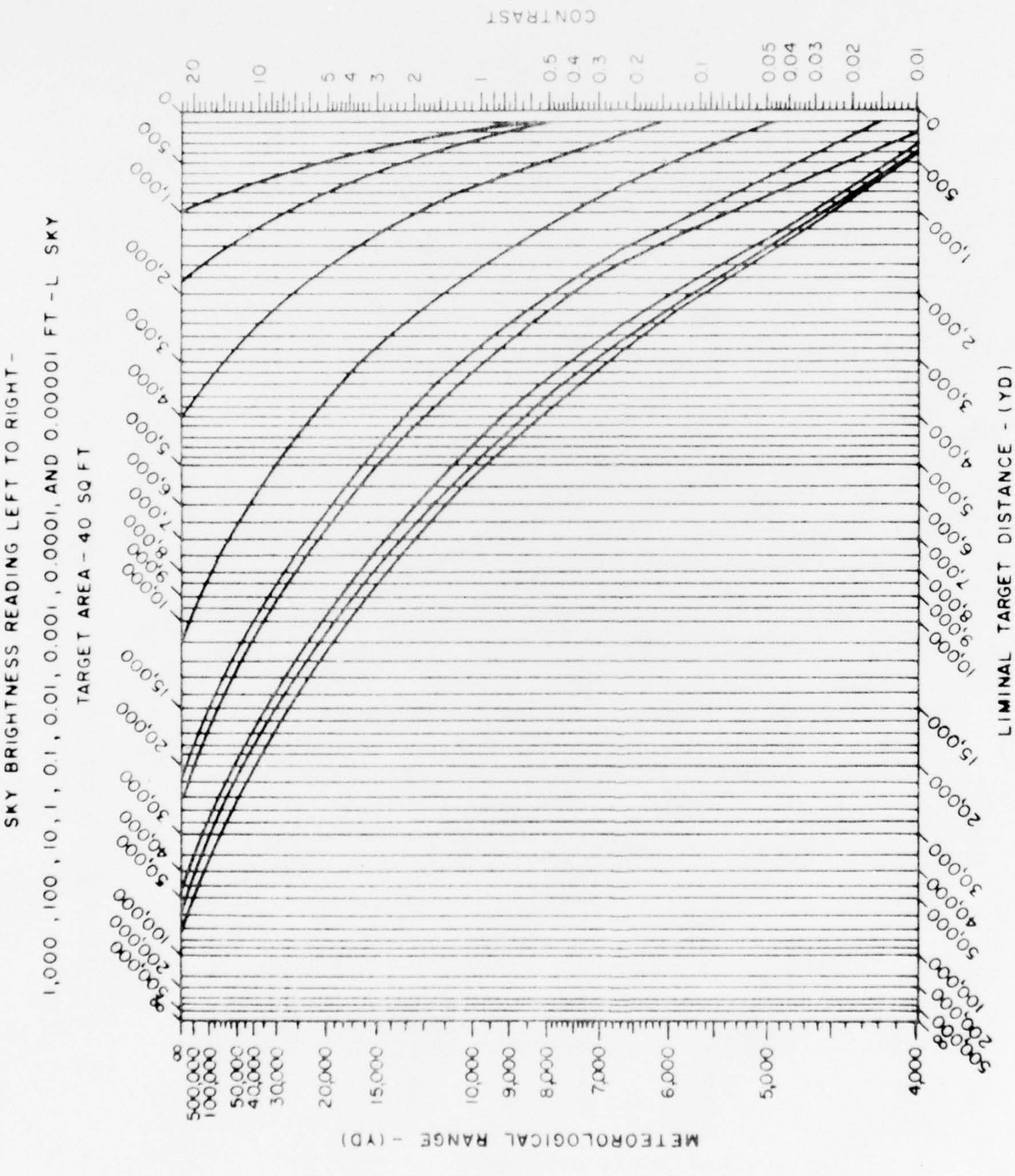

FIGURE 3 - Target Detection Distance; Target Area 40 Sq Ft.

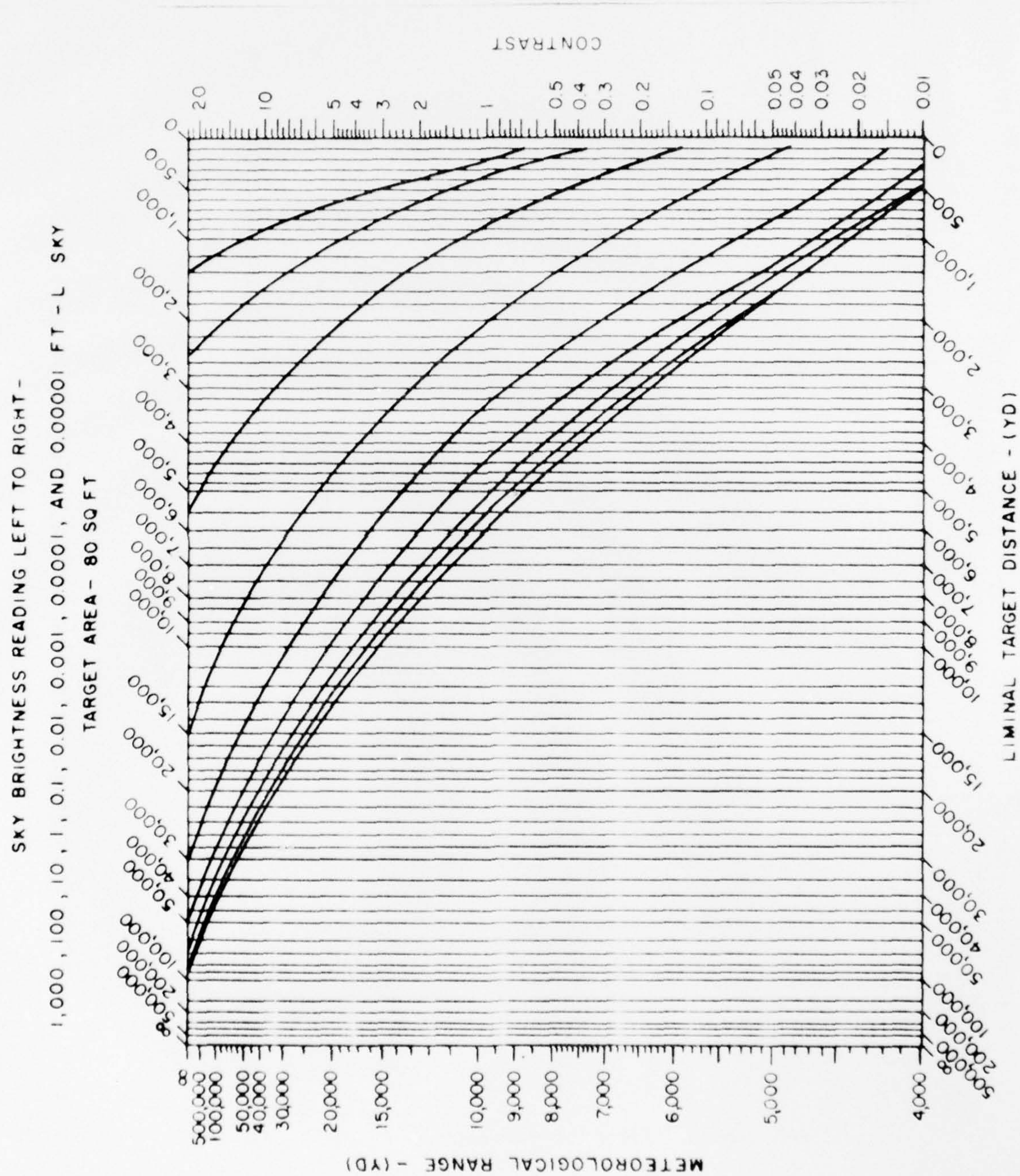

FIGURE 4 - Target Detection Distance; Target Area 80 Sq Ft.

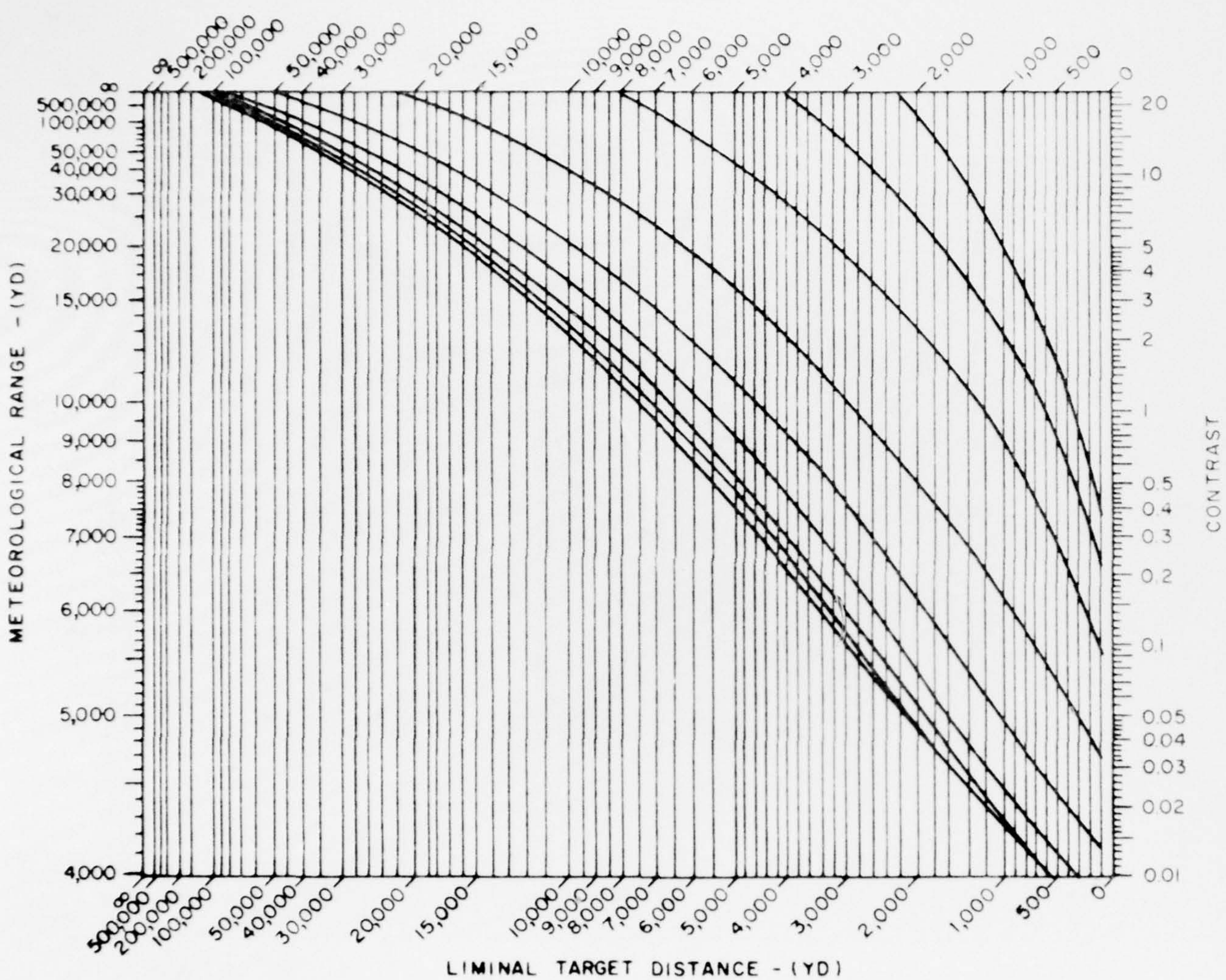

FIGURE 5 - Target Detection Distance; Target Area 200 Sq Ft.

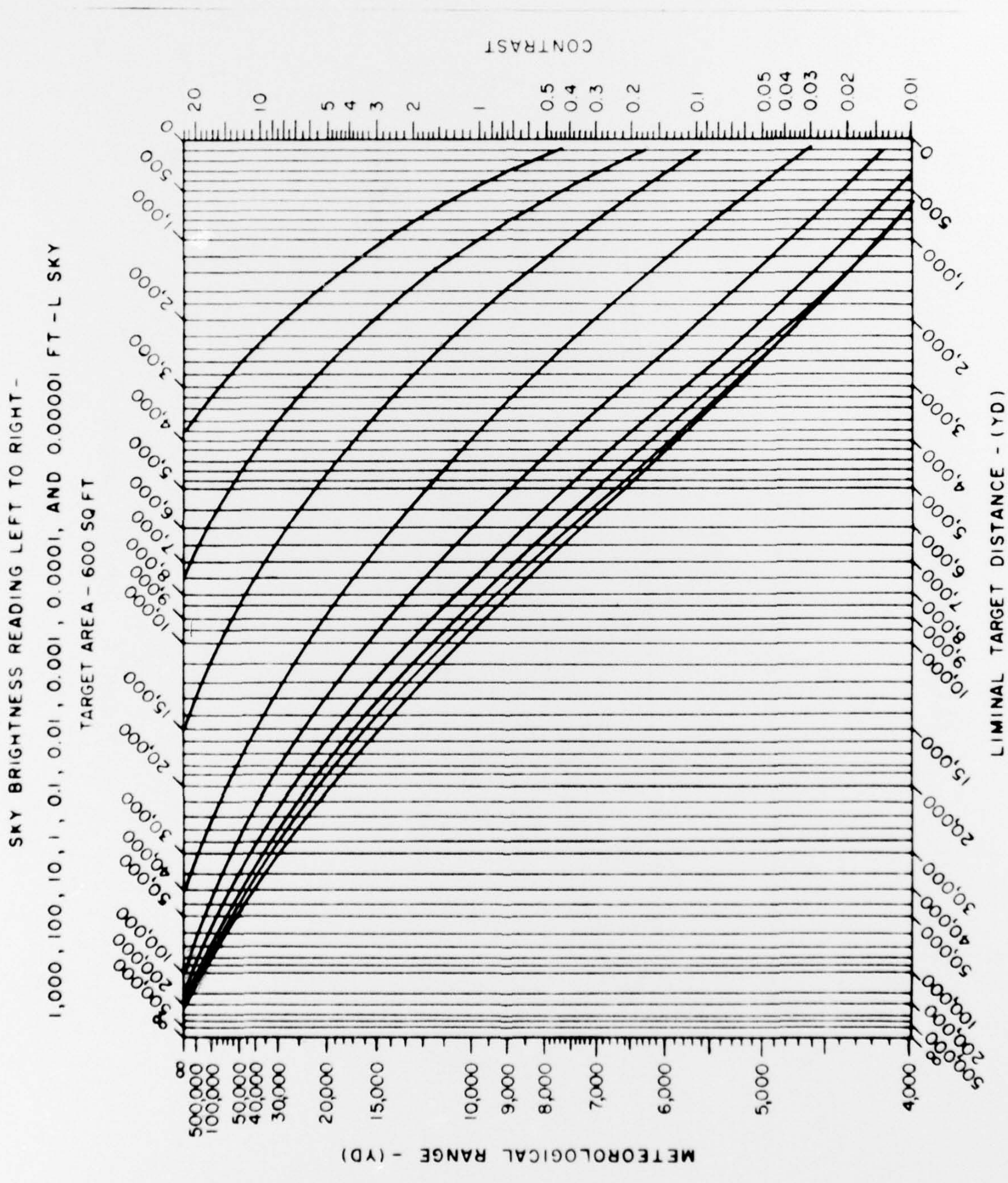

FIGURE 6 - Target Detection Distance; Target Area 600 Sq Ft.

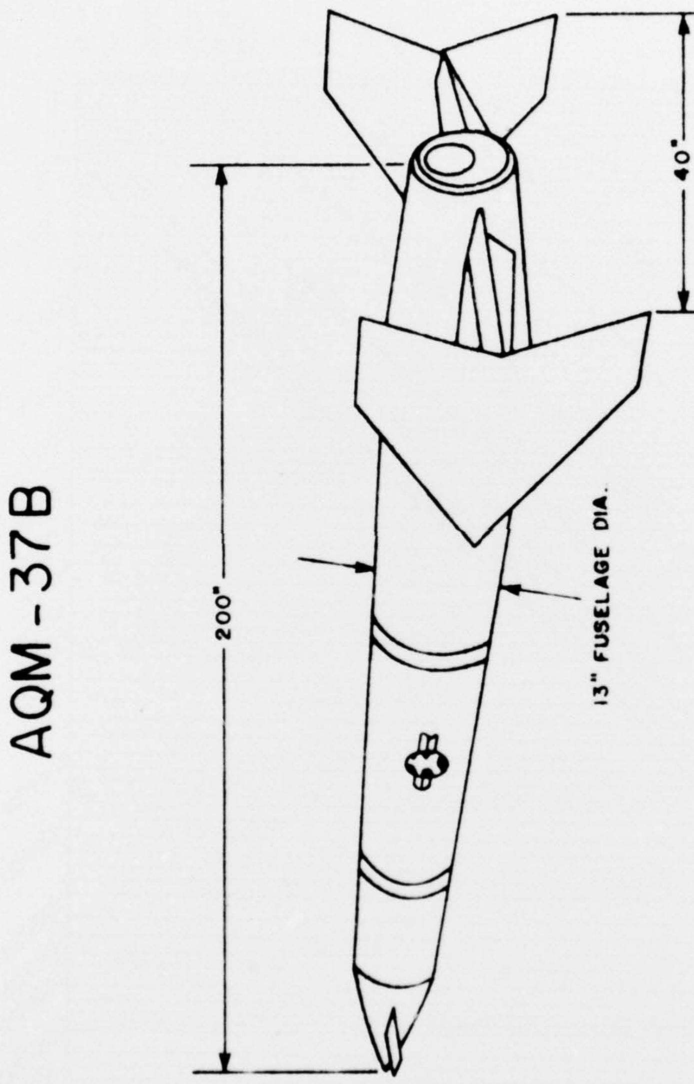

FIGURE 7 - AQM-37B Target.

TABLE II

VEHICLE DIMENSIONS

Vehicle	Dimensions (Ft)	
	Fuselage Diameter	Fuselage Length
MIG-25	10	69
MIG-21	7	44
AQM-37B	1.08	16.67

(MIG-25 wing span 40 ft; average wing width 12 ft)

TABLE III

MEASURED SURFACE REFLECTANCE

Surface	Reflectance (400-700 nm)
Aircraft Orange (New Paint)	0.34
Aircraft White (New Paint)	0.87
Aircraft White (Old Paint)	0.83
Aircraft Grey (New Paint)	0.45

where B is the source luminance. If E is expressed in ft candles, B is in ft lamberts.[5] The illuminations for conditions less than twilight are negligible, and will be discussed later.

SOLUTIONS

Table IV shows the calculated target areas, contrasts and detection distances for the three vehicles being evaluated at two meteorological ranges. The contrast values for the AQM-37B include an enhancement factor of 1.5 to allow for the color contrast effects in enhancing the target. The problem of color contrast in the detection of distant targets is still being evaluated and the enhancement factor used here may require adjustment. The value used is conservative.

In using the nomograms, the scales of meteorological range and liminal target distance may be multiplied by any factor to evaluate conditions not shown in the figures. The value assigned to the target area must be multiplied by the square of the factor. Conversely, the target area may be multiplied by any factor to evaluate targets of areas other than those shown. In that case, the meteorological range and liminal target distance scales must be multiplied by the square root of the factor.[1] The discrepancies between areas shown and actual target areas are small in columns 1, 2, 3 and 5 of table IV, and no area adjustments have been made. In columns 4 and 6 area adjustments were made in using the nomographs to provide more accurate distance estimates. As seen in table IV, the predicted detection distances for the AQM-37B target in both the head-on and side aspects are considerably shorter than those for either of the aircraft. The nomograms were then used to determine the contrast required to provide detection distances for the AQM-37B comparable to the aircraft detection distances. A straight edge was placed at 20,000 yd on the meteorlogical range scale and pivoted until the appropriate curve was intersected at the desired distance. The contrast was then read from the contrast scale. The values obtained are shown in table V. Two things must be noted in table V. The first, that no contrast values are shown for the full daylight condition. The reason for that is that the maximum distance at which a target of the size of the AQM-37B can be seen in a 20,000 yd meteorological range atmosphere is less than the detection distance for the aircraft regardless of the contrast value. The second thing to be noted is that a positive contrast value indicates that the object is brighter than the background while a negative value indicates that the object is duller than the background. The greatest negative contrast value is -1.0. The positive values are not limited. In the other light conditions the contrast values indicated to enhance the detectability of the AQM-37B are from +2.8 to +8.5. To achieve a positive value of 8.5 as indicated for a dark day, a light of 95 ft lamberts brightness would be required. To achieve a +8.0 contrast on an overcast day, a light of 900 ft lamberts would be required. The light intensitities required to achieve the indicated contrasts are shown in table VI. The detection distances with the light sources shown in table VI were those estimated from the nomogram for the 1 sq ft target size for the four daylight conditions. The results of those estimations are shown in table VII for the 20,000 yd meteorological range and in table VIII for the 5000 yd meteorological range. It is interesting to note in tables VII and VIII that the light sources rather than enhancing the detection distance in full daylight, actually interfere with detection. The detection both with and without the light source in full daylight is based, among other things, on

TABLE IV

VEHICLE DETECTION DISTANCES

	Target, Attitude, Area - Sq Ft					
	AQM-37B		MIG-25*		MIG-21*	
	Head-on	Side View	Head-on	Side View	Head-on	Side View
	0.92	18.004	78.50	690.00	38.47	308.00
Daylight						
Contrast**	+2.733	+2.733	+6.221	+6.221	+6.221	+6.221
1-Detection Dist. (yd)	3000	8000	14000	23540	12000	22338
2-Detection Dist. (yd)	1800	3800	5500	7700	5000	7600
Overcast Day						
Contrast**	-0.990	-0.990	-0.130	-0.130	-0.130	-0.130
1-Detection Dist. (yd)	1800	5250	4100	8292	3200	7446
2-Detection Dist. (yd)	1200	2850	2300	3600	1900	3400
Dark Day						
Contrast**	-0.990	-0.990	-0.130	-0.130	-0.130	-0.130
1-Detection Dist. (yd)	1450	4600	3600	7490	2800	6577
2-Detection Dist. (yd)	1025	2550	2150	3400	1750	3100
Twilight						
Contrast**	-0.990	-0.990	-0.130	-0.130	-0.130	-0.130
1-Detection Dist. (yd)	1050	3800	2800	6152	1800	5460
2-Detection Dist. (yd)	850	2150	1900	2900	1150	2700

*New Paint
**Color Enhancement Factor 1.5 (estimated)
1-Meteorological Range = 20,000 yd
2-Meteorological Range = 5,000 yd

TABLE V

CONTRAST REQUIRED TO MAKE AQM-37B DETECTION EQUAL TO AIRCRAFT DETECTION

(Greatest Contrast Required for 20,000 yd Meteorological Range)

	MIG-25		MIG-21	
	Head-on	Side View	Head-on	Side View
Daylight	---	---	---	---
Overcast Day	+8.0	+4.2	+4.0	+2.8
Dark Day	+8.5	+4.2	+4.5	+2.8
Twilight	+8.5	+4.2	+3.0	+2.8

TABLE VI

LIGHT INTENSITIES (FT LAMBERTS) REQUIRED TO ACHIEVE INDICATED CONTRASTS

Condition	Contrast						
	8.0	8.5	4.5	4.2	4.0	3.0	2.8
Overcast Day	900	950	550	520	500	400	380
Dark Day	90	95	55	52	50	40	38
Twilight	9	9.5	5.5	5.2	5.0	4.0	3.8

TABLE VII

AQM-37B DETECTION DISTANCES (YD) FOR VARIOUS LIGHT SOURCE ENHANCERS (HEAD-ON)

(Meteorological Range - 20,000 yd)

Light Source (ft L)	Day Condition			
	Full Daylight**	Overcast	Dark Day	Twilight
950	425	4200	>10000	>10000
900	620	4000	"	"
550	1300	3800	"	"
520	1400	3200	"	"
500	>1400	3100	"	"
400	1550	2800	"	"
380	1600	2700	"	"
95	1900	350*	3600	"
90	1900	600*	3500	"
55	>1900	1100*	2800	"
52	"	1100*	2700	"
50	"	1130*	2600	"
40	"	1200*	2400	"
38	"	>1200*	2300	"
9.5	"	1700*	400*	2800
9.0	"	>1700*	500*	2700
5.5	"	>1700*	1000*	2100
5.2	"	>1700*	1000*	2050
5.0	"	1750*	>1000*	2000
4.0	"	>1750*	1100*	>1800
3.8	"	1800*	1200*	1800

*Negative Contrast

**No sun reflection included. All negative contrast.

TABLE VIII

AQM-37B DETECTION DISTANCES (YD) FOR VARIOUS LIGHT SOURCE ENHANCERS (HEAD-ON)

(Meteorological Range - 5,000 yd)

Light Source (ft L)	Day Condition			
	Full Daylight	Overcast	Dark Day	Twilight
950	400	2400	>5000	>5000
900	550	2350	"	"
550	1000	2000	"	"
520	1020	1975	"	"
500	1040	1960	"	"
400	1080	1800	"	"
380	1090	1775	"	"
95	1150	350*	2200	"
90	>1150	500*	2100	"
55	1175	900*	1800	"
52	>1175	>950*	1750	"
50	>1175	975*	>1700	"
40	1185	1020*	1600	"
38	1190	1030*	1550	"
9.5	1195	1100*	300*	1800
9.0	>1195	>1100*	400*	1750
5.5	"	1110*	800*	1450
5.2	"	>1110*	>800*	1410
5.0	"	>1110*	820*	1400
4.0	"	"	880*	1300
3.8	"	"	900*	1250

*Negative Contrast

negative contrast. The light source reduces the negative contrast, and thus, rather than enhancing the detectability of the target, reduces it. The same situation is true of the other day conditions also. The light sources enhance detection if the contrast is positive. From the point at which the contrast becomes negative, the light source reduces detectability.

The results in table VII suggest that a light source of 950 ft lamberts will provide detectability equal to or greater than that of an aircraft in all but the full daylight condition on a clear day. On a less clear day, 5000 yd meteorological range, the enhancement provides detectability equal to or better than the head-on aspect of the aircraft, and slightly poorer than the side aspect of the aircraft. A different solution is required for the daylight condition.

ALTERNATIVES FOR DAYLIGHT DETECTABILITY ENHANCEMENT

The only options for enhancing daylight detectability which hold any promise of achieving the desired result involve placing an intense light source on the target in question. If a scheme could be worked out to take advantage of the natural conditions in adding light to the target, the desired result could be achieved without significantly increasing the size and weight of the target. One possible scheme for achieving that end is to make the front section, or nose, of the target a specular reflector or mirror. The sun reflecting off the sloped mirror then serves as the source which should render the target visible far beyond the point at which the actual size of the target is too small to be resolved.

The other alternative is to build an intense light into the target. A light source of between 200,000 and 300,000 ft lamberts, or candlepower, would accomplish the same effect as the specular reflector for daylight conditions. Determination of the adequacy of the alternatives required experimental evaluation.

LOW-LIGHT LEVEL DETECTION

To detect a target in ambient conditions which would produce sky brightness less than 1 ft lambert, it is necessary that the target be luminous. A light source adequate to render the target detectable in the conditions listed in table VI would make the target detectable at great distances. Even the 4.0 ft lambert source would be detectable at great distances under low ambient light conditions.

RECOMMENDATIONS

The preceding analyses indicate that a moderate light of proper design can achieve the desired target detectability. The bright daytime detectability is somewhat more questionable. If it is feasible to include a specular reflector in the design of the AQM-37B target, further evaluation of that alternative should be carried out. If the evaluation supports the preliminary assumptions, the detection enhancement scheme should include the specular reflector and a moderately intense light source of perhaps 100,000 to 500,000 candlepower.

The above recommendations are directed at enhancing target detectability. If enhanced target identification is required, a more complicated scheme is necessary.

The analyses reported in this paper represent an extension of the classical data to a specific, practical situation. The conclusions reached regarding the visibility of the specific targets should be evaluated in a field-type evaluation in which actual measurements are made to determine how accurately the detection distances have been predicted. The next logical step to follow the prediction validation would be to mock-up and assess the various alternatives for light enhancement of the target detectability. That assessment should include both an integral light assessment and the use of reflectors in several configurations to enhance target detectability.

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