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THE EFFECTS OF CHANGES IN FLARE INTENSITY ON THE RECOGNITION PROBABILITY OF VEHICULAR SIZE TARGETS

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The present specifications on minimum acceptable flare intensity are made without any quantitative information on how reductions in intensity influence an observer's ability to recognize targets. A study was conducted, using the Pyrotechnic Terrain Model, to examine the relationship between changes in the intensity of flares and target recognition. Four separate cases were examined having different illumination requirements for recognition. Using these data, three types of illumination flares at

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three ranges were evaluated to show the decrease in recognition and recognition areas with decreasing intensities.

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INTRODUCTION

Few successful field tests have been conducted in the past to determine the level and duration of illumination required from flares for the detection, recognition, and identification of standard military targets. Tests utilizing flares suspended by parachutes as a source of illumination had many serious disadvantages such as flicker, nonreproducibility of light levels, movement of the flare during burning, smoke, and unpredictable flight paths caused by wind changes. As a result it is virtually impossible to reproduce any set of conditions in order to examine the effect on performance of a change in one parameter, and the data gained from such tests provide little quantified information and are consequently of little value. Furthermore, since the actual flares used are generally of a multimillion-candlepower type, electrical sources which can be utilized to simulate the characteristics of a flare are completely impractical.

To overcome these problems, to provide valid statistical data for use in the field, and to eliminate expensive field tests, a model terrain program was initiated. The model terrain presently being utilized is a Southeast Asian type scaled at 160:1. The system can simulate exactly all the known parameters in a flare including flicker, spectral distribution, wind drift, oscillations, etc. As a result, it is possible for the first time to investigate the effect of each parameter of flare illumination in an area of interest with a quantitative and statistically sound procedure.

The pyrotechnic illumination model, the basic vehicle which is used in this program, has been used successfully in programs determining the illumination levels required for recognizing a variety of military targets under various conditions. The following reports on these studies have been published:

Picatinny Arsenal Technical Report (PATR) 4075, "Pyrotechnic Terrain Model, A New Dimension in Pyrotechnic Evaluation, Description and Initial Results," December 1970, by Jesse F. Tyroler.

PATR 4184, "Results of an Illumination Requirement Study Using a Pyrotechnic Terrain Model," November 1971, by Robert B. Davis.

TESTS

Procedures

The observers used for these tests were U.S. Army personnel having normal vision, either natural or corrected. They were given an orientation on the terrain model, the targets to be recognized, the method of target presentation, and the type of responses desired such as, "Large truck, side", or "Jeep, front". Subsequently they were "dark-adapted" for at least 30 minutes and positioned at the proper distance. The simulated flare was positioned in the desired orientation with respect to the observer and targets. The level of illumination was fixed, and the observer responded to the vehicular-size targets presented. After completing a series of observations, the illumination level was lowered approximately 20% and the same procedure followed until the illumination level was insufficient and recognition was no longer possible.

The illumination was measured with a Weston Model 1979 Illumination Meter which was modified for greater sensitivity. The illumination levels reported are given in terms of the footcandles on a surface at the target perpendicular to the source.

Four tests were conducted to determine the probability of recognition of military, vehicular-size targets. The specific conditions of these tests were:

1. Target illumination angle, 90°; simulated range, 660 m (2000 ft); background, dark-green, grassy area; observations from ground level.

2. Target illumination angle, 124°; simulated range, 490 m (1500 ft); background, medium-green, grassy area; observations from ground level.

3. Target illumination angle, 70°; simulated range, 1150 m (3500 ft); background, dark-green, grassy area; observations from ground level.

4. Target illumination angle, 110°; simulated range, 980 m (3000 ft); background, medium-green, grassy area; observations from ground level.

These four conditions were selected to ensure a distinctly different illumin-tion-level requirement in all cases and also because they were easily accessible positions on the terrain model. A total of 14 observers were used for these tests. They performed more than 16,500 separate observations in compiling the data. The resulting curves of Percent Recognition versus Illumination Level are shown in Figures 1, 2, 3, and 4.

Discussion of Results

It can be seen that in these four distinctly different cases all the curves exhibit a characteristic behavior, i.e., as the illumination level is increased, recognition increases rapidly until a plateau is finally reached at approximately the 90-95% recognition level where further increases in illumination have little or no effect on increasing recognition. This point on the recognition vs illumination level curve in this report will be referred to as the "critical illumination level" and, of course, is a different illumination level for each case.

If these four curves are normalized and plotted with Percent Recognition as the ordinate and Fraction of Critical Illumination as the abscissa, Figure 5 is obtained. It can be seen that all four normalized curves are very similar. The average of these four curves is plotted in Figure 6 and can be represented by the function

$$P = 1.25e^{-\frac{0.42}{F}} + 0.031$$

where P is the probability of recognition and F is the fraction of critical illumination at the target. This average curve is very significant and can be very useful for estimating some effects of variation in flare intensity on actual performance. For example, assume that Figure 6 approximates the percent recognition as a function of the fraction of critical illumination independent of the critical illumination level and the relative positions of target, observer, and flare (a reasonable assumption since it was true in the four distinctly different cases described). It can be concluded that if a target is illuminated by a flare from a fixed position relative to an observer and if the illumination level is above the critical illumination level, then changes in intensity in the flare (the illumination on the target being proportional to the intensity of the flare) will have little effect on the observer's ability to recognize the target. If the illumination is below the critical illumination level, changes in the probability of recognition will be roughly proportional to changes in intensity.

FLARE APPLICATIONS

There are three general categories into which the uses of illuminating flares fall and these can be useful in describing and defining specific figures of merit related to the effectiveness of each flare. They are:

Fixed Position

This situation would exist when a target is at a known location such as a bridge or bunker and that target must be illuminated to direct lethal fire or assess damage.

Specific Areas

In this situation an area must be illuminated to a level that if a target were present the observer would have a very high probability of recognition. This would be employed when securing an area against infiltration by enemy troops.

Search

This situation considers the probability of finding a target in a very large suspect area. This may arise when an aircraft searches for the location of enemy vehicles or positions.

FIGURES OF MERIT

In order to examine the effect of changes in intensity for each of these situations, it is necessary to specify both the flare type and the range of the observer from the target. An approach can be used similar to the one taken by Dr. M. Messinger in his notes on "The Time Fuze Accuracy Requirements for Illuminating Mortar Projectiles," dated April 1972, to determine a figure of merit for each flare application.

It has been shown in PATR 4184 that the illumination required for a 90% probability of recognition is a function of the relative angle of the observer, flare, and target as well as the range. Also, the illumination required for a 90% probability of recognition in a given target situation, R, is a function of the flare coordinates x_f, y_f, h; target coordinates x_t, y_t; and observer coordinates x_o, y_o so that

$$\underline{R} = R\ (x_f, y_f, h, x_t, y_t, x_o, y_o)\,.$$

Fixed position

In the case where it is necessary to illuminate a fixed position, if we assume that L is the actual target illumination and R is the critical illumination level, we define the step function u (L - R) such that u = 0.9 when $L \geq R$ and u = P when $L < R$, P being the probability of recognition as shown in Figure 6 and defined by the empirical equation

$$P = 1.25e^{-\frac{0.42}{F}} + 0.031$$

where F is the fraction of critical illumination at the target, $F = \frac{L}{R}$.
A figure of merit (E_f) relating to the effectiveness of a flare for the fixed position illumination case can be defined as

$$E_f = \int^{T} u\ (L - R)\ dt$$

where the integral is taken over the total burning time of the flare. By varying the intensity (I) in the illumination equation, (L), of the search case, one may compare the relative figures of merit for a given observer, target and source location and be able to analyze the effects of flare variations on effectiveness.

Specific Area

For the case where it is necessary to illuminate a specific area above the critical illumination level such as in anti-intrusion, perimeter defense, etc, we define the step function u (L - R) such that u = .9 when $L \geq R$ and u = 0 when $L < R$. A figure of merit for the area illumination case (E_a) can then be defined such that

$$E_a = \int^{T} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} u\ (L - R)\ dx\ dy\ dt$$

Search

In the case where a large area is to be searched for targets and only a small portion of the suspect area can be illuminated, we again define a function u (L - R) such that when $L \geq R$, u = 0.9 and when $L < R$, u = P where P is again the probability of recognition as shown in Figure 6.

The figure of merit, E_s, in this case can be considered to be the integral

$$E_s = \int^{T} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} u\ (L - R)\ dx\ dy\ dt$$

APPROXIMATE EFFECTS

Fixed Position

In this case, estimates of how changes in intensity of the flare affect recognition performance can be made fairly easily. If it is assumed that the position of the flare remains the same relative to the target, changes in the probability of recognition would be affected exactly as shown in Figure 6; that is, when the illumination is above the critical illumination level there would be little effect on the probability of recognition. When the illumination is below this level, it would correspond to the slope of this curve (Fig 6) which varies from 1/3 to 3/2. For most practical ranges, the illumination level would be below the critical illumination level and in these applications it can be roughly estimated that changes in the intensity would affect the performance proportionately.

Specific Area

In this report for a first approximation it will be assumed that the critical illumination level is dependent only on the range of the target from the observer, and the effect of changes in intensity for three illumination rounds at three ranges will be examined.

The following operational characteristics were used in this calculation for these three items:

Type of round	Candlepower (x 1000)	Ignition altitude (feet)	(meters)
60 mm mortar	320	600	200
81 mm mortar	500	1000	330
155 mm howitzer	1000	1800	590

PATR 4184 provides the approximate critical illumination levels as a function of range:

Range (feet)	(meters)	Illumination level, E_o (footcandles)
800	260	0.04
3000	980	0.40
5000	1640	1.00

The results are shown in Tables 1, 2, and 3. From these results it can be seen that for short ranges where the critical illumination level is low the change in area illuminated to the critical illumination level (approximately 90% probability of recognition) is roughly proportional to the change in intensity. As the range increases, the change in area becomes more sensitive to changes in flare intensity, as much as five times in the case of the 81 mm mortar. In addition as this sensitivity increases the flare becomes very ineffective for recognition purposes since it illuminates a smaller and smaller area to the critical value. For example, in the case of the 81 mm mortar flare at a range of 980 m (3000 ft), a 5% change in flare intensity results in a 25% change in the area effectively illuminated to the 90% probability of recognition. The area illuminated to the critical value for 90% recognition is only 7.85×10^5 square feet at the 980 m (3000 ft) range as compared to an area of 3.6×10^7 square feet illuminated to the critical level for the same flare at the 260 m (800 ft) range. It appears from these data then, that in the Specific Area case that percent changes in intensity influence the effectiveness at least proportionately and probably no more than double for practical ranges of the item.

Search

If the same rough assumptions are made as in the Specific Area Case and if the same operational calculations for the items are used, then the effect of changes in intensity on effectiveness is shown in Tables 4, 5, and 6. Again it appears from these data that in the Search Case changes in intensity influence the effectiveness at least proportionately and may generate changes in the effectiveness by as much as twice the percentage change in intensity.

CONCLUSIONS

Changes in recognition probability are roughly proportional to changes in intensity when the target is in a fixed, known position and the illumination is at the critical illumination level or lower.

In the case of illuminating an area to a high probability of recognition, fractional degradation in intensity of the candle can produce more than double the degradation in performance; however, this occurs in an area where the flare performance is poor anyway.

The possible change in effectiveness of recognizing a target anywhere in a large search area illuminated by a flare appears to range between one and two times the percentage change in intensity for all practical ranges and conditions of use.

For a rough estimate of the degradation of a flare for use in evaluating specifications, it can be expected that, generally, degradation in effectiveness is at least proportional to degradation in intensity and would probably not be more than twice the percentage degradation in intensity of a flare for any practical range. However, before any production specifications on flare intensity are written, rigorous calculations should be performed to show the expected degradation of the performance of the flare. These calculations should utilize the data on each type of flare, the angular relations and intensity requirements found in PATR 4184, and the mathematical approach formulated in this report.

Table 1

Effect of flare intensity on area illuminated[a]

Decrease in intensity (%)	Round	60 mm Mortar		81 mm Mortar		155 mm Howitzer	
	Range (feet)	800	3000	800	3000	800	3000
	Range (meters)	260	980	260	980	260	980
	CIL[c] (footcandles)	0.04	0.4	0.04	0.4	0.04	0.4
		Decrease in 90%-recognition area[b] (%)					
5		5.23	9.10	5.40	25	5.75	[d]
10		10.45	18.20	10.80	50	11.50	
15		15.68	27.30	16.20	75	17.30	
20		20.90	36.40	21.60	100[d]	23.00	
25		26.13	45.50	27.00		28.80	
30		31.35	54.60	32.50		34.50	
35		36.58	63.70	37.90		40.30	
40		41.80	72.80	43.20		46.00	

[a] Specific area case; at ignition altitude.
[b] There is no 90%-recognition area at a range of 1640 m (5000 ft) and a CIL of 1 footcandle.
[c] Critical illumination level.
[d] Under these conditions there is no 90%-recognition area.

Table 2

Effect of flare intensity on target recognition[a]

Decrease in intensity (%)	Round	60 mm Mortar			81 mm Mortar			155 mm Howitzer		
	Range (feet)	800	3000	5000	800	3000	5000	800	3000	5000
	Range (meters)	260	980	1640	260	980	1640	260	980	1640
	CIL[b] (footcandles)	0.04	0.4	1.0	0.04	0.4	1.0	0.04	0.4	1.0
		Decrease in target-recognition probability (%)								
5		4.9	4.5	7.7[c]	5.4	7.3	8.7[f]	5.4	7.6[d]	7.8[h]
10		10.2	12.3	11.5[d]	10.8	13.8	16.2	11.0	15.5[d]	22.1[h]
20		20.2	22.6	29.6[d]	20.6	27.0	35.0	21.0	30.3[e]	43.0[i]
40		40.6	46.0	56.5[f]	41.4	52.9	60.2	41.9	54.3[f]	76.1[i]

[a]Search case; at ignition altitude
[b]Critical illumination level
[c]Maximum recognition probability possible 80%, [d]70%, [e]60%, [f]50%, [g]40%, [h]30%, [i]20%, [j]10%.

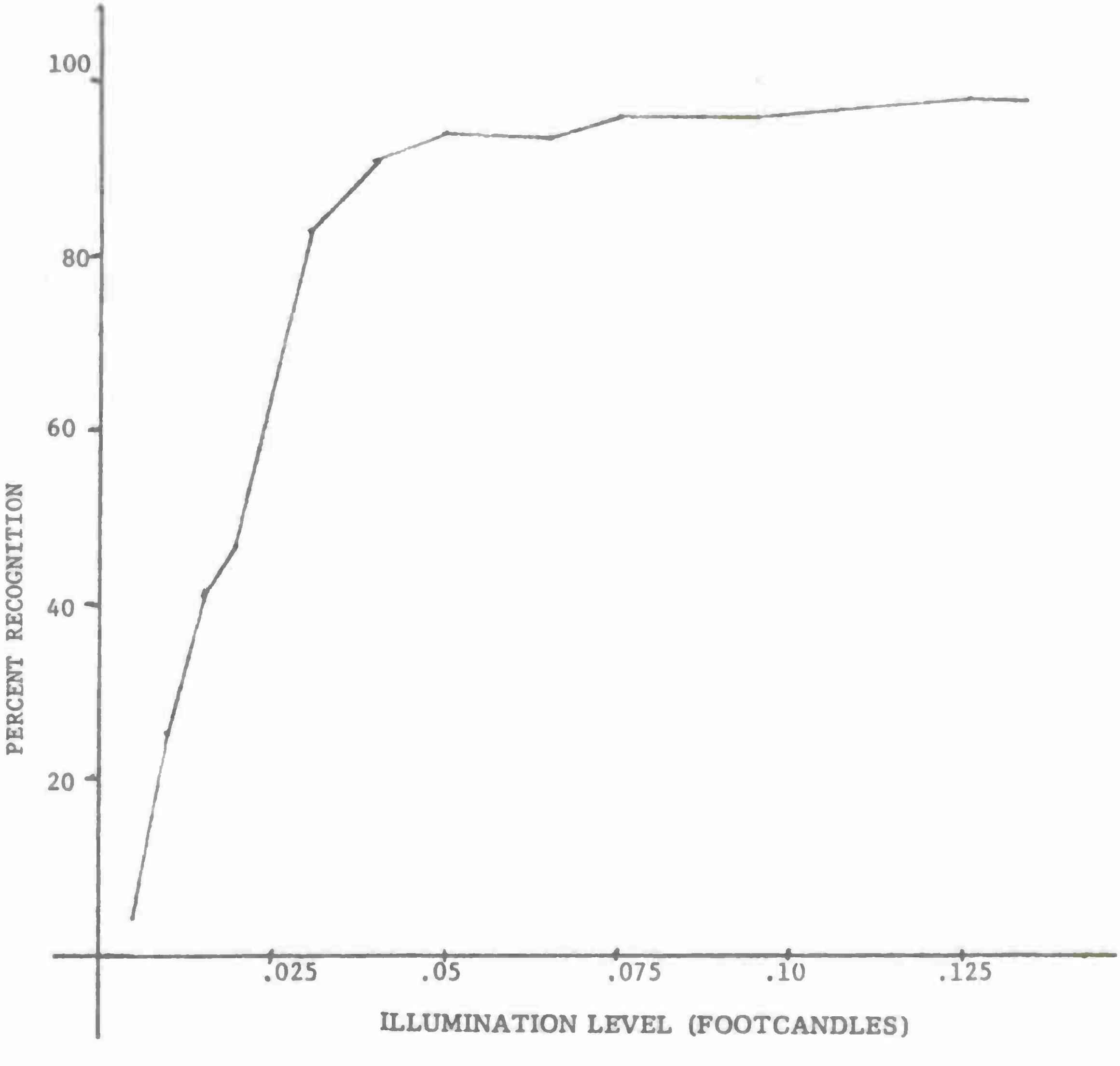

Fig 1 Recognition response to vehicular size targets against a medium green background at a simulated range of 490 m (1500 ft) and a target illumination angle of 124°

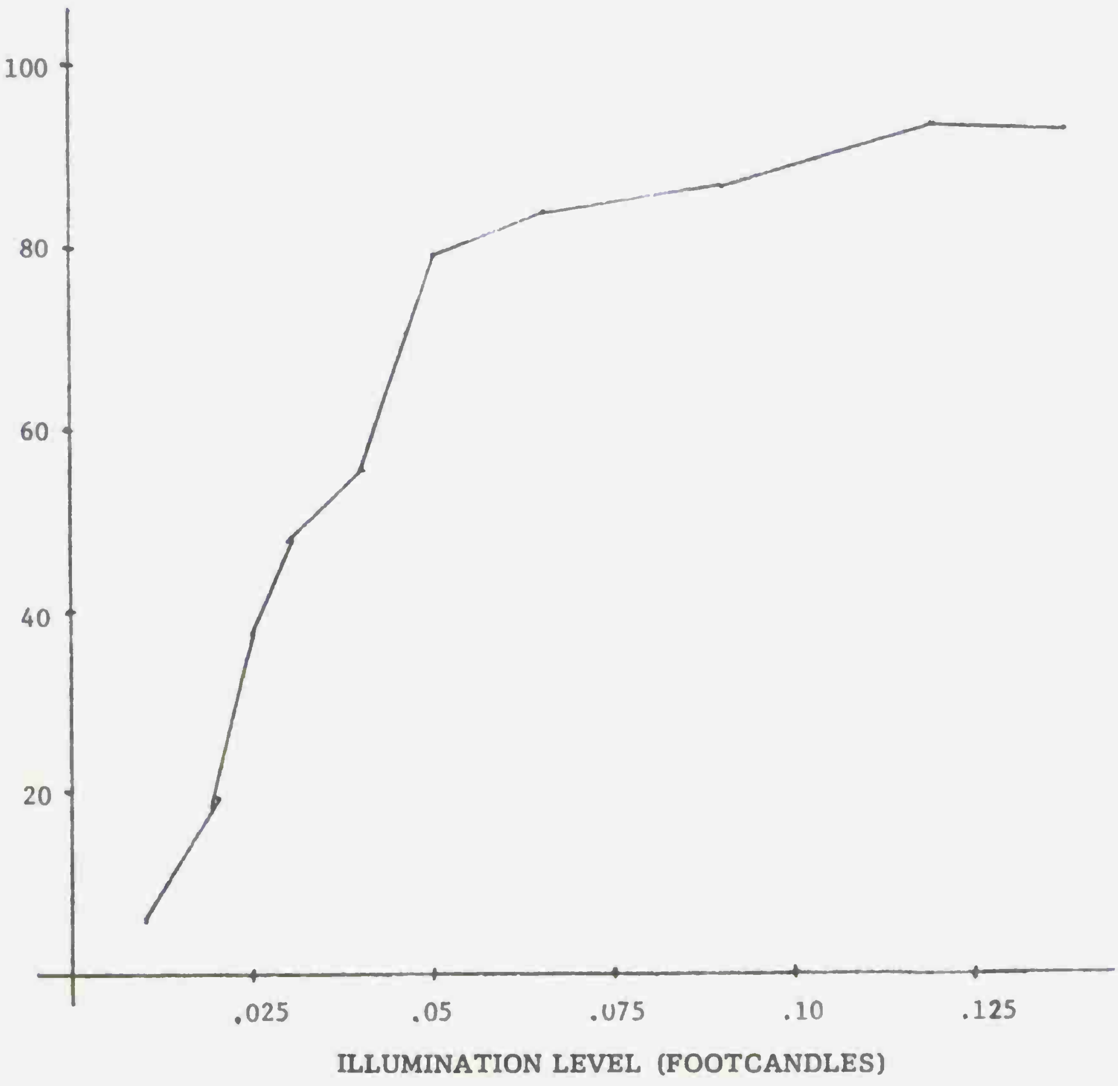

Fig 2 Recognition response to vehicular size targets against a dark green background at a simulated range of 654 m (2000 ft) and a target illumination angle of 90°

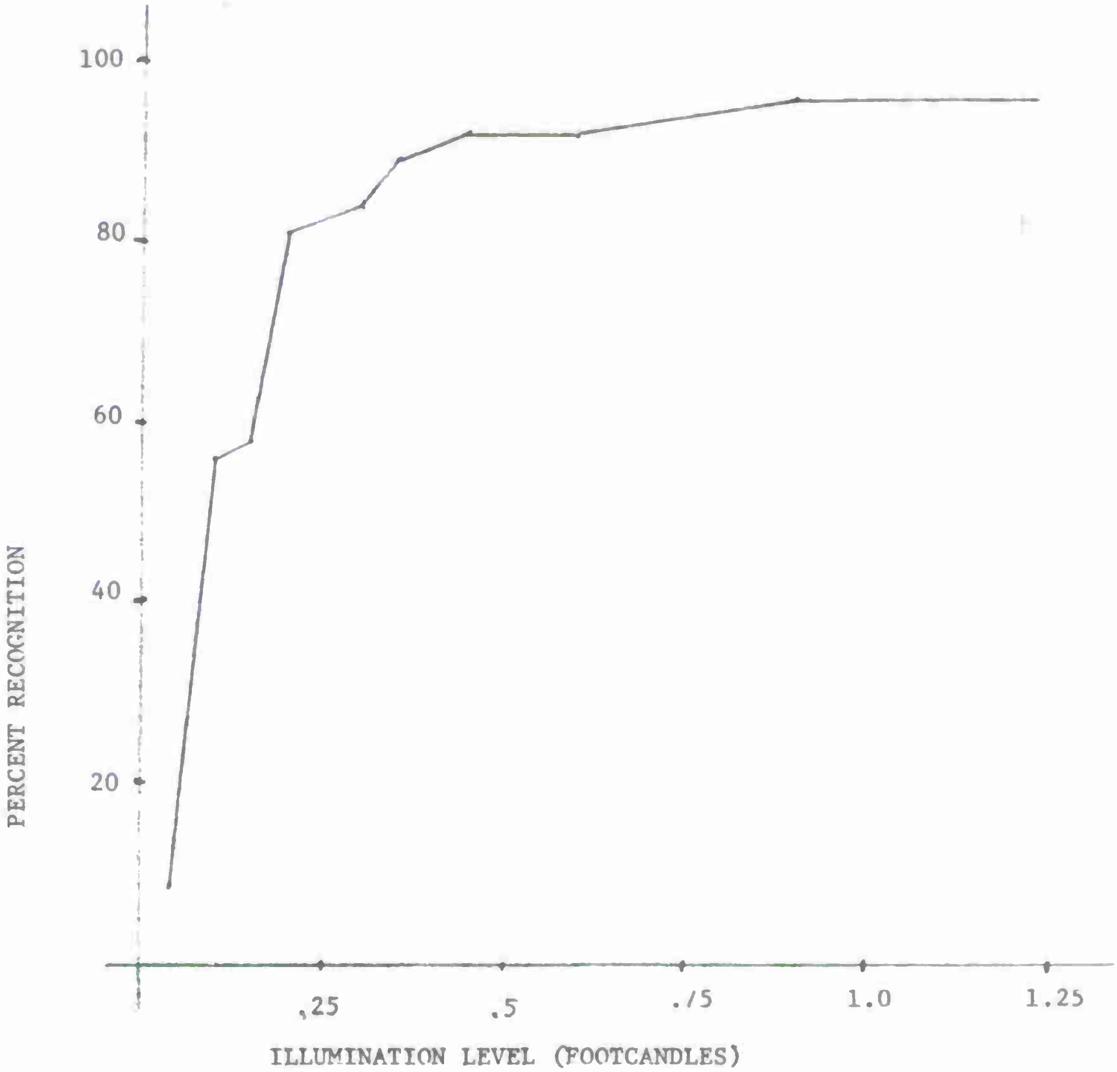

Fig 3 Recognition response to vehicular size targets against a medium green background at a simulated range of 980 m (3000 ft) and a target illumination angle of 110°

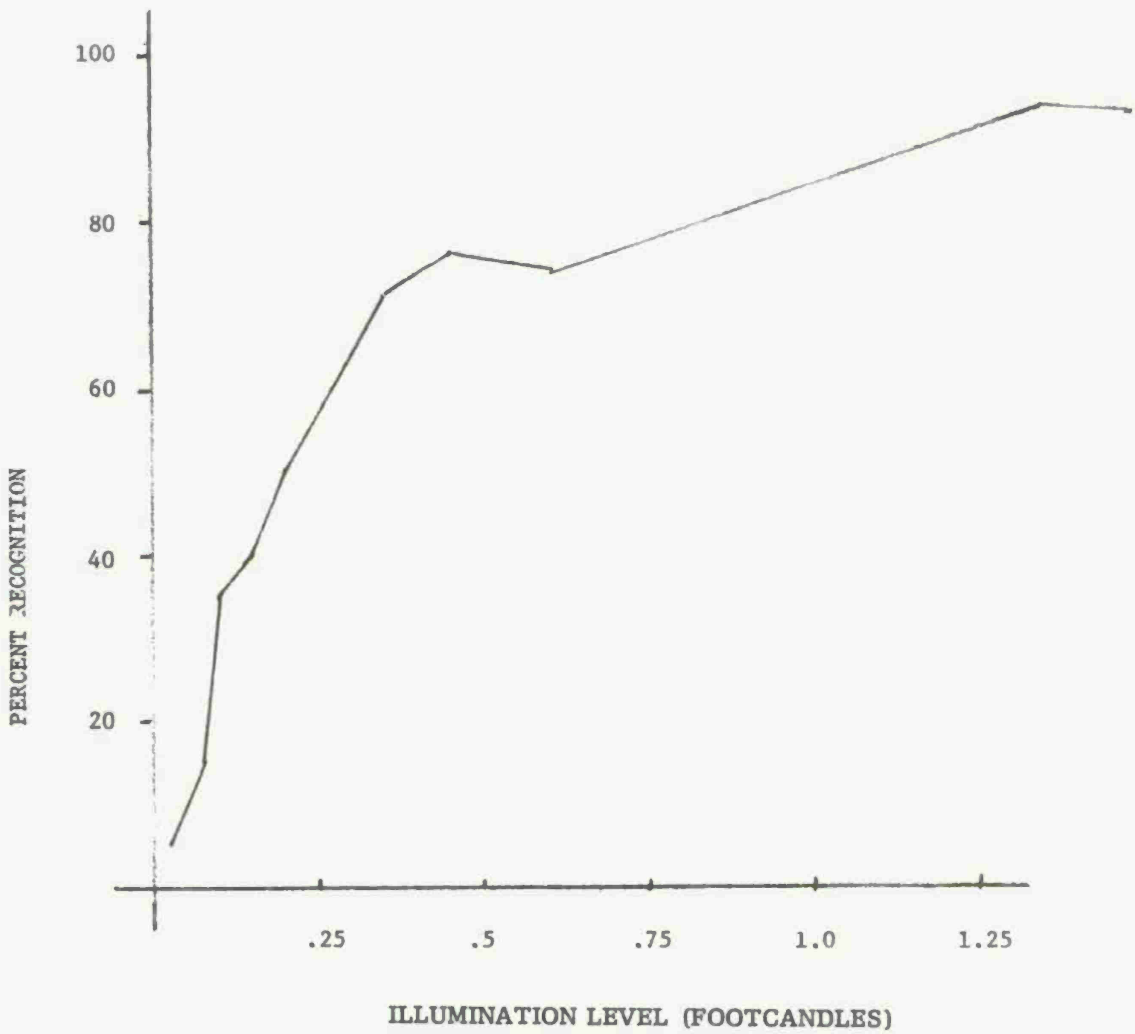

Fig 4 Recognition response to vehicular size targets against a dark green background at a simulated range of 1150 m (3500 ft) and a target illumination angle of 70°

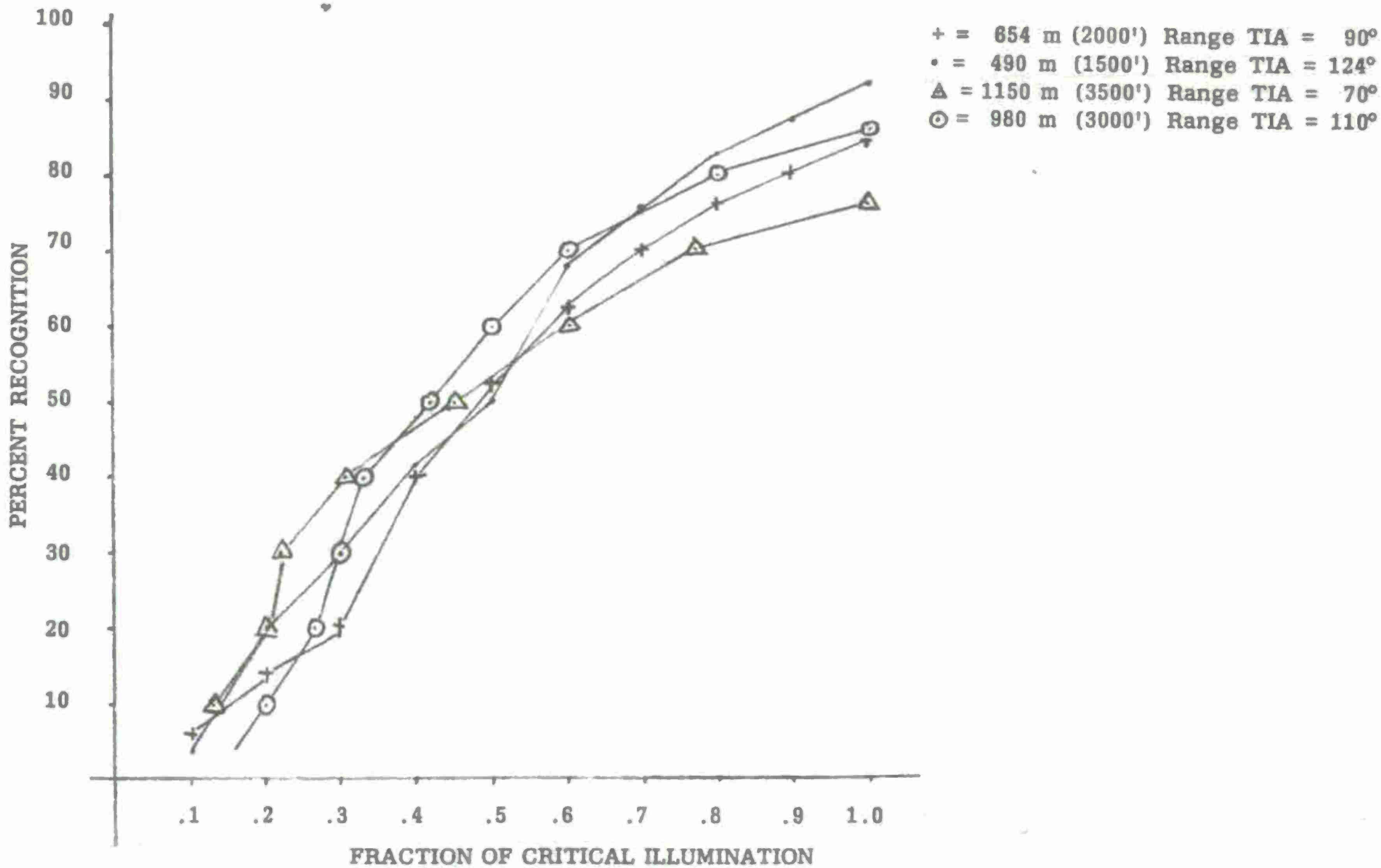

Fig 5 Portions of the response curve normalized at the critical illumination level

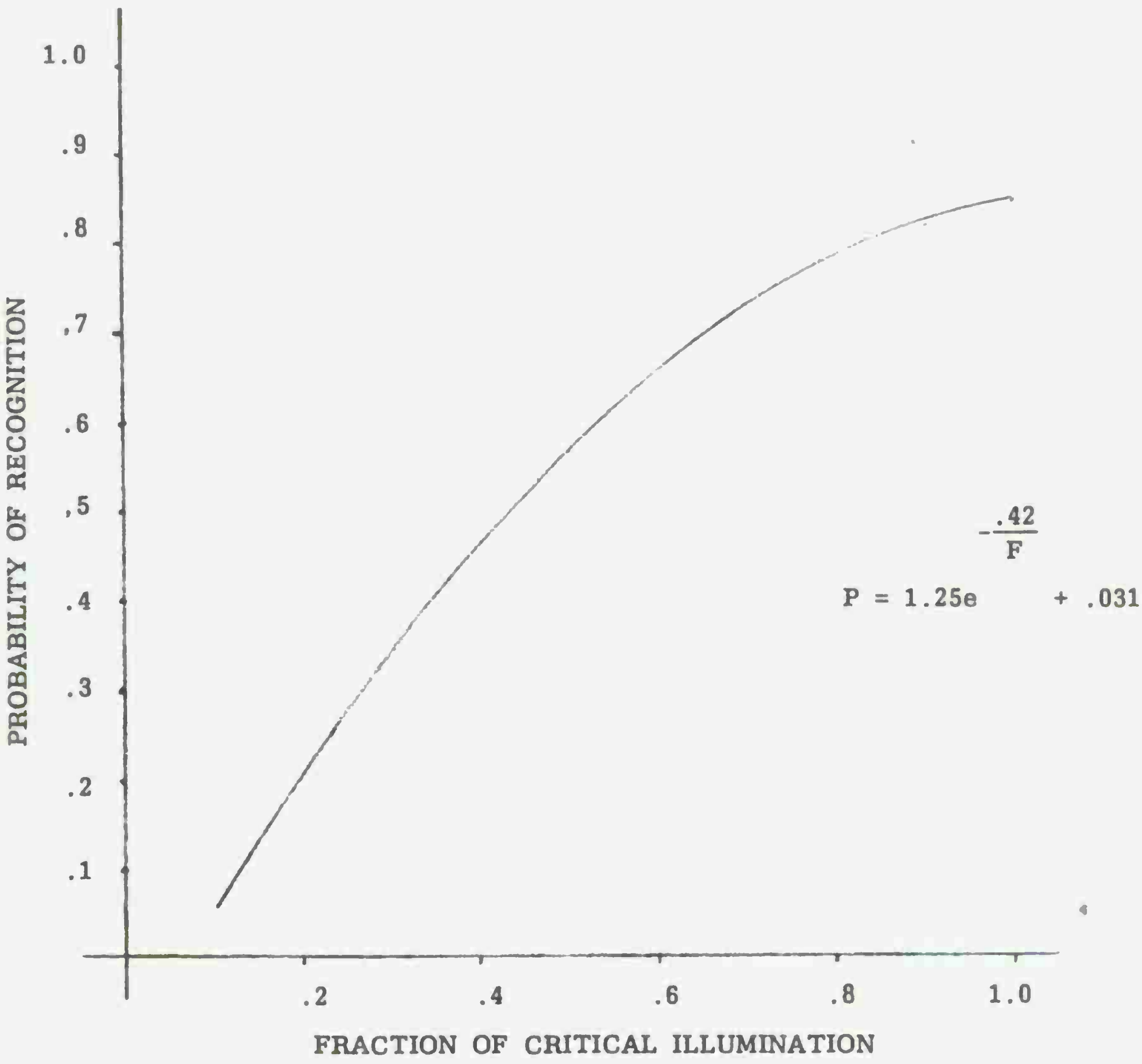

Fig 6 Average curve of the four normalized response curves

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