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AIR TO GROUND TARGET ACQUISITION

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PREFACE

Perhaps the major factor limiting the effectiveness of a military flight mission is whether the aircraft or weapon in question reached its geographical goal correctly. In this sense, the acquisition of a physical target by the use of aircrew vision could become a crucial issue. Vision is, after all, our only relevant sensor for distant objects, and human vision is a complex and elegant sense which currently defies replacement by any machine capability.

With target characteristics given (including size, shape, luminance and surround and/or lead-in features) visual target acquisition from aircraft is a process affected by many factors, which may for convenience be broken down into physical and biological ones. Physical parameters, governing the transmission of light from the target and surround to the eye, are adequately understandable and measurable, although they can, taken together, form a forbiddingly complex body of factors. They include time of day and year, and geographical location; on these depend foliage and ground cover, sun or moon angle, weather, visibility effects due to the atmosphere, and similar parameters. Aircraft height, speed, navigation accuracy, external view and occupancy similarly determine what chances of seeing all or part of the target the aircrew have, and aircraft height, in particular, interacts with geography to determine whether a target is screened by its surroundings or not. A third conglomerate of physical factors might be concerned with technical aids to vision, and could introduce two major complications, image quality (from TV or infra-red scanning equipment, for example) and image size (often, the magnification-field of view compromise inherent in, for example, binocular sights).

Biological factors, governing the transmission of information from eye via brain to motor act, are not nearly so readily specifiable and emphatically not so easily measurable. Just as things physical can seem after a few inspections commonplace and stable, so things biological seem to need their very variety and variability to survive. A human observer is firstly an individual, then a statistical member of a group; an aircrewman looking for or at a ground target is no exception to this generalization. Nevertheless, one can list a range of physiological optics and psychological titles which seem to refer to relevant and useful dimensions. In the first group come static and dynamic visual acuity, colour vision, and the ideas necessary to describe eye movement behaviour. In the second group come pre-mission briefing, experience and skill, which surely interact with each other, and dimensions related to competing tasks and decision style. Many features and events apparently compete for an aircrewman's attention, notably navigation and flying control duties on the one hand and distractions associated with concern for one's safety and survival on the other. It is known that individuals differ substantially in attentional capacity and its allocation. As to decision style, it may be illustrative to consider the caricature of a 19th Century military man who knows next to nothing and commits it dogmatically to several volumes, and the caricature of a 19th Century scientist who spends over 50 years collecting all the data he can and never utters an assured word. Somewhere between extremes like these may lie the normal population of adults from which aircrew are selected to perform visual target acquisition tasks.

Dr. Jo H.F. Huddleston
(Programme Organizer and Proceedings Editor)
Royal Aircraft Establishment,
Farnborough, Hampshire, U.K.

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TECHNICAL EVALUATION

An examination of data on the value of a single visual glimpse in acquiring a target supports the expected view that the foveal performance of the eye is the primary determining factor. An adequate description of foveal performance has been found to match up with much acquisition data, the description at the moment being simply in terms of the optics of the eye lens and the resolution and geometric layout of receptors in the fovea, plus a simple factor to represent the blurring and restorative properties of microminiature eye movements. It does not seem too cumbersome to work towards the inclusion of peripheral detection, accommodation, and pupil behaviour as factors in the foreseeable future, when it is expected that the likelihood of single glimpse acquisition of a wide range of visual stimuli may be adequately described mathematically. This description should then represent a general model of the performance of the basic visual lobe.

To model the eye's searching behaviour, that is to describe how this single glimpse visual lobe is directed from one part to another of a visual field to be searched, turns out to be rather less successful currently. A good fit to target acquisition data is not always achieved on the simple assumption that single glimpse detection performance is summed over a series of randomly aimed glimpses. On occasion, however, such random search descriptions fit laboratory data and, to a lesser extent, field data quite well. Hope for wider prediction of operational performance in the future lies in discovering how search is structured or biassed. One encouraging model assumes that the eye evaluates the search field peripherally for target-like objects, and directs foveal regard to them preferentially. (In passing, one may note that peripheral acuity does not seem to change with viewing distance). Nonetheless, the degradation of some components of laboratory performance to match up with those of field performance still requires arbitrary factors in the mathematics describing the acquisition, and these factors vary from experiment to experiment even when target luminance values are taken into account or controlled. Target-within-background relations are particularly troublesome in this context. It can be said, however, that the vagaries of visual search have very great authority in the determination of acquisition performance, and techniques to eliminate or structure search would bring handsome practical benefits.

Research is progressing slowly on the question of how observers make use of differences between target and non-target stimuli. A reasonably complete account can be given of discriminations based on contrast or size differences and differences in detailed shape when these parameters are taken singly, but these factors may have been examined as much for reasons of experimental convenience as for reasons of practical importance. It is strongly suspected that some total description of luminance edges and gradients throughout the entire search field will have to be added before adequate modelling of the acquisition of real targets in real backgrounds can be expected. A conjoint prediction from quantified size, shape, and pattern of light and shade seems some way away, and would still omit many factors (colour, for example, which assumes greater importance for objects nearer the airborne observer than those currently being examined).

It transpires that earlier formulations describing the visibility of briefly-exposed point light sources have been in considerable factual error. Continuing studies suggest that lengthening the exposure time may permit the use of lower source luminances than were previously thought to be effective. As to target illumination by flares, shielding of these high intensity sources from an observer's direct gaze, and using more than 2 to cover a given terrain strip, were found to have surprisingly little effect on observer performance. There is, however, an important interaction between flare height plus terrain slant range (to the observer) and observer height, indicating a preferred height band for an observer required to search illuminated terrain.

Leaving light sources and flare illumination aside, night operations making use of ambient light or heat energy for target acquisition depend for their effectiveness on technical aids to vision such as low-light TV or infra-red scanning systems. There is some work in hand on the calculation of flight paths yielding maximum coverage by appropriate airborne sensors of the terrain of interest, and this will probably have to proceed on a piece-meal, route-specific basis. Requirements imposed by human vision on the display of such sensor data turn out to be quite rigorous, and point to considerable weight penalties incurred by carrying such technical aids. Although design engineers would probably welcome firmer and more representative data on human perception of line-scan display surfaces, such data seem hardly likely to ease their equipment problem much since one can hardly hope for the limits of visual performance themselves to be radically changed by research. As to marking an acquired target by aiming the head, however, more knowledge is certainly required. In particular, the interactions between body, head and eye movements, and the effects of retinal disparity, cannot be adequately described at present, and a better description is needed to allow design specification of helmet-mounted aids.

A major hindrance to applied work continues to be observer variety and variation, which conspire to make repeated measurements on a number of individuals an absolute pre-requisite of reliable research. Some few workers have tried to understand perceptual differences between individuals in terms of psychophysical phenomena "higher" than, say, visual acuity, but their attempts have been largely thwarted. Complementarily, observers have been asked to state what target and background features they believe make a given acquisition task easy or difficult, but the initial outcome has hardly been helpful, although considerable refinement of this technique is possible. Comparisons between pre-flight briefing materials can, however, be made with some confidence, and tend to suggest that the appearance of target and background features cannot be adequately inferred from maps of the area, but can be well understood from oblique view diagrams approximating to forward-looking aerial photographs.

Dr. Jo H.F. Huddleston
(Programme Organizer and Proceedings Editor)
Royal Aircraft Establishment,
Farnborough, Hampshire, U.K.

THE LIKELIHOOD OF LOOKING AT A TARGET

by

Charles P. Greening, Ph.D.
North American Rockwell Corporation
3370 E. Miraloma Avenue
Anaheim, California 92803
Mail Code DF53

SUMMARY

Visual search behavior is characterized by brief glimpses of the terrain, separated by rapid eye movements, or saccades. The likelihood of looking at a target with any particular glimpse is, in most models of search behavior, assumed to result from either random motion or a mechanically systematic search pattern.

In the present study, it is assumed that the observer uses extra-foveal vision to evaluate the terrain before each saccade, to maximize the likelihood of looking at the target. Quantitative data on extra-foveal search, obtained in a different context by Williams, show that such behavior is lawful and predictable. The results are here applied to dynamic air-to-ground search, yielding target acquisition predictions which compare favorably with those obtained by other methods.

THE PROBLEM

Most tactical surveillance and attack systems depend, for their successful employment, upon the detection of a target by an observer. Tactical targets typically occur in somewhat cluttered surroundings, thus complicating the detection problem. Whether the detection is made by direct visual search of the terrain, or indirectly through use of a sensor/display system, the observer must somehow reject the clutter and detect the right object, subject to verification. The quantitative prediction of the effects of the confusion objects upon the search and detection process has proven to be difficult.

EXISTING APPROACHES TO THE PROBLEM

It is generally acknowledged that an observer searches a field-of-view in a series of saccadic movements. The relatively small area of most distinct vision, or the foveal region, moves from place to place over the scene, remaining fixed between jumps for a few tenths of a second. Very little visual information is received during the jumps. Hence, the success of a search effort depends upon the appropriate placement of the area of distinct vision during the pauses, or glimpses. The probability of looking at the target foveally with any particular glimpse depends, at least in part, upon the size of the area being searched, the presumed area of "distinct vision", and the method of distributing the glimpses.

Usually the problem has been attacked by assigning a definable limit to the area of distinct vision (or detection lobe), and then assuming that this area, or aperture, is moved either systematically, or randomly, or some combination, over the area to be searched.[1,2,3] The presence and characteristics of the non-target objects in the search field are presumed to affect the search performance by lengthening the glimpses,[3] or by modifying the effective search rate by a "congestion factor".[1]

AN ALTERNATIVE APPROACH

The approach to the problem suggested here rests on the assumption that the glimpse pattern of the observer is dependent directly upon the appearance of target-like objects in the peripheral visual field. Limited eye-movement data collected during dynamic search appear to confirm this assumption. When observers were looking for a missile site in a forest clearing, for example, more than four-fifths of their eye fixations fell in clearings or breaks in the forest. It would seem that this kind of performance could occur only if the peripheral view from each fixation provided enough information to guide the next saccade to a clearing.

A method of testing this assumption more fully was suggested by data obtained by Williams[4] in his eye-movement research on conspicuity of symbols for command and control displays. He found that it was possible to establish quantitative relationships between the "targetness" of the displayed non-target images and the likelihood of looking at them when looking for the target. For example, if the target image was a gray square one-half inch on a side, he found that other images on the display were looked at less and less frequently as they departed from grayness, or squareness, or half-inch-ness. Furthermore, these probability gradients were remarkably consistent in slope as the target was varied along any one dimension. Williams was able, after his experiments, to state than an object two-thirds as large as the target will attract the attention of the observer as often as an object four Munsell hue units different from the target, or as an object one Munsell value unit lighter or darker. Williams data were obtained with well-defined, nonsense objects in a static display. The relevance of the findings to the search for real-world targets in a dynamic field is not obvious. However, a preliminary study performed at Autonetics indicates that the method is promising. That study will be described in relation to other, previously published work.

VALIDATION OF A VISUAL SEARCH MODEL

One method of predicting target search and detection performance has been through the use of search models. An important class of models, based upon the PRC model of 1957,[5] computes the expected probability of detecting the target in a particular "glimpse" as the product of P_L (the probability of looking at the target), and P_R (the probability of resolving the target). The latter is almost purely an optical/physiological phenomenon and has been described on the basis of existing data and laws of physics. The probability of looking at the target, however, has been much less tractable.

The "glimpse model" used in studies at North American Rockwell, and a recent experimental validation study, have been described in some detail elsewhere.[6] Briefly, the model (see Eq. 1) yields a cumulative probability of target detection as a function of decreasing range, as the observer approaches the target area.

$$P_{cum}(x_k) = 1 - \prod_{j=k}^{N} \left(1 - P_L(j) P_R(j)\right) \qquad (1)$$

where:

- x = horizontal distance from observer to target along the ground track
- P_L = probability of looking at (with foveal vision) the target
- P_R = probability of resolving (seeing well enough to recognize) the target
- k = an integer such that $x_k \geq$ the minimum visual range, as established by field-of-view limitations
- N = an integer such that $x_N \geq$ the maximum visual range, beyond which detection is impossible.

The model, as expressed, will yield a curve of cumulative probability as a function of range for any set of target, background, flight geometry, atmospheric and observer parameters. The computed curve can then be compared directly with the results obtained in the field or in a simulation, provided all the necessary parameters can be determined. (See Figure 1.)

In the published study referred to above[6], all parameters involved in P_R were measured in the course of a dynamic, cinematic simulation using 35 mm color motion pictures obtained from flights over varied Southern California terrain. The values of P_L in that study were obtained by having judges view still photos of the target area under standardized conditions, and estimate the number of target-like areas in the field-of-view.

THE PRELIMINARY STUDY

The preliminary study using the new method of estimating P_L was based on the earlier, published work. No new simulation data were taken, but the computer model was re-run for each target, using the new values of P_L. In this preliminary study, a series of still photos of scenes used in the earlier target acquisition study was the basis for the application of the Williams findings to real-world search.

As a first step in the attempt to apply the Williams "probability gradients" to the detection process, the existing target photos were re-examined. It was immediately evident that, at the ranges at which detection normally occurred, distinctive hue differences were almost non-existent. Consequently hue was not considered in this validation attempt - only size and value.

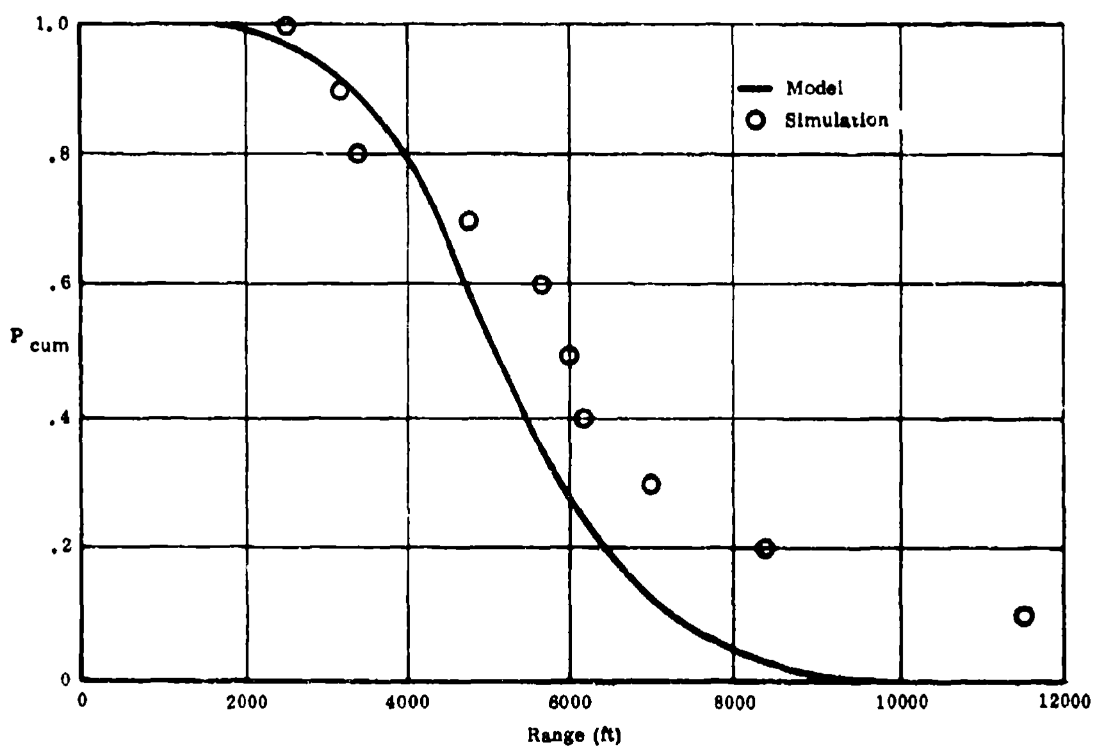

Figure 1. Computed and Measured Probability of Recognition for Target No. 103 - Four Silos

Figure 2 is a sketched representation of all the readily discernible objects in one of the target photographs (Target #103). Each of these objects was measured for width and height of image, and was given a value rating by comparing with a set of Munsell chips. In the case of targets with substantial vertical extent such as buildings, the size comparison was made using whichever dimension of the confusion object differed most widely from the corresponding dimension of the target. This choice was made because there were many objects in some of the fields whose shape was radically different from the target (e.g., smoke stack when the target was a building). For such cases, it did not appear that the confusion object attracted notice, even though its height might be identical with the height of the building.

The probability figures for the various objects in the field were computed as follows: First, the probability associated with the target size and target value were both arbitrarily set to 1.0. Next, for each confusion object, a probability value was read from the corresponding probability gradient presented in Williams' paper. Examples are shown in Figure 3.

For example, if an object in the field-of-view was just as high as the target and one-half as wide, the probability value associated with this object due to its size can be seen to be .22. Similarly, if this object is found to be one-half Munsell value unit darker than the target, its probability value due to that parameter can be read from the appropriate curve as .77. The combined probability for each non-target object was obtained by multiplying the size and value numbers together (see Table 1 for a sample set of numbers).

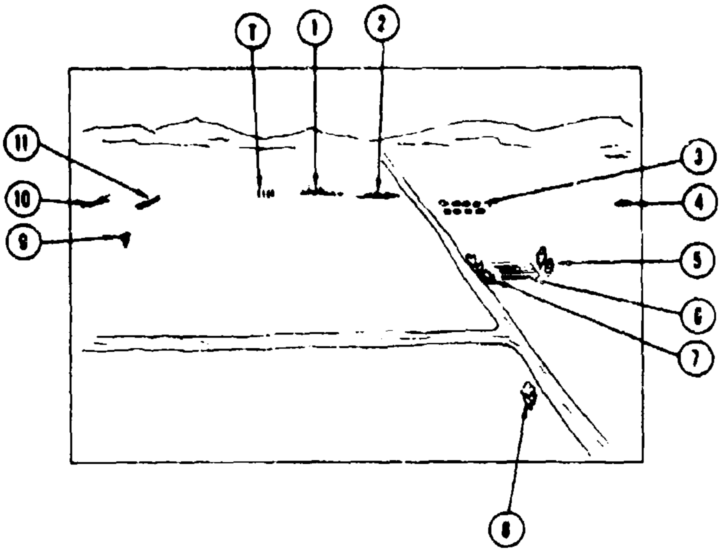

Figure 2. Sketch of Target 103 (Four Silos) and Vicinity

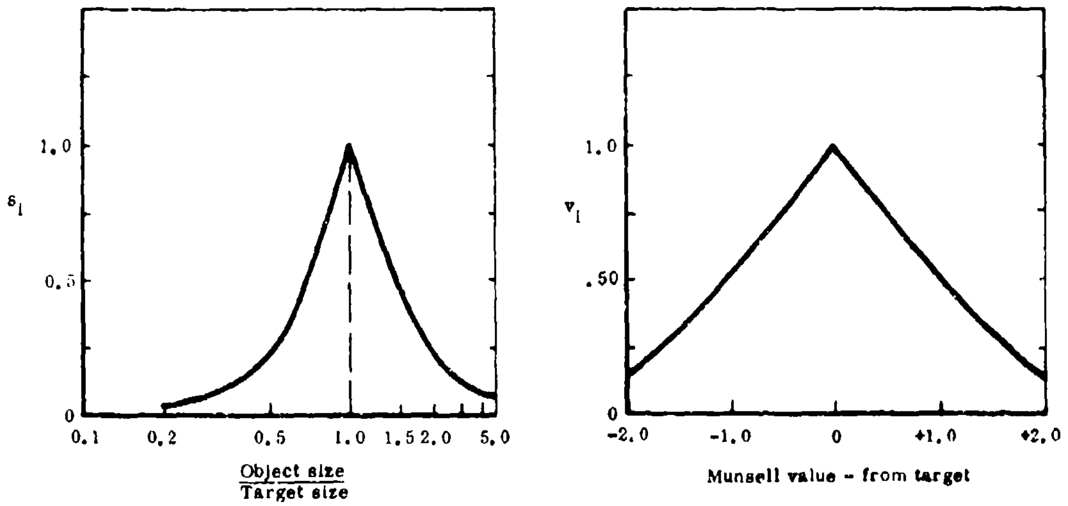

Figure 3. Discrimination Gradients (from Ref. 4)

Table 1. Computation of P_L for Target #103

Object	Size (mm)	s_i	Value (Munsell)	v_i	$s_i \times v_i$
Target	2.5 x 1	1.0	2.5	1.0	1.0
1	4 x 1.5	.35	3.5	.50	.17
2	12 x 1.0	.06	3.5	.50	.03
3	12 x 1.0	.06	7.0	0	0
4	2.5 x .5	.20	2.0	.75	.15
5	5 x 4	.07	3.5	.50	.03
6	10 x 2	.07	3.0	.75	.05
7	3.5 x 2	.20	3.5	.50	.10
8	3 x 2	.20	2.0	.75	.15
9	1 x 1	.16	4.0	.30	.05
10	4 x 1	.35	2.5	1.0	.35
11	10 x .5	.07	4.0	.30	.02

$\Sigma (s_i \times v_i) = 1.10 + 1.0$

$$P_L = \frac{1}{1 + 1.10} = .48$$

The number obtained by adding the probability products for all objects in the field is not useable in that form. Consequently, the probability of looking at the target was normalized by the use of:

$$P_L = \frac{1}{1 + \sum_{i=1}^{N} s_i v_i}$$

where: s_i is the relative fixation rate due to size difference

v_i is the relative fixation rate due to value difference

N is total number of measured objects in the field

For the remaining targets, P_L was computed by the method outlined above. The detection and recognition model was then exercised using the new values of P_L with all other values identical to those used in Reference 6.

The new method of computing P_L did not, in general, change the fit dramatically from that achieved in the earlier study. The major effect was one of making the slope of the curve steeper and increasing slightly the median recognition range. Qualitative judgement on the curve-fitting of the data in the 27 cases shows that approximately 11 were improved, 8 made worse, and 8 indeterminate. The median recognition ranges from the model, with the revised method of computing P_L, can be compared with the experimental values by computing the mean of the medians, and by computing a product-moment correlation. Figure 4 shows a scatter plot of median recognition ranges obtained from the model and from the simulator experiment. The correlation is .51 for these two sets of medians. The mean value of the medians is 3994 ft. from the model, and 4190 ft. from the simulator data - a difference of only 4.7 percent.

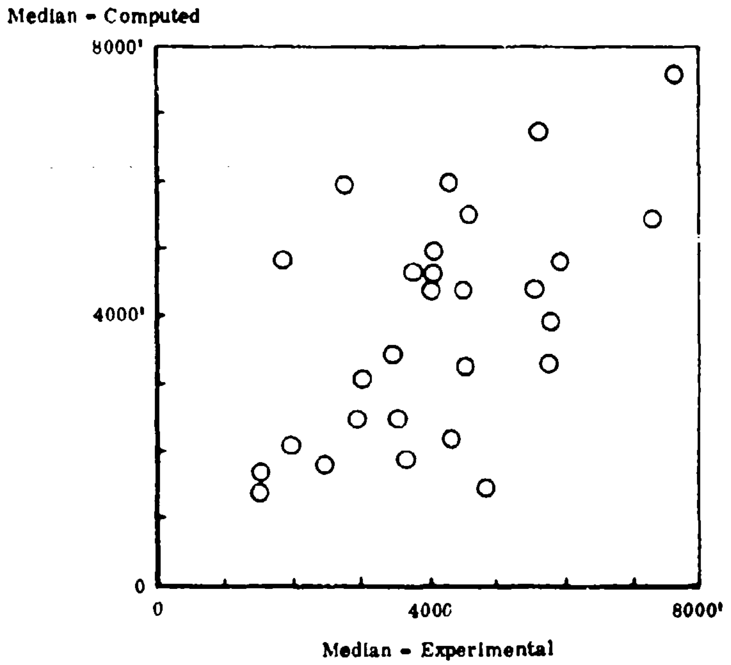

Figure 4. Scatter Plot of Median Recognition Ranges from Experimental Data and from Computer Model

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DISCUSSION

Dr Frick (US)

In Figure 1 of your paper, showing cumulative probability against range, is time implied in any way?

Dr Greening (US)

Only insofar as time is tied in with decreasing range, that is there is a controlled speed of aircraft approach. The model therefore has a controlled movement speed from the simulation.

Mr Overington (UK)

In your probability function graphs, is there any attempt to account for distance away from fixation point?

Dr Greening (US)

Yes; implicitly in the way the data were arrived at. You will find more in Williams' writings which are referenced in my paper. There is a distance function in there.

Mr Overington (UK)

I have the impression that these data were from highly supra-threshold, highly contrasting targets. If so, they would refer to highly conspicuous target and target-confusible objects in the scene, as opposed to poor visibility low contrast situations.

Dr Greening (US)

Yes. That assumption was made and borne out by the data. Objects in the real world are rarely aquired near threshold values; one is not generally pressing the operator hard.

Mr Overington (UK)

My experience doesn't always confirm that finding.

Mr Ericson (US)

Subjects' expectations, due to briefing and repeated trials, were probably accurate. Did you somehow try to set up the same fulfilled-expectation-situation in your real world task?

Dr Greening (US)

Yes, in the sense that part of our briefing data was a photograph of the target from the air (but not identical to the actual target run view). So they did see target-in-ground as part of their concept. Williams' people did have an image of the target right in front of them.

MODELLING OF RANDOM HUMAN VISUAL SEARCH PERFORMANCE BASED ON THE PHYSICAL PROPERTIES OF THE EYE.

by

Ian Overington
Head of Applied Optics Research
British Aircraft Corporation Ltd. (B.A.C.)
Guided Weapons Division
P.O. Box 77
Filton House
Bristol BS99 7AR
United Kingdom.

SUMMARY

The physical properties of the eye lens and retina together with the involuntary eye movements (tremor and drift) are considered as the basic factors defining single glimpse detection probability. Coupling of data concerning these with simple probability theories of information transmission from eye to brain via neural networks allows accurate prediction of several sets of basic laboratory threshold data.

Introduction of the concept of convolution of object profiles with the spread function of the eye lens allows extension of such single glimpse predictions to unsharp objects. The effects of atmospheric attenuation and range dependancy of subtended size may also be introduced at this stage. Using this comprehensive formula for single glimpse probability as an input a cumulative search probability model is developed for random search which takes account of search field of view, visual lobe effects and the transition from single glimpse to multiple glimpse situation at any part of the field of view.

SYMBOLS

$A_T(x)_M$ = Maximum gradient of the luminance profile across the edge of an object of interest.
$A_e(x)_M$ = Maximum of the absolute line spread function of the human eye.
b = Sky/ground luminance ratio.
C = Contrast ($= \frac{\text{object luminance}}{\text{surround luminance}} - 1$).
C_o = Intrinsic contrast (with no atmospheric attenuation).
d = Angular subtense of the diameter of a circle of equivalent area to the object of interest.
D = Linear diameter of the equivalent circle.
I = Field luminance.
m = Number of glimpses.
M . Magnification.
n = Number of foveal retinal receptors along a luminance contour.
n_o = Limiting number of foveal retinal receptors around the contour of the image of a 'point' object.
n_θ = Number of receptors along an image luminance contour at θ degrees from the fovea.
N = Number of overlaid glimpses.
p_f = Foveal single glimpse probability.
p_g = Single glimpse probability in a search situation.
R = Viewing range.
s = Number of separate glimpse positions (θ_F^2/θ_a^2)
t_g = Mean glimpse time.
t_s = Search time for 50% probability of acquisition.
v = Closing velocity.
Φ_f = Cumulative foveal probability when $N \rightarrow \infty$,
Φ_m = Cumulative probability in m glimpses.
Φ_N = Cumulative probability in N overlaid glimpses.
η = 1 - veiling glare.
θ = Angle off fovea in degrees.
θ_a = Radius of visual lobe.
θ_F = Radius of search field.
σ = Atmospheric attenuation coefficient.

1. INTRODUCTION

Modelling of random visual search performance is normally carried out on an empirical basis by attempting to couple together sets of basic detection threshold data such as those relating to foveal detection performance and relative peripheral performance, due allowances being made where appropriate for such items as magnification(if an optical aid is used) and atmospheric attenuation. This process cannot usually allow for such factors as image quality and, if one inspects the various literature on detection thresholds, must be highly dependant on which threshold data are used as a starting point. A multiplicity of threshold data have been compared by Davies (Ref.1) who shows that the contrast thresholds for a given size of target vary by 10 : 1 between experimenters.

Impetus was given to research at B.A.C. to attempt to put such modelling on a firmer foundation by results of a number of highly controlled field trials involving acquisition of aircraft through visual aids. Although not an air to ground exercise such trials provided an ideal controlled situation for studying random search and it is considered by the author that any findings are equally applicable to air to ground viewing in truly random search situations. That most air/ground situations involve structured search is another matter and is beyond the scope of the present paper. However, the basic modelling concepts developed herein may possibly be extended to encompass definable structured search.

The results of the above field trials, whilst being highly self consistent, were markedly inferior to expectations. Since it was known that the M.T.F.'s of the visual aids used were relatively poor the burning question to resolve was 'Is the inferior performance compared to that predicted due to inaccurate modelling of search, incorrect assumptions from input threshold data or the quality of the visual aid?'. In order to answer this question a much fuller and better understood modelling of the acquisition process was required than had hitherto been used.

Now a model of foveal detection performance for extended objects at a fixed field luminance had been developed at B.A.C. based on the physical properties of the human eye (Ref.2). With this model it had been shown possible to predict accurately a variety of laboratory threshold data available from literature including H.R. Blackwell's limited search and infinite viewing time experiments involving detection of disc targets (Ref.3), the experiments concerning the effects of aspect ratio on the detection threshold of rectangles by Lamar et al (Ref.4) and the effect of defocus blur on thresholds of simple stimuli studied by Ogle (Ref.5). The present paper shows how this model may be extended to cover peripheral performance and point objects and how image quality, atmospheric effects, stimulus growth and overlaying of glimpses may be included in one relatively simple mathematical formula. By coupling this formula with a cumulative probability function it is then possible to model any random search situation. Since the model is a relatively simple formula it is easy to assess the sensitivity of acquisition performance and the cumulative probability function to the various parameters.

2. THE BASIC FOVEAL MODEL

As a starting point it is necessary to consider the fundamental relationship between available visual stimulus and sensation produced for simple shaped, extended objects in plain fields. This is given in Ref.2 as

$$\log_e \left[\frac{(K_2 + K_3)C + 1}{K_3 C + 1}\right] = K_1 . f(n) + \delta \qquad \ldots\ldots\ldots (1)$$

where K_2 is a retinal image edge profile slope constant which is dependant on the spread function of the eye lens together with blur introduced by image motion associated with involuntary eye tremor and drift.

K_3 is an image positional constant.

K_1 and δ are constants associated with population sample, field luminance and probability level at which a decision is made as to the existence of an object.

C is the contrast of the object against it's background.

f(n) is a function of the number of retinal receptors (n) lying along the image contour.

For naked eye viewing K_2 and K_3 may be determined from measured data for the average eye.

N.B. In reference 2 the formula is stated in terms of $\log_{10}$ rather than $\log_e$ with obvious implications on the values of K_1 and δ quoted there and used here. Since the ultimate intention is to model random search, which must be an accumulation of single glimpse data, the main interest must initially lie in an appropriate form of Eq (1) for single glimpses. Then, from Ref.2, we may write

$$\log_e \left[\frac{(K_2 + K_3)C + 1}{K_3 C + 1}\right] = \frac{K_1}{\sqrt{n}(n-1)} + \delta \qquad \ldots\ldots\ldots (2)$$

where $f(n) = {}^1/_{\sqrt{n}(n-1)}$ is the reciprocal of the product of n(n - 1) possible comparisons between signal channels at deep neural level and a ${}^1/_{\sqrt{n}}$ neural noise factor (see Ref.2 for discussion and explanation of this). For foveal naked eye viewing of simple, sharp edged objects in plain fields this is fully definitive where the dimensions are in excess of 5 minutes of arc subtense at the eye. For smaller objects it is necessary to develop a correction formula. The effects of complex shapes, although significant, don't appear to be enormous (Ref.6) and for the purpose of this paper they will be ignored, the size being always considered in terms of an equivalent circle. For specific definable complex shapes, and in particular for line features, it will be seen possible to develop alternative forms of the basic equations.

Now with reference to Eq (2) the following observations may be made for a field situation:-

(i) C will in general be a function of viewing range, prevailing visibility and intrinsic target contrast C_o.

(ii) n can be defined in terms of linear object dimensions and viewing range.

(iii) Viewing range itself can, in the most general case, be defined in terms of rate of change of object distance and observation time.

(iv) K_1 will be a constant for foveal viewing at fixed field luminance. It will, however, be a function of angle off optical axis (c.f.Ref.7) for peripheral viewing, and of field luminance.

(v) δ, being a constant associated with the minimal signal required at the brain for a decision to be made, will in general be a constant for a fixed level of motivation but should vary with motivation.

(vi) K_3 may be considered a constant under most conditions.

(vii) K_2 will be governed by the imaging properties of the eye lens and the edge quality of the input stimulus. For viewing through visual aids and/or turbulent atmosphere the effective value must be factored to allow for the optical quality of the visual aid and/or atmosphere.

Thus, for approximate predictions of the single glimpse situation in the field it is necessary to derive a correction for small size, and to define C and n in terms of viewing range, K_2 in terms of optical quality and K_1 in terms of viewing angle.

3. EXTENSIONS OF THE FOVEAL MODEL

3.1. The Small Size Domain

For small object dimensions there is a gradual transition, for naked eye viewing, from the basic function

$$\log_e \left[\frac{(K_2 + K_3)C + 1}{K_3C + 1}\right] = K_1.f(n) + \delta$$

for both dimensions > 5 minutes of arc subtense to

$$\log_e \left[\frac{(K_2' + K_3')d^2.C + 1}{K_3'.d^2.C + 1}\right] = K_1.f(n_o) + \delta \quad \ldots\ldots\ldots \quad (3)$$

for both dimensions less than 0.6 minutes of arc where the object is effectively a point.

Here K_2' and K_3' are new slope and position constants associated with the point spread function of the imaging system (including the eye lens).

d is the angular subtense of the diameter of the equivalent circle (mins. arc).

n_o is a limiting number of retinal receptors associated with the image 'contour' of a point object.

These two formulae and the transition range can be approximated by

$$\log_e \left[\frac{(K_2 + K_3)B + 1}{K_3B + 1}\right] = K_1.f(n) + \delta \quad \ldots\ldots\ldots \quad (4)$$

where $B = \frac{\alpha^2.d^2.C}{(\alpha^4.d^4 + 1)^{\frac{1}{2}}}$

α being a constant which effectively defines the region of transition (on the size axis) from Eq (1) to Eq (3). It has a value of approximately 0.6 for naked eye viewing.

Also n can be represented by

$$n = 5.2\left(\frac{9d^4}{16} + 1\right)^{\frac{1}{4}} + \pi \quad \ldots\ldots\ldots \quad (5)$$

this being an approximation to give the correct function (approx.) for n at large radii (> 1.2' arc) (where $n \approx 2.86\,\pi(r + 0.35)$) (Ref.1) and at small radii (< 0.3' arc) (where $n_o \approx 9$).

For most purposes it is considered adequate and convenient to use a simpler approximation for n where $n = {}^9/_2\,(d^2 + 4)^{\frac{1}{2}}$.

Putting all the above into a form of Eq (2) containing only contrast and size we get:-

$$\log_e \left[\frac{(K_2 + K_3)B + 1}{K_3B + 1}\right] = \frac{K_1}{\left[{}^9/_2(d^2 + 4)^{\frac{1}{2}}\right]^{1.5}} + \delta$$

or $$\log_e\left[\frac{(K_2 + K_3)B + 1}{K_3B + 1}\right] = \frac{K_1}{9.55(d^2 + 4)^{\frac{3}{4}}} + \delta \quad \ldots\ldots\ (6)$$

The above is approximating $\sqrt{n}(n - 1)$ in Eq (2) by $n^{1.5}$.

3.2. Contrast and Size as Range Functions

We are now ready to consider the introduction of basic atmospheric effects and d as range functions.

Now for contrast:-

$$C = C_o.\exp(-\sigma R) \quad \ldots\ldots\ (7)$$

for viewing against the horizon sky (Ref.8)

where C_o is the intrinsic contrast of the object of interest,

σ is the atmospheric attenuation coefficient,

R is the viewing range.

Whilst this is not strictly true for other viewing situations (e.g. high elevation ground to air viewing) it was considered an adequate approximation for modelling the acquisition process for low flying aircraft and as such was used to check out the model predictions against field trials results.

For air to ground viewing a more complex formula

$$C = C_o\left[1 - b(1 - \exp(\sigma R))\right]^{-1} \quad \ldots\ldots\ (8)$$

must be used for the general case where b is the so called 'sky/ground luminance ratio' (Ref.9). In cases where the luminance of the target background approximates to that of the horizon sky Eq (8) approximates to Eq (7).

N.B. Equations (7) and (8) both assume a homogeneous atmosphere, and diffuse target and background surfaces, assumptions which themselves can lead to certain problems in a practical field situation (Ref.10).

Also $d = \frac{3.44\ D}{R}$

where D is the linear diameter of the equivalent object circle in metres.

R is the range in Km.

d is in minutes of arc.

Then we may write, from Eq (6)

$$\log_e\left[\frac{(K_2 + K_3)B + 1}{K_3B + 1}\right] = \frac{K_1.R^{1.5}}{(236D^2 + 80R^2)^{\frac{3}{4}}} + \delta \quad \ldots\ldots\ (9)$$

where $$B = \frac{0.36.(3.44)^2.D^2.C_o.\exp(-\sigma R)}{\left[0.13.(3.44)^4.D^4 + R^4\right]^{\frac{1}{2}}} = \frac{4.25\ D^2.C_o.\exp(-\sigma R)}{(18\ D^4 + R^4)^{\frac{1}{2}}}$$ for ground/air viewing

or, more generally, $$B = \frac{4.25\ D^2.f(C_o)}{(18\ D^4 + R^4)^{\frac{1}{2}}}.$$

The above is a semi-rigorous definition of the situation for naked eye viewing (i.e. assuming it is permissible to ignore shape effects).

3.3. Unsharp Objects

It may be that, instead of the object of interest presenting a good, sharp luminance discontinuity to the eye, the change of luminance across the edge of the object is gradual ('unsharp'). This situation can arise in simulation or can be due to viewing through imperfect visual aids, to certain forms of atmospheric turbulance or to fine shape structure on the object which is unresolved by the eye as discrete detail. In any of these cases the effect can be allowed for in modelling if the effective luminance profile as presented to the eye can be specified. For large objects (>10' arc) all that is necessary is to convolute the luminance profile of the object F(x) with the effective line spread function of the eye $A_e(x)$.

i.e. Image profile $$G(x) = \int_{-\infty}^{+\infty} F(x - \xi).A_e(\xi).d\xi \quad \ldots\ldots\ (10)$$

If now G(x) is differentiated with respect to x, x being measured perpendicular to the local image contour direction, the result, $\frac{d}{dx}G(x) = A_T(x)$, is a retinal image luminance gradient function. The peak value of this, $A_T(x)_M$, is then a measure of the maximum luminance gradient in the retinal image of the object F(x). But for viewing of 'sharp' objects the equivalent to the above is the line spread function of the eye, $A_e(x)$, (approximately) and similarly the maximum, $A_e(x)_M$ is a measure of the maximum luminance gradient in the retinal image of a 'sharp' object. Thus the ratio $A_T(x)_M/A_e(x)_M$ may be taken as a quality factor which must operate on K_2 in Eq (9).

N.B. The above is only strictly true for large objects and where $A_e(x)$ is the line spread function of the eye. For small objects (10' arc diameter and less) strictly speaking 2-dimensional convolutions with the point spread function of the eye should be used but the subsequent differentiation and taking of the ratio are identical.

3.4. The Aided Vision Case

For viewing through visual aids, in addition to allowing for optical imaging quality, we must allow for magnification and veiling glare.

Magnification is taken care of by writing MD in place of D in Eq (9) whilst veiling glare, which is a softening of general scene contrast, is allowed for simply by operating on $f(C_0)$ by a factor η.

Strictly speaking, in addition there should be a modification to α since the system point spread function will be larger than for the naked eye with consequent change in the size range for transition from a 'point' object to an 'extended' object. However, since the change to α is dependant on the shape of the system point spread function as well as it's diameter, and since a change of α only has a minor effect on thresholds of the smallest objects, it was considered an excessive complication to allow for it in the present model.

3.5. The Complete Foveal Single Glimpse Model

From the above the full equation for single glimpse foveal viewing may be written out. viz:-

$$\log_e \left[\frac{\left(\frac{K_2 \cdot A_T(x)_M}{A_e(x)_M} + K_3 \right) B + 1}{K_3 B + 1} \right] = \frac{K_1 \cdot R^{1.5}}{(236M^2 \cdot D^2 + 80R^2)^{\frac{3}{4}}} + \delta \quad \ldots . \quad (11)$$

where $B = \dfrac{4.25M^2 \cdot D^2 \cdot \eta \cdot f(C_0)}{(18M^4 \cdot D^4 + R^4)^{\frac{1}{2}}}$

3.6. Visual Lobes

To consider search one must consider detection lobes and extra-foveal detection. This may be covered adequately by invoking different values of n from Østerberg's data on retinal receptor concentration (Ref.11), thereby providing a measure of visual lobe size as a function of range for other set conditions.

An adequate fit is given by a relationship

$${}^{n}\theta/_{n} = {}^{1}/_{(\theta+1)^{\frac{5}{8}}} \qquad \text{(unpublished work by E.P. Lavin)}$$

where θ is the viewing angle considered measured in degrees from the fovea.

$$\therefore \left({}^{n}\theta/_{n}\right)^{1.5} = {}^{1}/_{(\theta+1)^{0.94}} \approx {}^{1}/_{(\theta+1)} \qquad \text{at least for small values of } \theta\ (<10).$$

Hence, for determination of visual lobe size, Eq (11) becomes:-

$$\log_e \left[\frac{\left(\frac{K_2 \cdot A_T(x)_M}{A_e(x)_M} + K_3 \right) B + 1}{K_3 B + 1} \right] = \frac{K_1 \cdot R^{1.5} (\theta_a + 1)}{(236M^2 \cdot D^2 + 80R^2)^{\frac{3}{4}}} + \delta \quad \ldots . \quad (12)$$

with B as for Eq (11) and where θ_a is the radius of the visual lobe in degrees. Eq (12) is then the complete equation of vision for acquisition of simple targets in a simple background in a single glimpse subject to the limitations on Pages 2 (shape), 4 (atmospheric attenuation laws) and above.

4. SIMPLIFICATIONS AND INTERDEPENDANCE OF VARIABLES.

Under conditions where $\left(\frac{K_2 \cdot A_T(x)_M}{A_e(x)_M} + K_3 \right) B$ is small (say<0.1) - a common situation for full daylight viewing - it is possible to simplify the left hand side (L.H.S.) of Eq (12) considerably.

Then $$\log_e \left[\frac{\left(\frac{K_2 \cdot A_T(x)_M}{A_e(x)_M} + K_3 \right) B + 1}{K_3 B + 1} \right] \approx \frac{K_2 \cdot A_T(x)_M \cdot B}{A_e(x)_M}$$ since $\log_e(x+1) \approx x$ for small x.

This leads to a much simpler equation to inspect; viz:-

$$\frac{4.25K_2 \cdot A_T(x)_M \cdot M^2 \cdot D^2 \cdot \eta \cdot f(C_0)}{A_e(x)_M (18M^4 \cdot D^4 + R^4)^{\frac{1}{2}}} = \frac{K_1 \cdot R^{1.5} (\theta_a + 1)}{(236M^2 \cdot D^2 + 80R^2)^{\frac{3}{4}}} + \delta \quad \ldots . \quad (13)$$

Now the L.H.S. of Eqs. (12) and (13) represents the average stimulus available to each retinal receptor pair lying along the image edge contour and the right hand side (R.H.S.) represents the stimulus required to reach threshold at a defined confidence level.

The R.H.S. contains experimental constants; range, angle off fovea, magnification and target size. Hence, if we hold these constant the R.H.S. becomes a constant and we may universally equate the remaining parameters in Eq (13), (i.e. C_o, η and $A_T(x)_M/A_e(x)_M$), whereupon $\left(C_o \cdot \eta \cdot A_T(x)_M/A_e(x)_M\right)$ = constant may be taken as invariant. This, of course, is little more than a statement of the obvious.

For Eq.(12) or (13) when $236M^2.D^2 \ll 80R^2$ (say 1 : 20) then the R.H.S. becomes independant of M and D. Also around the same condition $(18M^4.D^4 + R^4)^{\frac{1}{4}}$ becomes nearly equal to R^2. Thus under these conditions, i.e. where $\frac{M.D}{R} \ll {}^1/_{7.7}$, the stimulus situation becomes much simplified and $M^2.D^2.f(C_o).\eta/_{R^2}$ = constant for a given system quality (Ricco's Law for point objects).

At the other extreme when $236M^2.D^2 > 80R^2 \times 10$ Eq (13) simplifies to

$$\frac{K_2 \cdot A_T(x)_M \cdot \eta \cdot f(C_o)}{A_e(x)_M} = \frac{K_1 \cdot R^{1.5}(\theta_a + 1)}{60M^{1.5}D^{1.5}} + \delta \qquad \ldots\ldots (14)$$

Similarly Eq (12) also simplifies to

$$\log_e \left[\frac{\left(\frac{K_2 \cdot A_T(x)_M}{A_e(x)_M} + K_3\right)B + 1}{K_3 B + 1}\right] = \frac{K_1 \cdot R^{1.5}(\theta_a + 1)}{60M^{1.5}D^{1.5}} + \delta \qquad \ldots\ldots (15)$$

where $B = \eta . f(C_o)$.

Under these conditions, in either case, if threshold is designated by T,

$$\frac{(T - \delta)}{K_1} \propto \frac{R^{1.5}(\theta_a + 1)}{M^{1.5}D^{1.5}} \qquad \ldots\ldots (16)$$

which may be taken as a general law for extended objects.

5. THE SEARCH SITUATION

To this point all theory has been applied to probability of acquisition in a single glimpse. In a practical situation the target will be presented at some position in a bounded search field and the probability of detecting it in one glimpse will be related to the size of the prevailing visual lobe (for the instantaneous stimulus conditions) and the size of the search field. This will always apply for empty field search through a visual aid with any significant magnification, even when in a so called 'no search' mode, since the eyepiece field of view of most visual aids is between 30° and 50°. Even for naked eye viewing there is usually an uncertainty of position of several degrees, although this may not be so in certain well briefed situations. Thus the simple single glimpse probability defined by Eqs (12) and (13) is a very inadequate representation of the complete acquisition process. However, it is still the basic input. What is required is a modelling of the accumulation of probability of acquisition with successive glimpses as the stimulus grows through threshold.

If a weighted search pattern and a soft-shell visual lobe are considered - the realistic practical case - then the computation is very complex. Fortunately it is possible reasonably to approximate the visual lobe situation by defining a hard shell lobe as the 50% single glimpse probability envelope and saying that all targets within the envelope will be detected and all outside it will be missed. Averaged over a number of glimpses this should not be seriously in error. If also a uniform weighting to search within the field is assumed (a reasonably fair assumption if the observer has no prior information from which to structure his search) it may be shown that the single glimpse probability is given by

$$p_g = \left(\theta_a/\theta_F - \theta_a^2/4\theta_F^2\right)^2 \qquad \ldots\ldots (17)$$

where θ_a is the instantaneous value of visual lobe radius from Eq (12) using values of K_1 and δ appropriate to 50% single glimpse probability, and θ_F is the radius of the search field.

Then the total probability of detection in m glimpses will be

$$\Phi_m = \left[1 - \prod_1^m (1 - p_{gm})\right] \qquad \ldots\ldots (18)$$

This, of course, is only a true statement if the glimpses are independant.

The approximation of visual lobes as hard shells defined by the 50% probability contour is only adequate when the foveal single glimpse probability of detection is unity. When the foveal probability of detection is less than unity, θ_a must be defined as the radius for a probability of $p_f/_2$ and the total probability must be limited by p_f where p_f is the foveal single glimpse probability.

In this case the single glimpse probability is

$$p_f \cdot p_g = p_f\left(\theta_a/\theta_F - \theta_a^2/4\theta_F^2\right)^2 \qquad \ldots\ldots (19)$$

In general the cumulative glimpse probability after m glimpses is given where

$$p_{fm} - \Phi_m = p_{fm}(1 - p_{gm}) \cdot p_{f(m-1)}(1 - p_{g(m-1)}) \cdots p_{f1}(1 - p_{g1}) = \prod_1^m p_f(1 - p_g)$$

or

$$\Phi_m = p_f - \prod_{r=1}^{r=m} p_{fr}(1 - p_{gr}) \qquad \ldots\ldots (20)$$

For a 'no growth' stimulus situation p_{fr} and p_{gr} in Eq (20) are constant and equal to p_{fm} and p_{gm} respectively. In the case where the stimulus is growing through threshold fairly rapidly it is likely that p_{fm} after several glimpses will be unity and that the only glimpses which contribute significantly to $\bar{\Phi}_m$ are those where p_f is unity. In this case $\bar{\Phi}_m$ is given by Eq (18) approximately.

N.B. If one has not a bounded field (i.e. naked eye situation), it is considered that no correction for field boundary is required and it is then probably permissible to use $p_g = \theta_a^2/\theta_F^2$ instead of Eq (17).

6. PREDICTIONS OF LABORATORY THRESHOLD DATA

In order to check on the adequacy of parts of the extended model of vision it is necessary to find controlled laboratory data taken under appropriate circumstances against which to make predictions in the first instance. Now a majority of laboratory data is neither true single glimpse, true random search nor true infinite viewing time. However, three particular sets of data were considered appropriate - those of J.H. Taylor (Ref.7) for single glimpse detection of various sizes of objects in peripheral vision, those of Krendel and Wodinsky (Ref.12) concerned with empty field search and Blackwell's infinite viewing time foveal detection experiments (Ref.3) for studying small size effects.

6.1. Peripheral Vision

In order to check the adequacy of the extension of the model to peripheral vision an exercise was carried out to attempt to find one pair of constants K_1 and δ which would fit the whole range of J.H. Taylor's data obtained at a background luminance of 75ft.L.. It was found that one pair of constants would indeed provide a very adequate prediction of these data - $K_1 = 1.1$ and $\delta = 0.0004$. The predictions of Taylor's data using these constants are shown in fig.1.

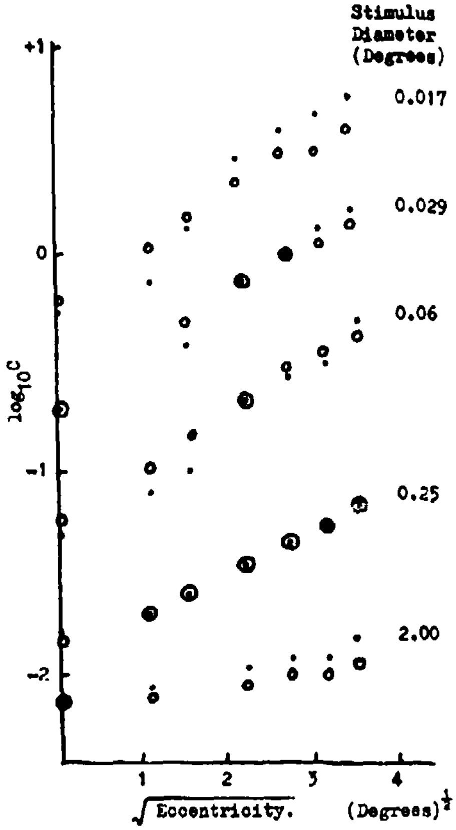


Fig.1. Predictions of J.H.Taylor's Peripheral Acquisition Thresholds using B.A.C. Vision Theory with Constants derived from Taylor's 0.25° Data.
• Taylor's Data. o Predictions.

6.2. Empty Field Search

Krendel and Wodinsky's data are available as a set of mean search times for different combinations of contrast, size, field luminance and search area. With such a set of data it is preferable to work backwards from the set of mean search times for various object sizes and contrasts and to compute a set of values of K_1 necessary to predict them by assuming δ is as used previously.

Now there is a suspicion of wasted glimpses for small search fields as found by Enoch (Ref.13). Also all other data for which the model had been used as a predictor to date were obtained at high photopic levels. Thus it was decided to compute values of K_1 for a selection of object contrasts and sizes at the highest field luminance tested by Krendel and Wodinsky and with the largest and smallest search areas studied. The largest search area, having a diameter of 43°, was well above the search field sizes where Enoch found significant wasted glimpses whilst the smallest search area, having a diameter of 6.8°, was within the region where Enoch found wasted glimpses.

For any particular situation if we take the search time for 50% probability this may be related to Eq (18) such that $0.5 = 1 - (1 - p_g)^m$ where $m = t_s/t_g$ (t_s = search time for 50% probability; t_g = mean assumed glimpse time).

For this exercise a value of 0.3 secs. was taken for t_g, this being the median value ascertained by a number of workers who have studied eye movements.

Then, from this value of p_g and Eq (17), one can derive a value of θ_a and, from Eq (12), a value of K_1. The questions are whether the values of K_1 for a given search area are constant, whether the mean value of K_1 obtained for the large search area is significantly different from that required to fit the Taylor data, and whether the values of K_1 for the small search area are appreciably greater than for the large search area. If the values of K_1 for a given search area are fairly constant this tends to support the modelling concept used. If the mean value of K_1 is greatly different from that to fit Taylor data it would suggest a marked change in basic foveal threshold performance due to search.

The results of the exercise to compute a set of values of K_1 are to be found in Table 1. It will be seen that the values of K_1 for the large search area are tolerably constant over a wide range of contrasts and sizes, particularly bearing in mind the fact that the tabulated results of Krendel and Wodinsky are taken from best fits to their data which they acknowledge themselves to be not always good. Of greatest importance is the fact that there are no obvious trends of K_1 in terms of size or contrast.

Search Field Diameter (degrees)	Target Diameter (mins.)	Contrast	Mean 50% Detection Time (secs.)	K_1
43	4.8	0.43 0.68	7.2 2.7	1.47 1.28
	13	0.086 0.11 0.14	21 11 3.3	1.91 1.88 1.43
	24	0.03 0.072	21 3.6	1.50 1.88
6.8	13	0.086	1.8	2.68
	24	0.03 0.038	8.3 3.7	3.00 3.50

Table 1. Selected mean acquisition times from Krendel and Wodinsky and values of K_1 to match with the model of equation (12) using glimpse times of 0.3 secs.

The average value of K_1 for the large search field ($K_1 = 1.62$) is appreciably higher than that required to fit the J.H. Taylor data. Part of this difference is to be expected due to the Krendel and Wodinsky data being obtained at a lower field luminance than that used by Taylor. In addition it is to be expected that the thresholds will be higher than those of Taylor due to the method of experimentation being one of free choice. The values of K_1 obtained for the 6.8° search field are less satisfactorily constant. They are, on the other hand, very appreciably higher than those for the larger search area, the ratio being approximately as would be predicted from Enoch.

6.3. No Search, Infinite Viewing Time

The opposite end of the viewing spectrum from wide field search is where we have no search at all, an extended viewing time and no stimulus growth. This is represented in the laboratory by Blackwell's classical Tiffany Foundation experiments (Ref.10).

Such a viewing situation must yield the absolute maximum acquisition ranges for a given set of field conditions. It was postulated by Overington and Lavin (Ref.2) that for such a situation the basic threshold formula for foveal vision should be modified by removing a $\sqrt{n}$ noise function. Thus the formula proposed for infinite viewing times instead of Eq (2) was

$$\log_e\left[\frac{(K_2 + K_3)C + 1}{K_3 C + 1}\right] = \frac{K_1}{n(n-1)} + \delta \quad \ldots\ldots \quad (21)$$

Converted into a size, contrast and range function similar to Eq (12) this becomes:-

$$\log_e\left[\frac{\left(\frac{K_2 \cdot A_T(x)_M}{A_e(x)_M} + K_3\right)B + 1}{K_3 B + 1}\right] = \frac{K_1 . R^2 . (\theta_a + 1)^{1.25}}{(236M^2 . D^2 + 80R^2)} + \delta \quad \ldots\ldots \quad (22)$$

where in the limit, for fixated foveal viewing, $\theta_a \to 0$.

The values of K_1 and δ necessary to fit the Blackwell data at 30ft.L. have been computed. They are found to be $K_1 = 1.05$ and $\delta = 0.0004$ which are virtually the same as those shown to be necessary to fit the Taylor data (obtained at 75ft.L.) using Eq (12). For a fit to a typical set of daylight data (e.g. 300ft.L.) it was found necessary to reduce K_1 to 0.74, retaining δ at 0.0004. The fits achieved for both 30ft.L. and 300ft.L. are shown in fig.2.

The implication of the close agreement of constants for similar luminance in this and the preceeding Sections is that for a fixed field luminance total visual performance for simple stimuli may be predicted by one pair of constants simply by invoking a progressive 'suppression' of receptor channel noise as glimpses are overlaid.

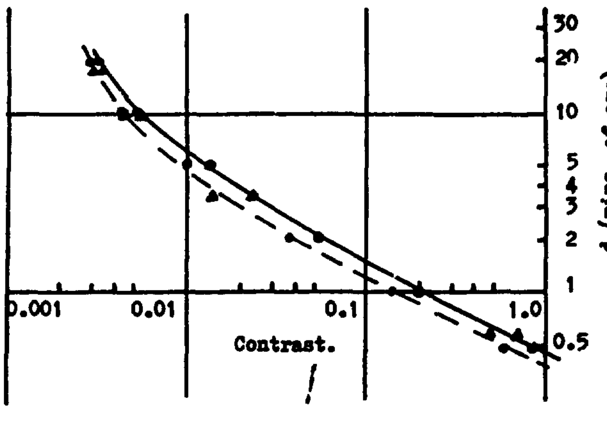


Fig.2. Theoretical Predictions of Blackwell Infinite Search Curves.
Data from Blackwell - ▲ 300 ft.L., ▲ 30 ft.L..
Theoretical Predictions - { • 300 ft.L. ($K_1 = 0.74$). ∘ 30 ft.L. ($K_1 = 1.05$).

It is postulated that the form of this progressive suppression of noise is itself a cumulative probability function. Then for a finite number of overlaying glimpses N, and with an infinite viewing time foveal probability $\Phi_f = 1$, we have

$$\Phi_N = 1 - \prod_{q=1}^{q=N} (1 - p_{gq}) \quad \ldots\ldots\ldots\ldots \quad (23)$$

where Φ_N is the accumulated probability in N glimpses.

p_{gq} is the single glimpse probability on the qth. overlaid glimpse.

For a search situation where $m\,\theta_a^2 > \theta_p^2$, we still have

$$\Phi_N = 1 - \prod_{q=1}^{q=N} (1 - p_{gq}) \qquad \text{where } N = m\,\theta_a^2/\theta_p^2 .$$

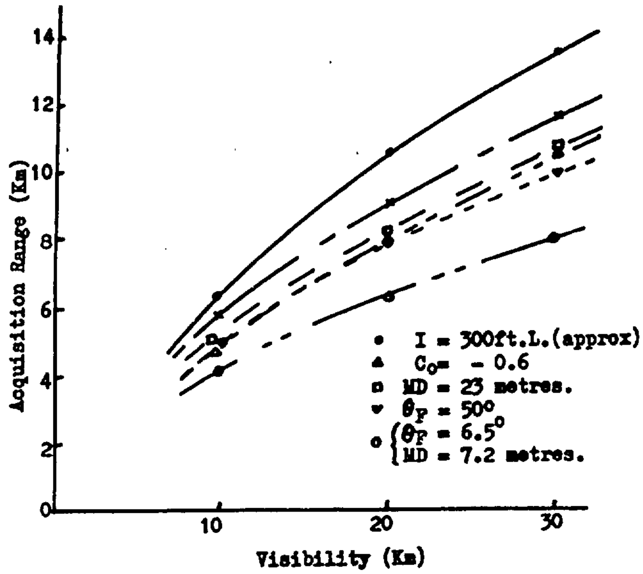


Fig.3. Acquisition Range v Visibility for a variety of Conditions where v = 0.2 Km/sec..
x Reference Conditions:- $\theta_F = 25°$, $C_o = -0.9$, MD = 30metres, $I^F = 30$ft.L.° (approx.).
All conditions plotted have $\eta = 1$, $A_T(x)_M / A_e(x)_M = 1$.
Other conditions quoted are variants from the reference condition.

However, in place of Eq (18)

$$\Phi_m = 1 - \prod_{r=1}^{r=s} (1 - \Phi_{Nr}) \quad . \quad . \quad . \quad (24)$$

where $s = \theta_F^2 / \theta_a^2$ and r relates to the rth of a finite number of glimpse positions s.

For a substantially no growth situation these formulae become simply

$$\Phi_N = 1 - (1 - p_g)^N$$

and $\Phi_m = 1 - (1 - \Phi_N)^s$

whence $\Phi_m = 1 - (1 - p_g)^{Ns}$

but $Ns = m$

$$\therefore \quad \Phi_m = 1 - (1 - p_g)^m \quad . \quad . \quad . \quad (25)$$

i.e. a simple cumulative probability function for m glimpses.

Equally in a no growth situation where foveal probability is p_f for single glimpses and Φ_f for infinite viewing time

$$\Phi_N = \Phi_f - \prod_{q=1}^{q=N} (\Phi_f - p_g)$$

$$\Phi_m = p_f - \prod_{r=1}^{r=s} (p_f - \Phi_N)$$

$$\therefore \Phi_m = p_f - \prod_{r=1}^{r=s} \left[p_f - \Phi_f + \prod_{q=1}^{q=N} (\Phi_f - p_g) \right]$$

or $\Phi_m = p_f - \left[p_f - \Phi_f + (\Phi_f - p_g)^N \right]^s \quad .. (26)$

This formula fits all end conditions and explains the transition from single glimpse to compound glimpse situations.

N.B. $N \nless 1$ but can have any value greater than unity (i.e. is not limited to integer values).
When N = 1: $1 < s < \theta_F^2/\theta_a^2$. When N > 1, $s = \theta_F^2/\theta_a^2$.

In a stimulus growth situation, of course, the stimulus is growing through threshold during the accumulation of overlaid glimpses. Thus each overlaid glimpse is 'stronger' than the preceeding one. The detailed mathematics of accumulation of overlaid glimpses in this situation, which involves growth of visual lobes interacting with search accumulation, is beyond the scope of the present paper. It is therefore recommended that, for the present, the fixated foveal viewing model in a growth situation be used solely as a predictor of absolute maximum acquisition range as growth tends to zero. A probable minimum acquisition range may then be predicted by assuming approximately 20 overlaid glimpses necessary to approach the infinite viewing condition. Knowing the approach speed and assuming an average of 3 glimpses/second the maximum differential closing of range during accumulation of glimpses may readily be computed.

7. PRACTICAL USE OF THE COMPLETE MODEL

We are now in a position to consider the total random search situation (assuming independence of glimpses) and the best performance with search tending to zero.

Now the main purpose of this comprehensive model is to study acquisition performance in a stimulus growth situation in the field. For the computation in a search and stimulus growth situation a

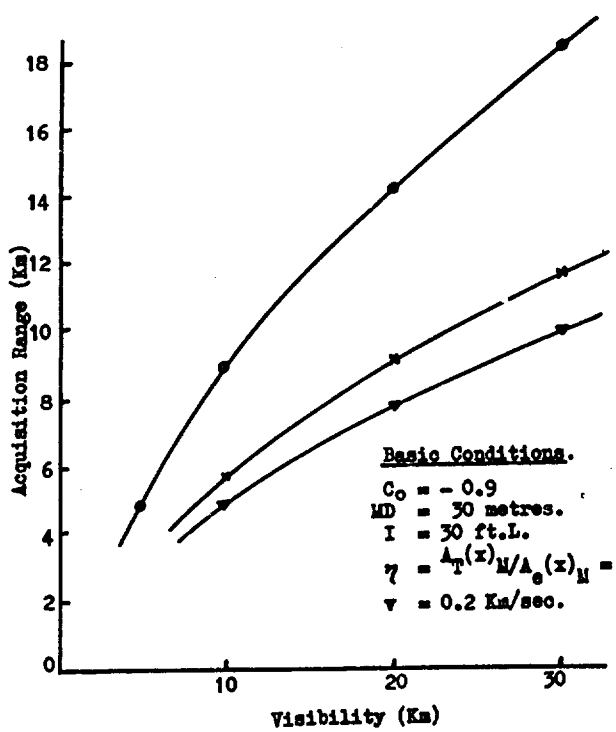


Fig.4. Acquisition Range v Visibility for Various Search Conditions (Large Target).
o $\theta_F = 0$ (single glimpse foveal).
x $\theta_F = 25°$. ▽ $\theta_F = 50°$.

value of R is first obtained from Eq (12) or (13), with $\theta_a = 0$ (i.e. for foveal single glimpse detection). This value of R is then used as a starting point for search probability computations.

A set of range increments are next chosen from the computed value of R. (Increments of 0.2Km. are found to be appropriate for aircraft approach). For the first of these ranges Eq (12) or (13) is used to compute a value of θ_a. The value of θ_a is entered into a probability program together with θ_F and a single glimpse probability computed. A number of glimpses for the differential range is computed from mean glimpse time and approach speed using $m = \Delta R / v t_g$ where ΔR is a range increment, v is the closing velocity (Km/sec) and t_g is the average glimpse time. By interpolation the cumulative probability over these glimpses is produced. Finally more values of range are injected into Eq (12) or (13) and the above procedure repeated until the required cumulative probability is achieved or the complete cumulative probability profile is constructed.

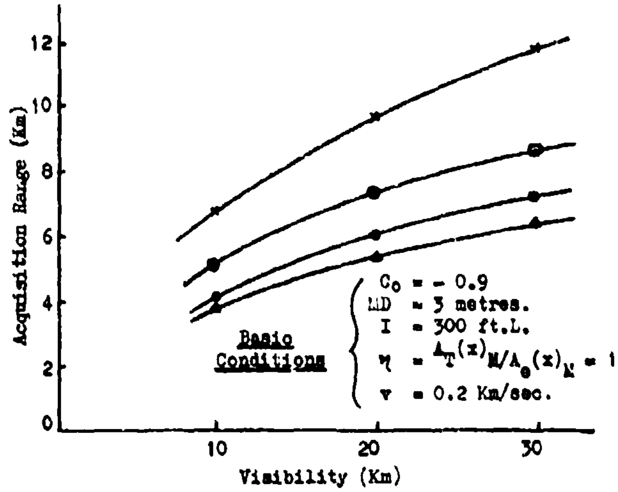


Fig.5. Acquisition Range v Visibility for Various Search Conditions (Small Target).
× Fixated foveal (no search, no growth).
⊙ $\theta_F = 0$ (single glimpse foveal).
o $\theta_F = 2.5°$ ▲ $\theta_F = 5°$

For predictions of 'no search' performance for a set of viewing conditions a value of R is obtained from Eq (22) with θ_a set equal to zero.

A computer program has been written which combines Eq (12) and (13) by inclusion of a 'power' constant on the R.H.S. and also allows an alternative input from Eq (13). This program then allows computation of an appropriate 50% probability acquisition range (single glimpse or infinite time) and goes on to compute the complete cumulative probability/range curve where appropriate.

8. SOME SAMPLE OUTPUTS

Amongst the factors studied using the model to date are some typical relationships between acquisition range and prevailing visibility for a selection of target sizes and search areas, the effects of search area on acquisition range and accumulation of probability for specific sizes, and the effect of image quality on acquisition performance. Some sample results are shown in figures 3 - 7. In figure 3 are shown a number of acquisition curves as functions of visibility. It is interesting to note that they are all of very similar shape. Certain of these curves, most particularly the wide field search curves, have been verified in field trials as being accurate in both trend and absolute value (visibility being measured along the mean inclined viewing path which is very different from meteorological horizontal ground visibility - see for instance Ref.14). In figures 4 and 5 the massive effects of search on acquisition in a stimulus growth situation are well illustrated. Note particularly the vast difference between best fixated foveal acquisition and that with 10° diameter search field in fig.5. Fig.6 illustrates the change of slope of the cumulative probability curves as a function of both visibility and search area. Finally in fig.7 can be seen the effects of degrading the retinal image sharpness by a factor of 2.

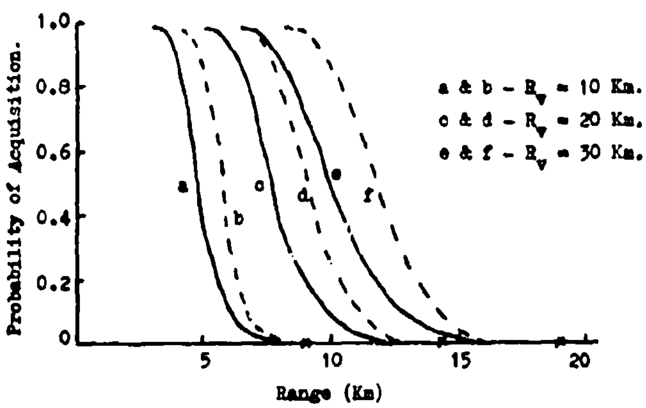
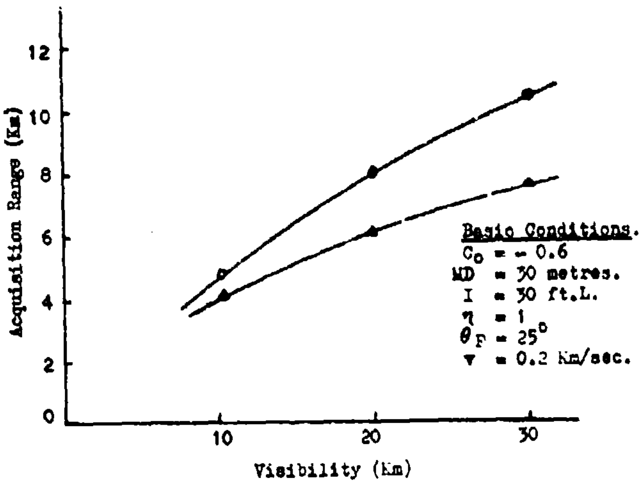


Fig.6. Typical Probability / Range Plots as a Function of Search Angle and Visibility. (v = 0.2 Km / sec.)
——— $\theta_F = 50°$ – – – – $\theta_F = 25°$
× Foveal single glimpse acquisition range (p=0.5).

9. CONCLUSIONS

It has been shown possible to develop a complete model of the visual acquisition process for a random search situation based on the physical properties of the eye. With the model it becomes possible to investigate the interactions between such factors as search field area, retinal image quality, target growth rate and visibility, as well as their interactions with the more 'standard' parameters,



size, contrast and luminance. Practical situations studied to date show search area to be a major factor contributing to acquisition range, overshadowing the effects of many other parameters. This suggests that there are major advantages to be gained by, where possible, minimising search and developing optimal rather than random search strategies.

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Fig.7. Typical Effect of Image Quality on Acquisition Range.

○ $A_T(x)_M / A_e(x)_M$ = 1.

△ $A_T(x)_M / A_e(x)_M$ = [illegible]

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DISCUSSION

Group Captain Whiteside (UK)

Could you tell me again about the possible use of binoculars in your search field and how this relates to the previous speaker's mention of the use of extra-foveal information. You're dealing with an empty field, aren't you?

Mr Overington (UK)

An empty field, yes. Normal search modelling is associated with hard shell visual lobes, but could be applied to the more difficult soft shell idea. This is what triggered my own question to the previous speaker about off-axis distance. Obviously, performance falls off with distance from the visual axis, and I seem to have modelled this reasonably well. An optical aid inevitably increases field of view by magnification, and therefore any object is pushed off-axis by a similar factor, so its threshold is suppressed. The effect is to degrade peripheral thresholds, in a subjective sense, but not quite as much as to offset the improvement due to magnification. You lose some of your optical aid's advantage.

Group Captain Whiteside (UK)

Is it actually better or worse?

Mr Overington (UK)

This sort of modelling could answer that, but we haven't had chance to consider enough cases to get a general answer. The only answer I can give is that in specific field conditions where we used a x10 sight, overall performance was no better than naked eye. I don't think this should be generalised; it depends on a whole host of conditions.

Dr Grether (US)

In your presentation I had trouble differentiating field data and data computed by your model. All your points sat on the curve, which they didn't do with Dr Greening's data.

Mr Overington (UK)

In the text, continuous lines are predictions (except for the small infinite search time data) and circles are data points from laboratory or field.

Dr Vos (Netherlands)

I have a question on your constants K_2 and K_3. Do they both relate to image quality?

Mr Overington (UK)

Yes, but not to sharpness. You need to refer to the full paper, or to Optica Acta. K_2 is directly related to edge slope gradient, K_3 defines the position of this maximum gradient region and in normal symmetrical imagery will be half way up the edge. But if you get asymmetric optics this could be shifted, giving a long-tailed flat-topped curve. It also changes slightly as one runs into the small size region.

Dr Vos (Netherlands)

Your two basic formulae, for small and large objects, leave out the middle ground of contrast effects.

Mr Overington (UK)

I actually ran the two together in the model, from small to large size effects. An arrow in the Figure shows the general formula as well as the small and large cases.

The "K" Factor in Air-to-Ground Acquisition Modelling.

D. G. SILVERTHORN

BRITISH AIRCRAFT CORPORATION LIMITED
GUIDED WEAPONS DIVISION : BRISTOL WORKS

SUMMARY

The simplest acquisition task from the modelling viewpoint is that of detection under conditions in which the target and its location are fully learned. This task is scored as a "potential detection range". The starting point at B.A.C. for modelling this task is the Tiffany Data (Blackwell, 1946) which provides the probability of detection at a given target contrast as a function of angular size and field brightness. The link to detection range is provided by appropriate size-range and contrast-range functions.

This paper illustrates that correspondence obtained between the shapes of the probability-range curves is good both for field and simulated field detection data, but that actual performance levels are much lower than predicted. A "degradation" factor (the K factor of the title) has been introduced to cover this discrepancy and a similar fudge factor has been invoked to cover differences between simulated and direct field trial data.

The paper examines the factors on which K is dependent and describes relevant experiments at B.A.C. and the associated attempts at modelling them. It is at once a progress statement and an indication of the necessary further studies.

LIST OF SYMBOLS

A, a	-Area
B_o	-Field (or background) brightness Ft. Lamberts
b	-Sky-ground brightness ratio
C	-Apparent contrast
C_o	-Intrinsic Contrast where contrast is defined as the ratio of the brightness difference between target and background to the background brightness
g_t	-Glimpse time
H	-Altitude
K	-Degradation Factor
n	-Number of
p	-Probability density
p_g	-Single glimpse
p_f^g	-Single glimpse foveal
R	-Range
S	-Stimulus value
t	-Statistic "number of standard deviations"
V	-Visibility
X, Y	-measures in Cartesian coordinates
α	-angular subtense
ϕ	-Cumulative Probability
θ	-Angle off axis
σ	-Standard deviation

The symbol $\hat{}$ (circumflex) over any other symbol refers to the median value.

1. INTRODUCTION

Modelling in any sense requires a definition of aims, identification of relevant parameters, the collection of relevant theoretical and/or empirical data, assembly, or programming and finally validation. It is an iterative, learning process; it is a simplified, incomplete expression of the reality; its success and its value depends on the ability of the modeller to identify the relevant parameters. In a sense, the model stands for a scientific hypothesis and as such should be capable of predicting effects which advance the understanding of underlying processes. Arising from this, the sensitivity of the end product to the various input factors and to their interactions can be assessed with the aim of simplification and also to stimulate further development. Again, in validating the model against experimental or field data, it must be expected that inconsistencies will be revealed when such data is derived from situations akin to but not identical with the system modelled. The model however would be of little value if it had no capability for extrapolation: part of the validation process must be to determine the limits to extrapolation.

This paper first considered the aims of modelling target acquisition for the air-to-ground case and is followed by a summary of the relevant parameters to be considered. A simple model for the no-search case is discussed and is used to introduce the K or degradation factor as a necessary element. A more advanced model for the no-search case, best handled by a digital computer program, is given and the results of certain comparisons with flight and simulated flight experimental studies are described.

2. MODELLING AIMS

Modelling in the present context aims to predict the probability of acquiring the designated target as a function of its range as the target is approached on a defined course.

The term acquisition is used to cover "detection" as a response to the presence of an object, and "recognition" as a response to the presence of an object matching the target description. The acquisition task may be performed under no-search or search conditions, with the naked eye or aided.

The accuracy requirement, an important part of any statement of modelling aims, is complex and has not been fully defined at the present level of study. I shall leave it here simply as ± 50% on the threshold detection range, $\hat{R}$, as given by the model itself and excluding errors in the measurements of input parameters such as visibility. Some such statement is necessary if the modelling is to be efficient.

Starting from a 'best' performance prediction, the approach adopted has been to identify the sources of degradation likely to affect the real world situation and to estimate the magnitude of the degradation or K factor. The "best performance" prediction as used in the present studies is for the no-search case and is based on the 'area theory' of detection as exemplified in the Tiffany data (Reference 1). This data describes the detection of circular disc targets in a plain field as a function of their angular diameter α their contrast C and also of the field brightness B_0. Unlimited viewing time was given to each, well practiced, subject using the psychophysical "method of constants".

There are alternative starting points which are well summarised by Davies (Reference 2A). In his paper to this conference, Overington describes his development of an alternative based on an edge detection theory.

The level of accuracy given above might suggest that a crude model, such as $\hat{R} = K V$ might be adequate. Inspection of experimental and field data shows this not to be the case; the range of values of K needed is too wide. More detailed modelling can be expected to show the dependence of K, as defined in this manner, on other factors as listed in the following section.

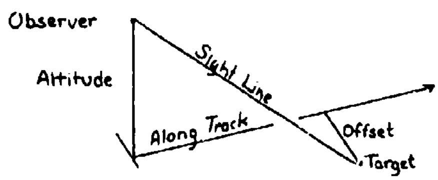
3. IDENTIFICATION OF RELEVANT PARAMETERS

Briefly, these may be considered in four principal groups as follows:

3.1. Visual characteristics of the target and field as projected along the sight-line.

Real-world targets are usually three-dimensional objects of complex interior detail; while the dimensions can be regarded as fixed, brightness levels will depend on the direction and intensity of incident illumination and the reflective properties of the various target surfaces. The field will generally be structured: the level of background clutter, the presence of objects confusable with the target and target screening will affect acquisition. The target position in the field will be known for the no-search case and unknown, but within a defined area for the search-case.

The sight-line direction may be resolved in terms of along-track range, offset and altitude. These are taken as the basic geometric factors affecting acquisition.



These and their rates of change may have psychological and well as physiological implications for the observer.

3.2. Modification of the target/field characteristics by transmission through the atmosphere.

The principal effects here are well established and operate by attenuation of the target intrinsic contrast. The simplest expression of the effect is given by:

$$C = C_o e^{-3.92 R/V} \qquad (1)$$

(where the constant 3.92 relates to a visibility defined by the 2% residual contrast point). A more appropriate expression for air-to-ground viewing is given by:

$$C = \frac{C_o}{1 + b\left(e^{3.92 R/V} - 1\right)} \qquad (2)$$

(which reduces to (1) for a sky-ground brightness ratio, b=1).

The validity of these expressions depends on a homogeneous atmosphere: altitude (or layering) effects, the presence of broken cloud between sun and sight-line, precipitations and localised industrial haze are typical factors which may upset this homogeneity.

3.3. Modification of the target/field characteristics by imaging systems. The relevant factors here include:

(i) Properties of the imaging system, such as magnification, veiling glare, transmission loss, field of view and blur. Similar factors will apply when simulating real world situations for experimental purposes.

(ii) For optical systems, the interaction with the optical properties of the eye. - e.g. aperture effects.

(iii) Interaction with the observer's interpretive capacity - particularly for Infra Red and Radar imagery.

3.4. Observer Characteristics

The observer, receiving a visual input, will correlate this with memorised information to reach a decision and then to make an appropriate response. Factors affecting his performance include:-

(i) Optical efficiency of the observers visual process. Mechanical effects of the environment, particularly vibration, should be included here. Target and Field motions relative to each other and to the observer can also be expected to affect visual performance.

(ii) Psychological factors, affecting the ability of the observer to interpret the visual scene in the light of the briefing given and to make the appropriate decision in both search and no-search modes. In the search case, approach speed and search area must additionally be considered. Implications of the required response for the observers decision making must not be neglected.

4. A SIMPLE NO-SEARCH MODEL

4.1. Mathematical Description

We assume an approach along the sight-line to a target of area A_o normal to the sight-line. At a range R then, the angular diameter α_R of the circle of equivalent area is given by:

$$\alpha_R = 3879 \frac{A_o^{1/2}}{R} \qquad \text{———(3)}$$

Assuming a visibility, V, the apparent contrast C_R at range R is taken as given by equation (1) viz:

$$C_R = C_o e^{-3.92 R/V}$$

The Tiffany data as reported by Blackwell for foveal, unlimited viewing time is approximated, for the threshold, by:

$$\hat{S} = \alpha \hat{C}^{1/2} \qquad \text{———(4)}$$

for small angular sizes, $\alpha < 5$ minutes of arc. $\hat{S}$, the threshold stimulus, is a constant for a given background brightness.

We similarly describe the stimulus magnitude at range R by $S_R = \alpha_R C_R^{1/2}$ which by substitution from (1) and (3) becomes:

$$S_R = \frac{3879 (A_o C_o)^{1/2}}{R\, e^{1.96 R/V}} \qquad \text{———(5)}$$

Since A_o and C_o are "intrinsic" characteristics of the target we define an intrinsic stimulus

$$S_o = 3879 (A_o C_o)^{1/2} \text{ whence}$$

$$S_R = \frac{S_o}{R\, e^{1.96 R/V}}$$

which in Naperian logarithms becomes

$$\log_e S_R = \log_e S_o - (\log_e R + 1.96 R/V) \qquad \text{———(6)}$$

Using the approximation

$$\sigma_{\log_e C/\hat{C}} = 0.542$$

for the "frequency of seeing" surve given by Blackwell, we find

$$\sigma_{\log_e S/\hat{S}} = \tfrac{1}{2} \sigma_{\log_e C/\hat{C}} = 0.271$$

The probability of detection at range R is then given by:

$$\phi_R = (2\pi)^{-1/2} \int_{-\infty}^{t_R} e^{-t^2/2}\, dt \qquad \text{———(7a)}$$

where

$$t_R = \frac{\log_e S_R - \log_e \hat{S}}{\sigma_{\log_e S/\hat{S}}} \qquad \text{———(7b)}$$

Finally, simulating the approach to the target by incremental steps in range, and calculating at each step $\log_e S_R$ from (6), t_R from (7b) and thus ϕ_R from (7a), we therefore map out the cumulative detection probability. By its derivation, this describes the probability of detection given unlimited viewing time at each range. While this is not of much practical field value, it does correspond in experimental situations to what we have called "Potential" detection probability.

From this analysis certain other features of the model follow:

(i) The range at which a given probability ϕ is reached is given by:

$$\log_e R_\phi + 1.96 R_\phi/V = \log_e S_o - \log_e S_\phi \qquad \text{(8a)}$$

where

$$\log_e S_\phi = \log_e \hat{S} + t\,\sigma_{\log_e S/\hat{S}} \qquad \text{(8b)}$$

In particular, the median detection range is given by

$$\log_e \hat{R} + 1.96 \hat{R}/V = \log_e S_o - \log_e \hat{S} \qquad \text{(9)}$$

(ii) Since $\log_e S$ is, approximately, normally distributed about $\log_e \hat{S}$, then $(\log_e R + 1.96 R/V)$ is, approximately, normally distributed also, from which it appears that neither log R nor R can be normally distributed. However, for purposes of plotting cumulative probability curves as predicted by modelling, and determined from experimental data, it has been found helpful to express these curves in PROBIT v LOG RANGE form (where PROBIT = t + 5 : this will be recognised as equivalent to plotting on normal probability paper).

4.2. A First Comparison With Experimental Data

Figure 1 illustrates at (A) model predictions and at (B) certain experimental results expressed in similar form. The model was not used here to predict the experimental results but to show that the general form of results is compatible. An interesting point arises here: the value of $\sigma_{\log_e S/\hat{S}}$ used in the model is derived from Blackwells "average observer" while the experimental results are based on 4 replications by each of 6 observers. This suggests the Blackwell variance to be too high, which is in accord with values commonly found in our own experimentation on thresholds. This discrepancy may be due to the different psychophysical methods used by ourselves and Blackwell. Since we use a curtailed method - the "threshold tracking" method-we acquire data from individual subjects over a matter of a few days while the more elaborate method of Blackwell involves subjects for much longer periods.

It will be observed also that the experimental results depart from the expectation provided by the model for the 10Km visibility case. While we can largely discount results at greater than 90% or less than the 10% levels on the basis of their low accuracy in probability, there does remain an effect to be explained.

4.3. The Degradation Factor, K.

In order to seek a match between the experimental data and the model prediction it is convenient to introduce a degradation factor K into the model. This we assume, in the first place, to operate on the threshold stimulus $\hat{S}$ such that the degraded stimulus $\hat{S}_K$ is given by:

$$\hat{S}_K = K\hat{S}$$

where K is greater than unity in the sense of degradation and less than unity in the sense of enhancement. Thus

$$\log_e \hat{S}_K = \log_e K + \log_e \hat{S} \qquad \text{(10)}$$

Replacing $\log_e \hat{S}$ in equation (8b) to represent the operative threshold characteristic and combining with (8a) and (10) gives:

$$\log_e R_\phi + 1.96 R_\phi/V = \log_e S_o - \log_e \hat{S} - t\,\sigma_{\log_e S/\hat{S}} - \log_e K \qquad \text{(11a)}$$

or for the threshold range

$$\log_e \hat{R} + 1.96 \hat{R}/V = \log_e S_o - \log_e \hat{S} - \log_e K \qquad \text{(11b)}$$

Clearly, the degradation term, $\log_e K$, can be seen to describe also a degradation of the intrinsic stimulus through intrinsic contrast and, or absolute area. This incidentally provides a means to represent magnification and veiling glare factors in sight systems (sight transmission loss can be represented directly by a degradation of the threshold stimulus).

4.4. Further Comparison with Experimental Data

The task set required subjects to detect a diamond shaped target aided by a X10 magnification sight. The simulation provided a target growth situation as represented in equations (1) and (3). The target was presented on a plain illuminated screen so observed through the fixed sight as to appear randomly in one of several positions. Targets of two sizes were used; visibilities of 10, 20 and 30Km were simulated. Each of six subjects completed four runs at each size and visibility condition against randomly selected target positions. Figure 1 illustrates at B the cumulative probability curves for the three visibilities at one size.

To estimate the degradation factor, using equation (11b), the median detection ranges for each size-visibility combination were extracted and used to calculate values of $2^{(\log_e R + 1.96 R/V)}$. Using the intrinsic contrast of 0.8 set in the simulation and the two sizes ($7.4m^2$, $14.8m^2$) together with the sight magnification, values of S_o were obtained. A value −0.575 was taken for $\log_e \bar{S}$, consistent with the Blackwell Foveal unlimited viewing time data of 10ft Lamberts, which assumed the sight transmission loss. The values of K then obtained from (11b) were:

A_o	V(Km)	K	A_o	V(Km)	K
	10	18.3		10	19.3
7.4	20	16.7	14.8	20	17.1
	30	17.2		30	16.3

Using the mean value of K viz 17.5 in (11a) the median, 10 and 90% points were estimated with $\sigma_{\log_e S/\bar{S}} = 0.271$.

The data is illustrated in Figure 2, together with the predicted 10, 50 and 90% points, as a function of visibility. For all practical purposes a good fit can be claimed – but it remains to show how far the degradation factor can be predicted. There is clearly no single source of degradation and the following components have been identified for the present example.

(i) Task differences between the experiment and implied by the simple model: in particular there is an element of search in the experimental task which is more akin to the Blackwell 6 second, 8 position search case. This difference, estimated from the Tiffany data is represented approximately by a degradation factor of 1.6. A stimulus growth situation, in one direction only, is provided by the experimental task. Davies (Reference 2) suggests that for this case an increase in $\log_{10} \bar{\epsilon}$ of 0.55 is appropriate. This is equivalent to an increase of 0.633 in $\log_e \bar{S}$, or to a degradation factor of 1.9.

(ii) Sight effects. Transmission loss and magnification factors have already been included in the modelling. There remain veiling glare and blur effects. The latter has not been estimated for the sight used but the veiling glare effect has been estimated at providing:-

Apparent contrast = 0.7 x target contrast at the screen.

This is equivalent to a degradation factor of 1.2. A further factor, whose magnitude has not been estimated, concerns the setting up of the sight in terms of focus and inter-pupilary distance of the relatively inexperienced subjects.

(iii) Effects of target simulation as they affect the quality of the image presented on the screen. Intrinsic contrast and the effect of visibility were checked at one position on the screen and for a relatively large target. A bias was in fact found in the contrast measurement but the corrected value has been used in the present modelling. While it is now felt the method of checking out the simulation was inadequate, more detailed studies of the equipment have shown that the degradations introduced from these sources would be relatively small. A factor not considered is that of degradation of the simulation by vibration in the optical systems.

(iv) Subjects; although practice was given, it was not as comprehensive as that given to subjects in the Tiffany experiment and it has been found that our equipment engineers perform consistently better than experimental subjects in this simulation. However no controlled studies have been carried out and we are not able to estimate the degradation factor applying.

The combined degradation factor taken over all factors for which estimates have been made thus amounts to 1.6 x 1.9 x 1.2 = 3.64 – which falls far short of the figure 17.5 estimated to be present. Subsequent checks of the equipment showed that sight setting-up could be a very critical factor and also an optical component to be at fault. These were subsequently corrected and much improved results obtained. As far as the modelling is concerned we have to reconsider whether the experimental situation is covered by a simple degradation of the no-search case.

5. A SECOND NO-SEARCH MODEL

5.1. Specification

This model is developed from the simple model of the previous section and provides for:

(i) Alternative targets; either a cuboid of given dimensions (height, width, length) or a cone of given height and base radius. The bases of both cuboid and cone lie in the ground plane.

(ii) A straight and level approach to the target with given altitude and offset, and in the case of the cuboid, normal to the plane containing one face.

(iii) Calculation of A_R, the target area normal to the sight-line at range R along track, to replace A_o in equation (1).

(iv) Atmospheric attenuation of contrast as represented in equation (2) i.e. including the sky-ground brightness ratio. (The target is assumed to have no interior detail and to present a constant intrinsic contrast against a plain field).

(v) The stimulus characteristic to be expressed as tabular values of threshold contrast against angular subtense; thus removing the size constraint existing in the earlier model. The "frequency of seeing" curve is here represented in $\sigma_{\log_e c/\varepsilon}$ whence the statistic t of equation (7b) becomes $t = \frac{\log_e C_R - \log_e \mathcal{E}_R}{\sigma_{\log_e c/\varepsilon}}$. The degradation factor is represented by a shift in the contrast axis vis $\mathcal{E}_K = K\mathcal{E}$ or $\log_e \mathcal{E}_K = \log_e K + \log_e \mathcal{E}$. Hence it is the square of the degradation factor of the previous model.

No direct validation of thos model has been attempted. It is thought more useful to draw comparisons with experimental data obtained from flight and simulated flight situations. The chief problem arising from realistic situations is that of obtaining an accurate description of the target size and contrast. In its absence we can expect only to draw broad comparisons on the effects of principal factors. Two types of acquisition task must be distinguished here: acquisition when the targets position in the terrain is exactly known and acquisition when the position of the target (if present at all) is uncertain within a defined search area. It is considered that the first task is covered by the present model through the degradation factor as considered in the previous section. The second task however requires a different modelling approach as given in the next section.

5.2. Some Exercises with the Model

General exercises have been completed for a wide range of levels in the various factors, particularly for the cuboid target. Offset was generally ignored since, as far as the model is concerned, it is symmetrical with altitude. The general form of the results obtained are in good agreement with the predictions of the simple model previously described. A typical sample of the cumulative probability plots obtained is given in Figure 3 while Figure 4 summarises some of the results obtained. Of particular note is:

(i) The predicted altitude effect which is given by
$\bar{R}$ at 1220 Km = ($\bar{R}$ at 150m) + 0.3 (in km) for a cube of 10m side
$\bar{R}$ at 1220m = 1.12 ($\bar{R}$ at 150m) + 0.8 (in km.) for a horizontal square of 10m side and the difference is negligible for a vertical square of 10m side.

(ii) The effect of sky-ground ratio is considerable and draws attention to the need for good photometry.

A special exercise was carried out to predict acquisition performance against targets of similar shape but differing scales (the "Scale-factor" effect). The full-scale target used was a cuboid of full-scale dimensions 18.3m high x 91.5m long x 18.3m wide. $\frac{3}{4}$, $\frac{1}{2}$ and $\frac{1}{4}$ scale targets were also used. The scale factor effect was examined for various contrasts in the range 0.05 to 0.25, alti[illegible] 75, and 150m, zero offset, sky-ground ratios 1 and 5, visibilities 10, 40km and infinite, and degradation factors of 1 and 5. It was found that the results could be expressed closely at any probability level by [illegible] R_o [illegible](s,V) where R_s and R_o are the detection ranges for a target of scale s and full scale respectively.

For $V = \infty$, $f(s,V) = s$; $V = 40km$, $f(s,V) = s^{\frac{1}{2}}$; $V = 10km$, $f(s,V) = s^{\frac{1}{3}}$

The latter two results reflect a curious coincidence in the choice of visibilities!

5.3. Some experimental studies completed at B.A.C. with implications for modelling.

NOTE: These accounts refer to Ciné, Terravision and STAF simulations, outline descriptions of which are appended.

1 Altitude

A number of experiments have been carried out at B.A.C. in which altitude has been variable but the most relevant of these was a direct study of the effects of altitude on both potential detection and, on potential recognition performance. The Terravision simulation was used: each of six subjects performed the acquisition task against each of six targets at each of four altitudes: 61m (200 ft.), 122m (400 ft.), 232m (760 ft.) and 608m (2000 ft.). The targets were:

(1) Wing of a country house
(2) Signal box on a railway siding
(3) A specified oil storage tank of a group
(4) Main block of a power station
(5) Vertical plane square of 10.7m side
(6) Horizontal plane square of 10.7m side.

Mean potential acquisition ranges taken over subjects and targets for each altitude were as tabled below. It was found that the relationships of both detection and recognition ranges to altitude could be expressed in the form:

$$\bar{R} = k H^n$$

"Best fit" procedures yielded $k = 2.34\ 10^3$ and $n = 0.25$ for detection and $k = 1.30 \times 10^3$ and $n = 0.28$ for recognition. For ease of computation it was assumed $n = 0.25$ for both cases, adjusting the value k for recognition to 1.61. Using these values detection and recognition scores were predicted as given in the table below together with estimated errors with respect to actual values.

TABLE OF MEAN RANGES (Km) ALTITUDE (m)

SCORE	61	122	232	608
Detection	2.22	3.12	3.64	4.57
Recognition	1.55	2.31	2.59	3.28
Predicted Detection	2.56	3.04	3.46	4.55
Percent Error (Detection)	+15	-3	-6	0
Predicted Recognition	1.84	2.19	2.50	3.28
Percent Error (Recognition)	+19	-5	-3	0

(The negative sign on percent error indicates an underestimate)

The level of error achieved is well within the requirement, although not shown here are differences between targets. The errors howeverin both scores at the 61m altitude are relatively large: it would therefore be dangerous to extrapolate the present result below this altitude. Since the simulation used provides essentially an infinite visibility, we can expect the parameter k to include degradation factors as considered previously. Thus a better working model for the altitude effect might be:

$R_H = R_{608} \left(\frac{H}{608}\right)^{\frac{1}{4}}$ covering both detection and recognition. To use this of course it is necessary to predict the acquisition range R_{608} at an altitude of 608m.

It will be noted that the altitude effect found in the study is much greater than that predicted by the model. This result is confirmed in other experimental studies including those of Dyer (Reference 3). A likely reason for the observed better performance with increasing altitude is the reduction in screening afforded: this is less by direct obscurations since in the present study targets were located to avoid this but rather by target to background merging. This being the case, the model should approximate high altitude conditions (apart from visibility effects) better than the lower. Alternative reasons for the observed discrepancy include possible variations in target intrinsic contrast as a function of the sight-line direction, and thus of altitude, but the broad agreement with Dyer's flight data suggest this is a second order effect or that the simulation agrees well with the real world in this respect.

2. Speed Studies

In various B.A.C. studies where it has been an experimental variable, speed has had a small effect on acquisition tasks where the target position relative to the terrain has been given. This is in accord with the view that such tasks have a relatively small search content and can be modelled by simple degradation of the no-search case provided the target area acquisition is not delayed by a paucity of terrain clues.

3. First Run Versus Potential Recognition Performance

An experiment was carried out, using the ciné acquisition simulation, to study the learning effect over consecutive runs against each of six specified targets. The six, relatively inexperienced, subjects used were given map briefings as to the target location. It was found that the learning could be expressed as:

$$\hat{R}_n = a - b\,e^{-cn}$$

Average values of the parameters a, b, c taken over subjects are given below for the six targets.

Target	a	b	c	a'	P %
1. Motorway Road Bridge	4.78	5.15	0.88	4.97	59
2. Reservoir Causeway	5.45	5.77	1.02	5.62	64
3. Radio Masts	7.77	6.90	0.54	7.34	42
4. Maintenance Building	8.29	8.31	0.90	8.30	59
5. Motorway Junction	5.05	3.18	0.76	4.12	53
6. Blenheim Palace	7.51	6.01	0.76	6.76	53

For n greater than 3, no significant increase in recognition range was found and the plateau level reached was not significantly different from the median potential recognition range, $\hat{R}_{max}$. From the tabulated values of a and b above, the approximation

$$\hat{R}_n = a'\,(1 - e^{-cn})$$

can be proposed, where $a' = (a + b)/2$, given also with the table above. The ratio of median first run acquisition range $\hat{R}_1$ to median potential range $\hat{R}_{max}$ based on this approximation is given in the table also, expressed as a percentage P. The mean value of P is 55, suggesting the relation

$$\hat{R}_1 = 0.55\ \hat{R}_{MAX}$$

as a useful working prediction. The median acquisition ranges for each target and the predicted acquisition ranges on this basis are given in the table below together with the estimated percent error.

Target	1	2	3	4	5	6
Median 1st Run Acquisition Range (Km)	3.14	3.56	3.90	5.06	3.56	4.69
$0.55\ \hat{R}_{max}$ (km)	2.74	3.08	4.02	4.57	2.26	3.72
% Error	12.6	13.7	3.1	9.6	36.8	20.8

These errors are within the required error margin of ± 50% for $\hat{R}_1$ assuming roughly similar errors in estimating $\hat{R}_{max}$.

A further experiment with important implications for modelling was carried out to investigate the relationship between first run acquisition and potential acquisition performance under different briefing conditions. The ciné acquisition simulation was again used. Briefing conditions were as follows:

Condition A. Prior experience of the route by flying over it, correlating with a map. The scored run was then carried through at 450 Knots the target being named and its map location given.

Condition B. In addition to the map with target location marked, target photographs taken from various ranges were given. The target background was kept to a minimum to avoid giving location cues. The scored run was carried through at 450 Knots.

Condition C. A slow speed run at 180 Knots with the map briefing only.

Condition D. A high speed run at 450 Knots with the map briefing only.

Potential range measures were taken for a single slow forward run immediately following the first run condition. From a population of 48 (R.A.F. aircrew) subjects, groups of 12 were drawn to cover each Target/brief condition in a balanced manner. The median first run acquisition and potential range scores obtained under the various briefing conditions and for each of the four targets used are given, in kilometers, in the following table:

	Briefing Condition							
	A		B		C		D	
Target	$\hat{R}_1$	$\hat{R}_{max}$	$\hat{R}_1$	$\hat{R}_{max}$	$\hat{R}_1$	$\hat{R}_{max}$	$\hat{R}_1$	$\hat{R}_{max}$
1. Power Station Pump House	6.06	8.85	3.21	6.13	5.09	8.87	5.64	7.76
2. Gravel Works	5.39	8.64	4.02	7.34	6.89	11.72	3.97	7.35
3. Road/River Bridge	4.12	5.03	3.26	5.12	4.54	6.03	3.69	4.29
4. Road/Rail Bridge	2.90	4.85	3.05	4.27	2.16	5.88	2.32	5.36

Overall, for first run performance $\hat{R}_1$, results for conditions B and D are similar but less than those for conditions C and D which are also similar. Average values of $\hat{R}_1/\hat{R}_{max}$ taken over targets for each briefing condition are: A, 0.68 ; B, 0.61 ; C, 0.57 ; D, 0.62. These are rather higher than the mean value of 0.55 obtained in the previously described experiment. However using the relation $\hat{R}_1 = 0.55\ \hat{R}_{max}$ to predict the first run acquisition ranges, the percent errors were found to be:

	Briefing Condition			
Target	A	B	C	D
1	-20	6	-4	-24
2	-12	1	-6	2
3	-33	-14	-17	-29
4	-8	-23	49	30

(where the negative sign implies an underestimate)

While these results are still within the required error tolerance for $\hat{R}_1$, the margin of error now permissible in $\hat{R}_{max}$ is apparently reduced. Examination of the tabulated values given above shows $\hat{R}_{max}$ to be dependent to some extent on the briefing condition for the preceeding first run. Thus it is inferred that the potential acquisition range was not fully developed in this study i.e. $\hat{R}_{max}$ has been underestimated. This, to an undetermined extent, counters the bias in the error table above.

Both experiments then give some hope that if the potential detection range can be predicted fairly closely by the model - say within 10-20% - we will be able to predict first run performance within the specified accuracy. Expressed in this manner it is not possible to give the relationship between 1st run and Potential as a degradation factor as presently used in the models.

4. Detection - Recognition

While measures of "detection" and "recognition" performance have been taken in several B.A.C. studies, there has been no special study of their relationship. In that subjects were required in these experiments first to record detection then recognition, their responses are likely to be biased. Several inconclusive attempts have been made to quantify the relationship from the data available including one study to determine whether elapsed time or elapsed range was the relevant parameter. Typically, from the altitude study described previously, the mean ratio recognition range/detection range is 0.72 with negligible variation with altitude.

From the results of the scale factor studies reported below it may be inferred that the modelling of recognition involves factors of shape and target/background relationship which are not covered by the present model and cannot then be entirely expressed through the degradation factor K. Again, the results described in the previous section imply that, in the complex terrain situation, detection, as performed, contains some elements of recognition.

5. Scale Factor Studies

Two experiments were carriedout, one using the Terravision simulation, the other, STAF. In both, two cuboid targets of different shapes, each at three scales $(1, \frac{1}{2}, \frac{1}{4})$ were placed in turn at the same position in the terrain. The results of first-run detection tasks against these targets in both simulations showed no scale factor effect contrary to the model predictions given above. Various artefacts in the simulation, experimental design and experimental procedures were examined in an attempt to explain the observed result. The most likely explanation however is that the basic requirement of the model for a simple target in a plain background - is violated. In the simulations, the targets were intimately related to complex backgrounds (they can be said to "merge" with the background) and under such conditions it is likely that subjects were responding, unanimously, to a different criterion to that supposed.

A further effect was noted: in a modelling exercise which attempted to match the experimental results for the smallest target (least affected by "merging") no degradation factor was required for the STAF data but a degradation factor, in excess of 75 was required for the Terravision data. This reflects the difference in display quality and a similar effect is noted in the "Vehicle detection" exercise reported below.

In view of the limitations of a televisual display due to its line structure, it would appear improper to model the observed Terravision data by a degradation factor. A correct modelling of the contrast growth situation as it appears on such a display is required to cover both real world cases and simulations thereof.

6. Vehicle Detection Study

The model has been used to examine the relationship between acquisition performance in certain field trials and in a Terravision simulation of these trials against a vehicular target placed in a large uncluttered area of terrain. Using measurements of size and contrast of the displayed target, an attempt was made to match the observed median detection performance by estimating the degradation factor required and to match the observed variance by appropriate values of $\sigma_{\log_e c/\bar{c}}$. A similar attempt was made to match the results of the field trial. For the experiment, the required values were K = 50 and $\sigma_{\log_e c/\bar{c}} \ll 0.15$. while for the field trials, K = 5 and $\sigma_{\log_e c/\bar{c}} = 0.15$. The latter values are entirely within our expectations while the former again reflect the limitations of a televisual display.

6. MODEL FOR UNSTRUCTURED SEARCH

6.1. General Description

This model is based on the accumulation of detection probabilities over a sequence of single glimpses each randomly directed at the search area. The glimpse time g_t is used to determine the number of glimpses in a given interval of time (or of range in the target approach condition). Glimpse times such as given by Ford, White, Lichtenstein (Reference 4) show an approximate spread of from 0.1 to 0.6 seconds with a median value of about 0.33 secs. This is the value commonly used in our studies. For any particular glimpse (at range R) the target is assumed to have a stimulus value as given by Equation (2) for apparent contrast and by Equation (3) for the angular subtense. Since the glimpse will in general be directed at an angle θ with respect to the sight line to the target, the single glimpse detection probability will be a function of both stimulus value and θ. The empirical data of J.H. Taylor (Reference 5) provides the threshold contrast C_0 for detection at 0^0 off axis as a function of angular size. This, together with a standard deviation $\sigma_{\log_e c/\bar{c}}$ can be interpreted as a detection probability/θ profile - what I have termed the Target Detectability Profile. (T.D.P.). If a degradation factor is to be used in the model it is assumed to operate, as previously, on the contrast threshold. Assuming the search to be uniform over the search area, the (T.D.P.) can be approximated in the model by a rectangle of height p_f (the foveal single glimpse probability) and width θ corresponding to a probability $p_f/2$. For $p_f=1$, this corresponds to the conventional hard shell lobe.

With this approximation two alternative models are available:

Type 1, in which the average single glimpse probability is taken over all possible target positions in the search area. Here the single glimpse probability is given by

$$p_g = p_f \left(\sqrt{\frac{a}{A}} - \frac{a}{4A} \right)^2$$

where lobe area, a, and search area, A, are measured normal to the sight line at range R. Thus

$$a = \pi R^2 \hat{\theta}_R^2$$

This model further assumes the target always to be in the search area and that there are no field-of-view restrictions.

Type 2 in which the single glimpse probability is obtained for the given target position in the search area when:

$$p_g = p_f \frac{a'}{A'}$$

The model for this case calculates a' as the lobe area within the search area and also within the field-of-view and A' as that part of the search area within the field-of-view. As the approach to the target is made, the interaction of field-of-view with lobe and search areas of course changes appropriately: if at any time the target is found to be outside the field-of-view, $p_g = 0$.

For both types, values of p_g are found for each glimpse (by interpolation from samples in order to reduce computation) and these are then accumulated. Previously this has been calculated from:

$$\phi_N = 1 - \prod_{n=1}^{N} (1 - p_g) \qquad \text{——— (12)}$$

The start point, n = 1, is taken for a range R_{max} when the value of p_g is vanishingly small. The distance travelled is given by:

$$R_{max} - R = V.N.\ g_t$$

The accumulation however has been found to predict superior acquisition to the no-search case under certain conditions. This is clearly incorrect and the method now adopted is to limit the search probability by the no-search probability. Properly we should take the single glimpse foveal probability and accumulate this, however these probabilities are not independent and Equation (12) does not hold, and an alternative such as now proposed by Overington in his companion paper is required. In the meantime we have used the no-search model as previously described.

6.2. Examples of the Application of the Search Model

Typical outputs for the Type 1 model are given in Figure 5 , illustrating the effects of glimpse time and velocity for various sky-ground brightness ratios. For reference, the corresponding no-search probability curves are also given. It is immediately apparent that the distributions obtained differ in form for those obtained for the no-search cases and that the magnitude of the difference is very sensitive to sky-ground ratio. It can be seen also that there are limiting probabilities at near-zero ranges from which detection success rates can be determined.

Data from a "widescale search" experiment has also been used as a basis for modelling. In this experiment, using the Terravision simulation, subjects were required to detect a single cone target during simulated straight and level flight along one side of a defined search area. (The field-of-view available - 50° to one side of centre - was rather less than that generally obtained through a cockpit window). The search area measured 1.7 Km wide by 5 Km long and targets were centred nominally at the intersections of a 4 x 3 rectangular grid.

By using cone targets it was hoped to control intrinsic contrasts in the simulation. From sample measurements values ranging from 0.5 to 0.75 approximately were found. Where measured they were used in the modelling, otherwise an average value was used. The degradation factor required in the model was estimated from the observed data by trial-and-error methods and found to be of the order 75. Figure 6 illustrates the observed success rates as a function of offset for two speeds, 100 Knots and 400 Knots; also shown are the success rates estimated by the model. Clearly the model underestimates the observed success rates particularly at the higher speed. Again it is suggested that the effect is explained in terms of the nature of the televisual display and it is assumed that with realistic modelling of this effect, the need for so large a degradation will disappear. The model also showed a much smaller offset effect than was observed in the experiment. The most likely explanation here is that subjects changed their search strategy according to the perceived task difficulty: it is suggested that search was concentrated more at the lower offsets rather than uniform. Intermittent target screening, present in the simulation but not in the modelling may have been a contributory factor to this offset effect.

7. BROAD CONCLUSIONS

Modelling to date has had mixed success but I would make the following particular points.

(i) the degradation factor as defined can be used only for particular purposes relating to changes in the stimulus or stimulus response characteristic. It will not conveniently describe such effects as observed in altitude or such constraints as appear when televisual displays are used. Modelling the televisual display is an important requirement if only to make better use of simulations such as the Terravision system.

(ii) If the conditions modelled are widely different from flight or simulated flight conditions, particularly in respect of the target background relationship, then the model will fail.

(iii) While better descriptions of target contrast (in terms of the illuminating conditions) and of non-homogeneous atmospheres are both desirable, it is just as important to have good photometric measures of intrinsic contrast, visibility and sky-ground brightness ratio.

(iv) For search cases, glimpse distributions other than the assumed uniform distribution must be modelled.

(v) Effects of terrain screening need to be modelled for both search and no-search cases.

(vi) Concepts of "Detection" and "Recognition" need reconsideration.

APPENDIX. SIMULATIONS FOR AIR-TO-GROUND ACQUISITION STUDIES

1. Ciné

Air-to-ground ciné films, obtained for a wide range of terrains and targets at fixed speed (180 Knots) and fixed altitude (2000 feet, 610m) and processed under controlled conditions, are replayed under laboratory conditions using a back-projection facility incorporating a special De Oude Delft screen material. Acquisition range is calibrated from frames-to-go.

2. Ciné -Tele

Cine' films, as above, are alternatively displayed through a 625 line close circuit television system. T.V. monitors to 14" inch diagonal have been used to provide displays in moving cockpit simulations.

3. Terravision (as manufactured by Redifon Ltd)

A terrain is modelled, at a scale typically of 3000:1, on a moving belt. A television camera scans the terrain through an optical system so as to simulate the view of the ground through a cockpit window in a manoeuvring aircraft. This view can be relayed directly on a television monitor mounted in the cockpit simulation or recorded on video-tape for subsequent reproduction. The system does not include a visibility simulation which is adequate for acquisition studies so is used effectively with an infinite visibility. The display quality is poor although, part from the absence of colour, experienced aircrew are not over critical. There are range constraints in acquisition due to the television system - as the target size diminishes through the equivalent of 1 T.V. line width, the contrast attenuates rapidly. Perspective changes with approach conditions are realistically reproduced although the field-of-view, roughly 30° x 50°, is somewhat limited. Acquisition range is measured directly by the belt drive system or by calibration of elapsed time from a defined start point.

4. STAF System (Still-Target Acquisition Facility).

High quality still photographs, as positive transparencies, are mounted on a large translucent screen and back-illuminated. In this way, daylight brightness levels can be approached. The subject is seated on a motorised chair and is moved towards, or away from the screen, and normal to it, at a controlled rate, over a distance of some 30 feet. This represents a dive approach under effectively an infinite visibility condition. Perspective and screening across the photograph remain unrealistically constant as an approach is made but this is considered of minor importance. Acquisition ranges are usually measured in terms of the distance between chair and screen and may be calibrated as real-world detection ranges if required.

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NOTE: No references are given to any B.A.C. studies mentioned in this report: if further information is needed please write to me.

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FIGURE 1. EXAMPLES OF CUMULATIVE PROBABILITY CURVES

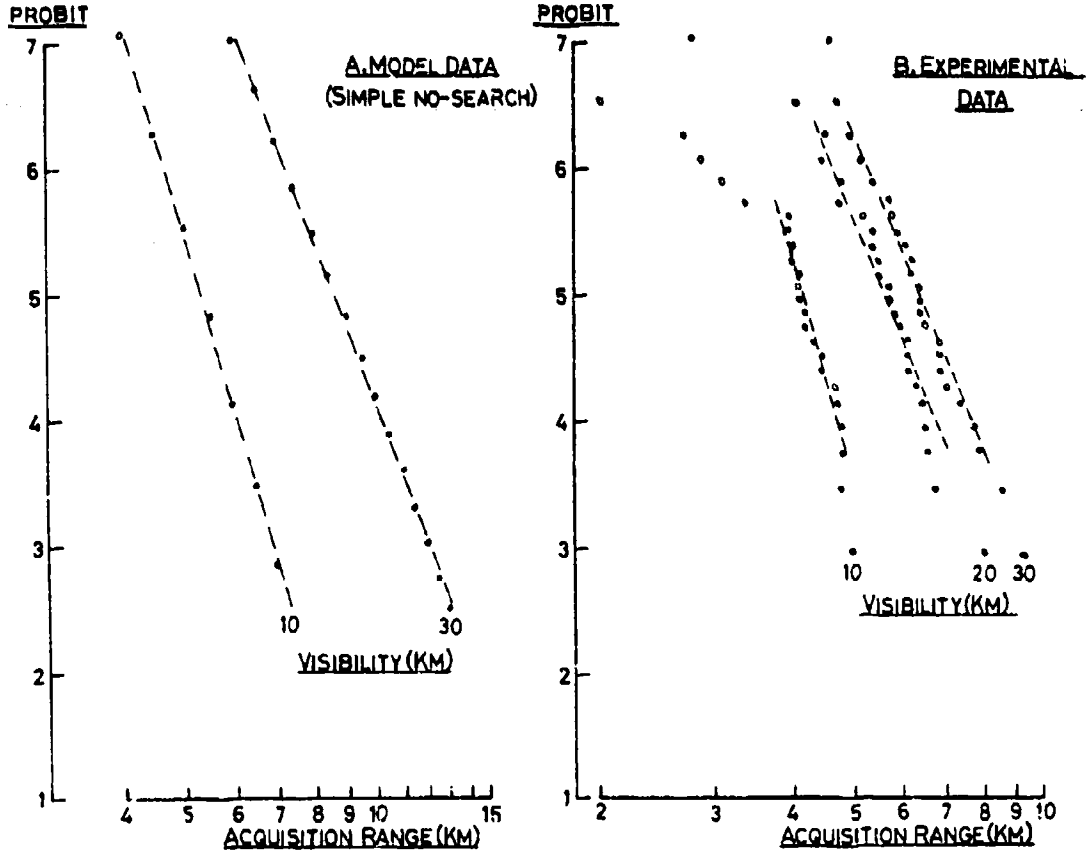
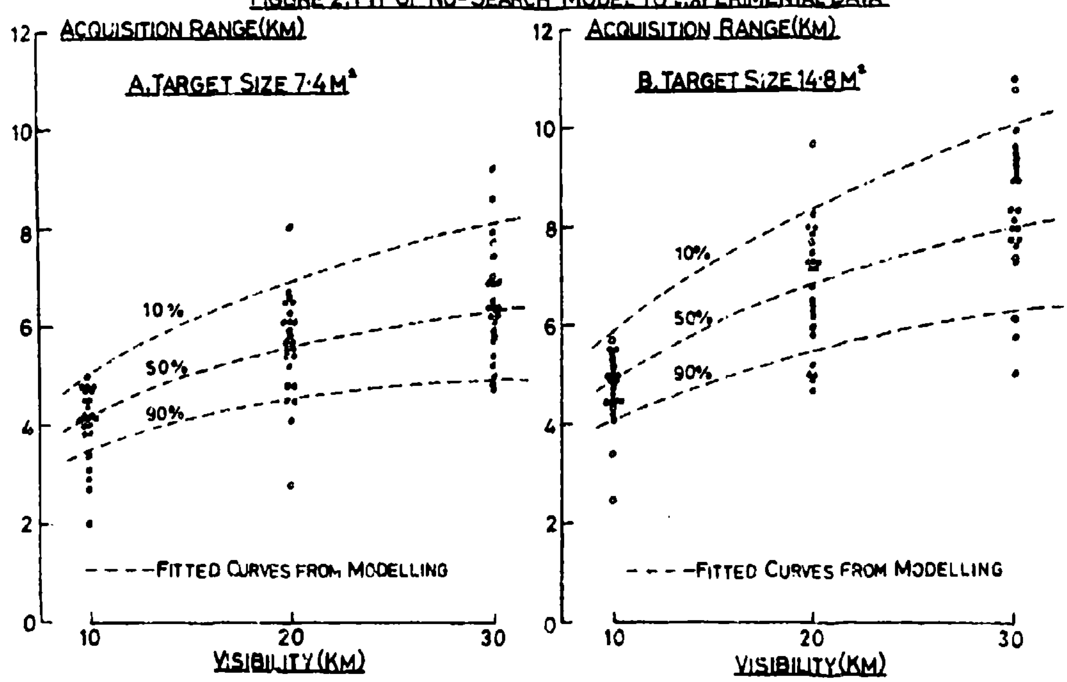
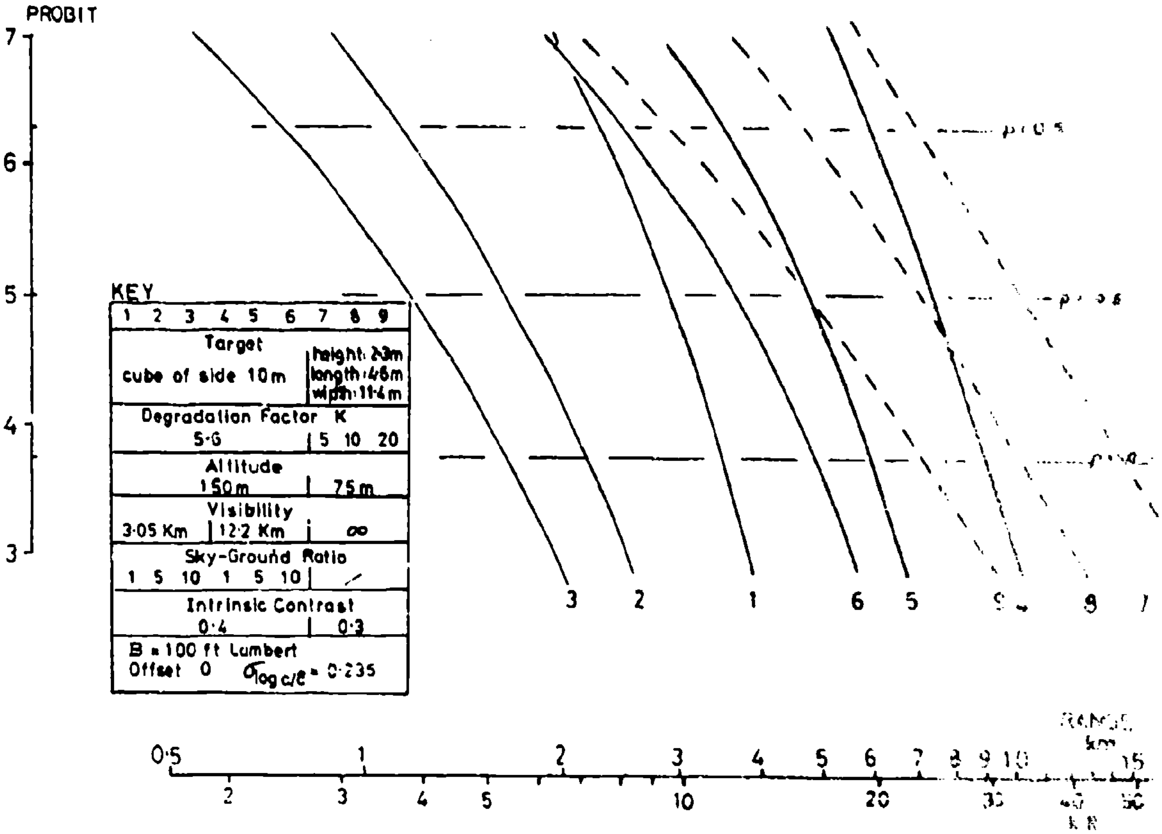


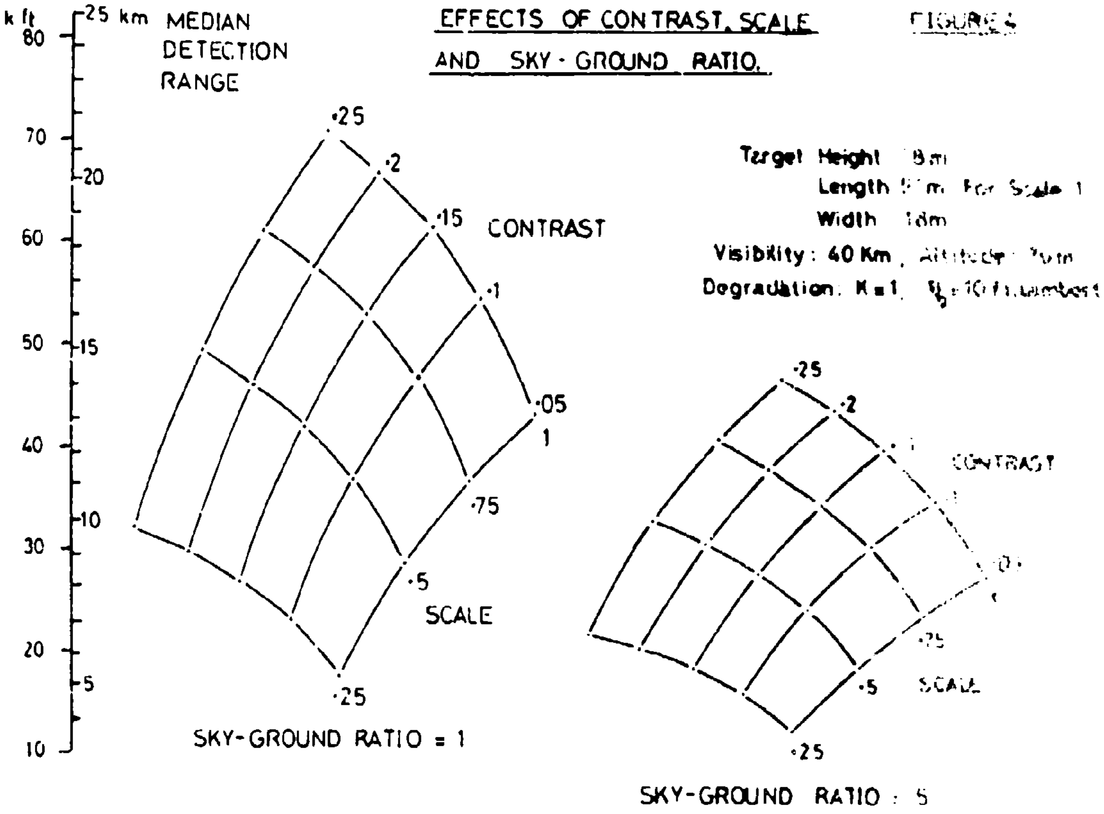
FIGURE 2. FIT OF 'NO-SEARCH' MODEL TO EXPERIMENTAL DATA



CUMULATIVE PROBABILITY CURVES FOR NO-SEARCH MODEL



EFFECTS OF CONTRAST, SCALE AND SKY-GROUND RATIO.



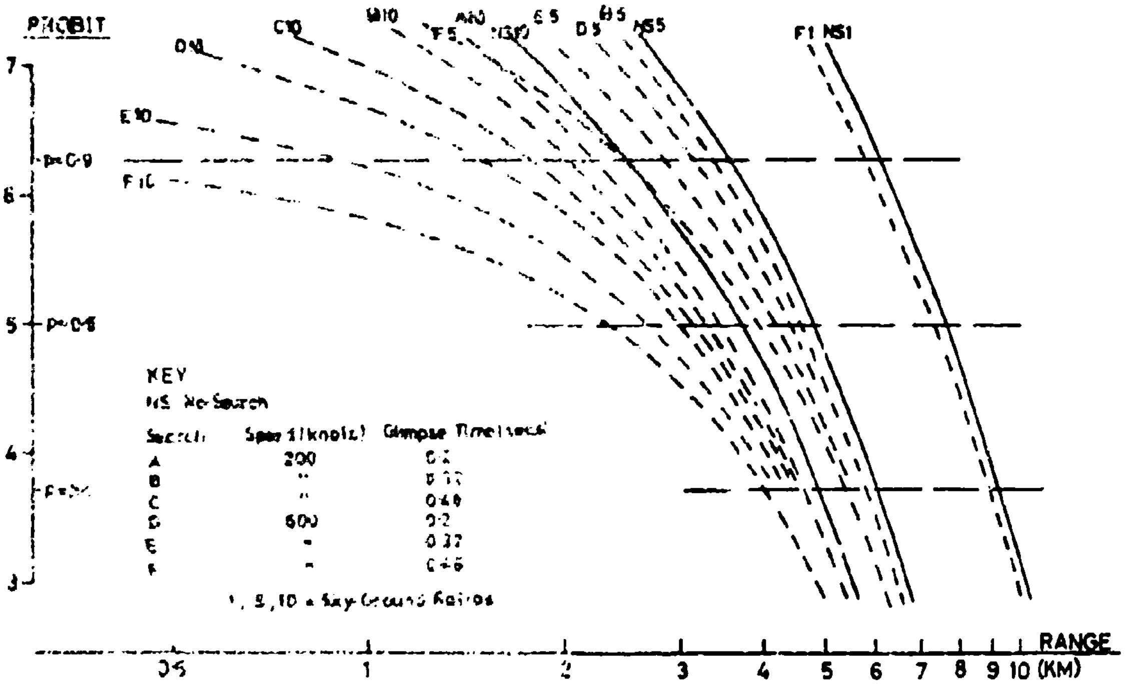
CUMULATIVE PROBABILITY CURVES FROM SEARCH MODELLING — FIGURE 5

Altitude: 1·22 Km (4 Kft), Visibility: 12·2 Km (40 Kft)

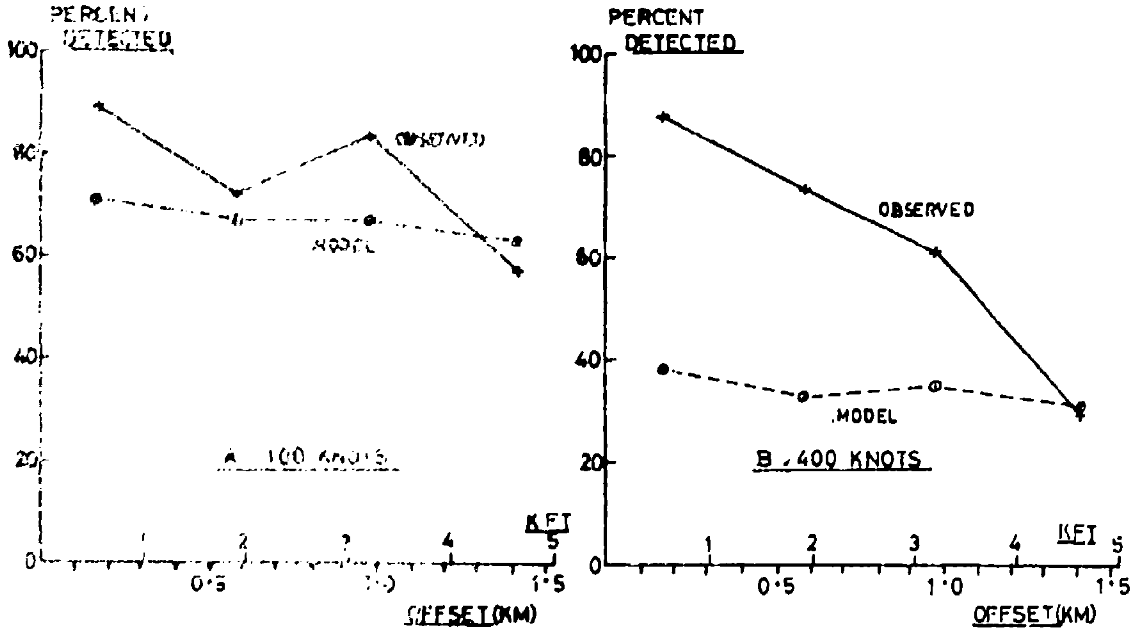
Target: Cube of side 10m (33 ft), Intrinsic Contrast: 0·4

Search Area. Square of side 0·5 Km (1·64 Kft), Offset: 0

Degradation Factor: K = 5·6 $\sigma_{\log c/\varepsilon} = 0{\cdot}235$



"WIDESCALE SEARCH" SUCCESS RATES — FIGURE 6



CALCULATION AND SIMULATION OF THE EFFECTS OF TWO COMPLEX SEARCH SITUATIONS

by

C I Howarth, J R Bloomfield and M E Dewey
Department of Psychology, University of Nottingham
University Park, Nottingham NG7 2RD, UK

SUMMARY

Two attempts were made to elucidate complex search situations.

In the first, using Howarth and Bloomfield's theoretical work as a basis, calculations were made of the cumulative search time data likely to occur when a target that was an extreme example of a distribution of objects was presented among a sample of these objects. The calculations covered variations in (i) the target-nontarget cut off point, (ii) the size of the visual lobe area associated with the target, and (iii) the response time th.. was necessary after a target was located.

The second, a simulation study making use of the Monte Carlo method, treated a situation in which a number of targets were presented among many nontarget objects. A single target, which had a small visual lobe area associated with it, was presented with a variable number of targets, with large visual lobe areas. The size of the visual lobe areas associated with the two kinds of target were varied, as were the number of the large lobe area targets and the length of the response times necessary after a target had been located. The likely effect of these variations on the time needed to locate the single target is reported. In general, more time was needed the smaller the lobe area of the single target, the greater the lobe area of the large lobe targets, the greater the number of the latter present, and the longer the response times. The cumulative curves obtained changed in shape as the four variables altered in these directions. The change in shape is likely to be found with human observers who adopt the most suitable strategy for locating the small lobe area target.

Symbols

- P_s = probability of detecting a target in a single glimpse
- a = area covered by the visual lobe in a single glimpse
- A = total search area
- θ = eccentricity, angular distance away from the fovea at which a target can be detected in a single glimpse
- d_B = diameter of nontarget, background discs
- d_T = diameter of target disc
- m = gradient of straight line obtained by plotting θ against $|d_B-d_T|$
- $\bar{t}$ = mean search time
- t_s = fixation time
- n_r = response time in fixation units
- x = intercept of n_r axis, when n_r is plotted against the reciprocal of $|d_b-d_T|$
- y = gradient of straight line obtained by plotting n_r against the reciprocal of $|d_B-d_T|$
- P_n = probability that a target will be found within n fixations

A. INTRODUCTION

Most work on visual search has involved simple, single target search tasks. In an attempt to elucidate more complex search situations, we carried out two studies making use of a computer. In the first, we made calculations of the search times likely to occur when a target that was an extreme example of a distribution of objects was presented among a sample of these objects. The calculations were carried out using as a basis our previous theoretical work (Howarth and Bloomfield, 1; 2; 3). In the second, a search task involving the location of a number of targets among many nontargets was simulated, using the Monte Carlo method (i.e. employing a random number generator). The studies were undertaken so that some of the variables of possible interest might be singled out for more detailed empirical study. Also, some indication might be given of the generality of the results of a subsequent experimental programme.

B. CALCULATION OF LOCATION TIMES WITH A CONTINUOUS DISTRIBUTION OF TARGETS AND NONTARGETS

1. Search situation

These calculations involve the following paradigm. A distribution of objects was considered. An arbitrary cut-off point was selected. All objects falling beyond this point were taken to be targets, with the remainder being nontargets. Then, the cumulative probability of a target being located, if one was present, was calculated. The calculations covered variations in the target-nontarget cut-off point, the size of the visual lobe area associated with the target, and the response time that was necessary after a target was located.

2. Functions used in calculations

The basis for these calculations was provided by our previous theoretical work (Howarth and Bloomfield, 1; 2; 3). From the known characteristics of the eye, we derived an equation relating the extent to which a target differs from the nontargets to the time necessary to search for it. Briefly, this derivation is as follows:

The average probability of detection in a single glimpse, p_s, is related to the average area, a, covered by the visual lobe in a single glimpse and to the total search area, A, as follows:

$$p_s = \frac{a}{A} \qquad (1)$$

If θ is the angular distance away from the fovea at which the target can be detected in a single glimpse, then, on the assumption that the area covered by the visual lobe in the plane of search is circular,

$$a = \pi \theta^2 \qquad (2)$$

(In fact, this area is elliptical, but the error in estimating a introduced by adopting an assumption of circularity is relatively small.)

Bloomfield and Howarth (3) empirically determined θ for a target disc presented among regularly arranged nontarget discs. They found that

$$m\theta = |d_B - d_T| \qquad (3)$$

where d_B is the diameter of the nontarget, background discs, d_T, the diameter of the target, and m the gradient of the straight line obtained by plotting θ against the difference between these diameters. A similar relationship has been sinced obtained in a more extensive experiment by Bloomfield(4).

From equations 1, 2, and 3, the relationship of p_s to the diameter difference can be derived:

$$p_s = \frac{\pi(d_B - d_T)^2}{A.m^2} \qquad (4)$$

The mean search time, $\bar{t}$, is dependent on the type of search strategy that the observer uses. If t_s is fixation time:

$$\bar{t} = \frac{t_s}{2}\left(\frac{1}{p_s} + 1\right), \text{ for an efficient, exhaustive strategy}$$

$$\text{and } \bar{t} = \frac{t_s}{p_s}, \text{ for an independent glimpse strategy.} \qquad (5)$$

Substituting (4) in (5) gives

$$\bar{t} = \frac{t_s}{2}\left(\frac{Am^2}{\pi(d_B - d_T)^2} + 1\right) \text{ efficient}$$

$$\text{and } \bar{t} = \frac{t_s\, Am^2}{\pi(d_B - d_T)^2} \text{ independent} \qquad (6)$$

Since t_s, A and m should be constants for a given search situation, both equations (6) lead to

$$\bar{t} = \frac{1}{(d_B - d_T)^2} \qquad (7)$$

providing, in the case of the efficient strategy, that $\bar{t}$ is large compared to t_s.

Equation (7) was found to fit data from a number of simple search experiments involving the location of a target disc in a display containing many nontarget discs. It could also be adapted to fit data obtained using a single low contrast target in an unstructured background.

The calculations were carried out using the assumption that the observer's fixations would be independent of each other. Then, p_n, the probability that a target would be detected with n fixations, is given by

$$p_n = 1 - (1 - p_s)^{(n-n_r)} \qquad (8)$$

where n_r is the time needed to respond after locating a target, in fixation units.

Bloomfield(5) suggested, for location of a single disc target among a number of nontarget discs, that response time is related to the target-nontarget diameter difference, as follows:

$$n_r = x + \frac{y}{|d_B - d_T|} \qquad (9)$$

where x is the intercept on the n_r axis and y is the gradient of the straight line obtained when n_r is plotted against the reciprocal of the diameter difference.

The present calculations were carried out using equation (8), with the values of p_s and n_r given by equations (4) and (9) respectively.

3. Method

A population of discs was considered. They varied in diameter, but were normally distributed. It was assumed that on each search trial a sample of the population was present. The mean of the population was used as an estimate of d_B.

A cut-off point could be selected. If a particular disc fell beyond this, it was considered to be a target. The area beyond the cut-off point was divided into segments of 0.5 standard deviation units, and the mid-point of the segment was taken as an estimate of its d_T value. Then, for each d_T value, the probability of the target being located on each individual fixation after search commenced was calculated. The probabilities thus obtained were accumulated for twenty fixations (the equivalent of between five and seven seconds, assuming fixation times of 1/3 to 1/4 seconds).

The search area, A, was taken to be approximately that used by Bloomfield and Howarth(3), and the value of m used (m = 0.02) was that empirically determined in the same study. The values of x and y were taken as 0.0 and 4.0 respectively. Bloomfield(5) estimated values approximately of 0.2 for x and of 3.4 and 4.1 for y when using a similar, if simpler, situation. Integer values were used here because the time scale used in these calculations was in complete fixations.

With this general situation, we investigated the effects of variation in the position of the cut-off point, in diameter difference, in the visual lobe area, and in response time.

4. Calculations and discussion

(i) Variations in target-nontarget cut-off.

The standard values of d_B, A, m, x and y were used. The cut-off point was taken at 0.5, 1.0, 1.5, 2.0, or 2.5 standard deviation units from the mean of the population, d_B. Calculations were made for targets up to 4.5 standard deviation units from the mean, taking the mid-point of each half standard deviation unit as an estimate of d_T for that half unit. Thus, for the cut-off of 0.5, d_T was 0.75, 2.25, 2.75, 3.25, 3.75, or 4.25; while for the cut-off of 2.5, it was 2.75, 3.25, 3.75 or 4.25.

For each cut-off point, the probability of locating a target from each possible half standard deviation unit segment was calculated in successive fixations. The probabilities were added and accumulated, giving the overall probability of finding a target for each cut-off point. In order to compare different cut-off points directly these probabilities were divided by the probability that a target would be present. Figure 1 shows the results of this procedure. It gives the cumulative probability that a target will be found, given that one is present, for five cut-off points.

As the cut-off point is moved further from the mean of the distribution it becomes more probable that a target will be located quickly, since increasing the distance between the cut-off point and the mean increases the average diameter difference between target and nontarget.

(ii) Variations in diameter difference.

From the above calculations, the difference in time needed to locate targets from different half unit segments can be shown. They are illustrated in figure 2 using a standard cut-off point of 2.5. The figure shows the cumulative probability of a target being detected from each segment beyond the cut-off point, given that one is present.

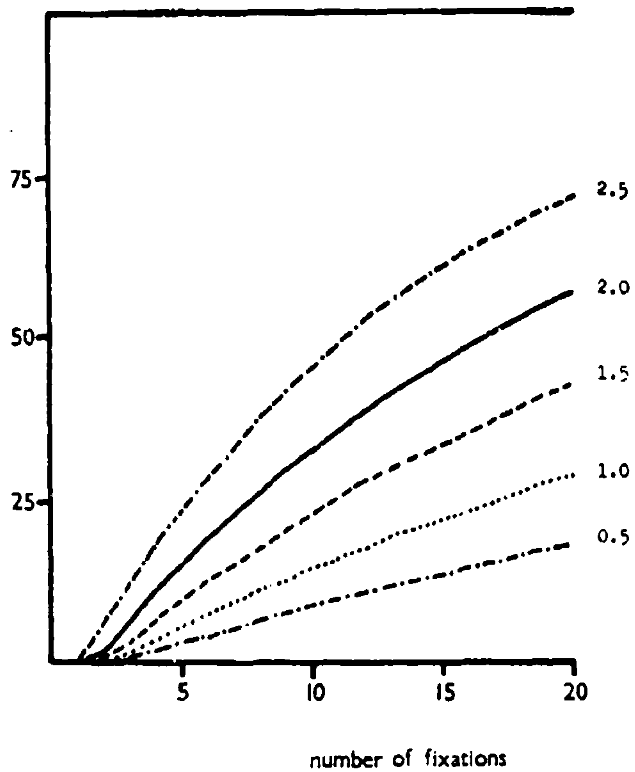


Figure 1: cumulative distributions for five target-nontarget cut-off points.

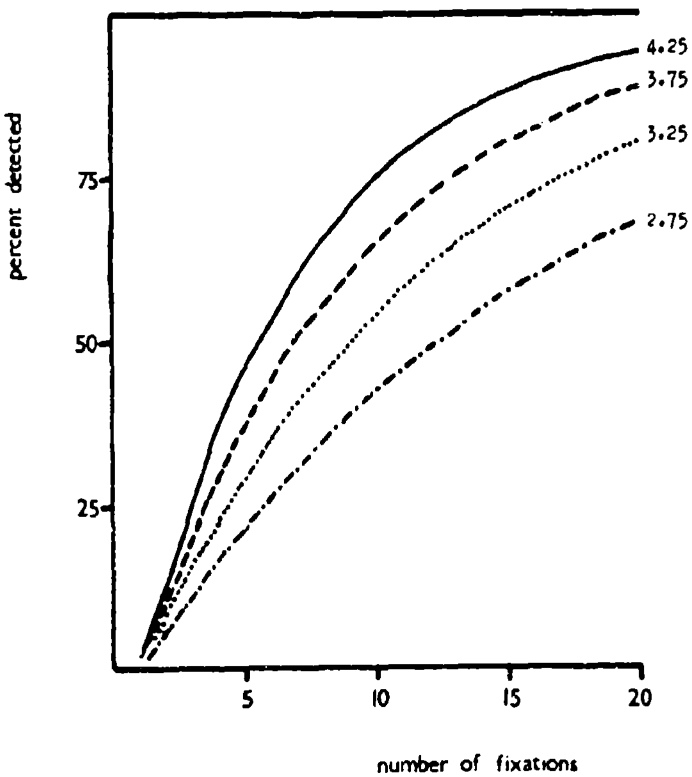


Figure 2: cumulative distributions for four target segments.

The figure shows a pattern of curves similar to that obtained by Bloomfield(5), in an experiment involving search for a single target among a number of larger nontargets. As the target-nontarget difference increases, the probability of a target being found quickly increases.

(iii) Variations in visual lobe size

Weymouth(6) suggested that, for a wide range of experimental conditions, there is a simple linear relationship between the size of the target and eccentricity, θ, for values of θ up to 20 degrees of arc from the fovea, when visual acuity is measured in linear units, $\Delta\alpha$, rather than as a reciprocal. Thus

$$\Delta\alpha = m\theta \quad (10)$$

He pointed out that m varied with variations in experimental conditions.

In equation (3), $\Delta\alpha$ was replaced by $|d_B - d_T|$, but it remains one of the same family of equations, and m varies with the conditions in it, too. For example, M Firth in this department, has shown that visual lobe size contracts as nontarget density increases, implying that m would increase with density.

The possible effects of variations in m were calculated with the standard values of the other variables used. Figure 3 shows the likely effect of changes in m between 0.01 and 0.04. As m increases i.e. as the visual lobe area decreases, the probability of locating a target quickly decreases.

(iv) Variations in response time

Bloomfield's(5) equation for response time was

$$n_r = x + \frac{y}{|d_B - d_T|} \quad (9)$$

Response time changes with the complexity of the response required. For example, if the observer has to mark by hand a target's position or to remove if physically from the display, there will be a considerable increase in the time needed compared with a task in which he has to release a shutter on locating it. A change of this type would result in an increase in n_r for all target-nontarget differences, and would be achieved by increasing x. The standard cumulative curve shown of figures 1 and 3 would simply be shifted along the time axis by an appropriate constant.

There may also be changes in y. Bloomfield's(5) estimate of y = 3.4 was obtained for an irregular arrangement of nontargets, while his estimate of y = 4.1 was for a regular arrangement. The regular arrangement appeared to make the discrimination of the target from the nontargets more difficult. Changes in nontarget density probably have a similar effect. The effect of y values of 1 and 10 are compared with the standard (y = 4) on figure 4. The effects are not large- however, they do not simply produce shifts along the time axis, but also a change in curvature.

(v) Comment

These calculations indicate the likely effects of variations of various kinds. We had hoped to extend this approach to a multi-target situation but this w.s impractical. We therefore decided to use a different approach.

C. SIMULATION OF A MULTI-TARGET SEARCH SITUATION

1. Introduction

Little empirical work has been carried out in multi-target search situations. When a display containing one target only is presented, it is easy to record the length of time it takes the observer to locate it and to check whether he is correct in indicating its position. However, with several targets neither task is quite so simple. The observer has to locate the targets by giving their co-ordinate positions on the display, or by indicating their positions on a chart or grid, or by touching or pointing at them. Whichever response is made, his search performance will be interrupted and delayed for some time. In addition, the response times will accumulate in each search trial. Thus, the 'search time' measured for each target will include a cumulative response time, which will be greater the later the target is found. The resultant data will be dependent on the particular response required, and may be quite specific to the particular set of experimental conditions.

2. Search situations

This simulation involved the following paradigm. A number of targets were interspersed throughout a regular array of nontarget objects. A single target that was similar to the nontargets (and, therefore, that had a small visual lobe area associated with it) was presented on each trial with a variable number of targets that were different from the nontargets (and had a large visual lobe area). The size of the visual lobe areas associated with both kinds of target were varied, as were the number of large lobe area targets and the length of the response times necessary after a target had been located.

3. Method

A regular 20x20 array of objects was represented internally in the computer. One object represented a small lobe target and a number of others represented large lobe targets. The remainder were designated nontargets. Lobe size was a function of the radius of the circle surrounding the target within which an observer would have to fixate in order to see it (a hard shell visual lobe is assumed).

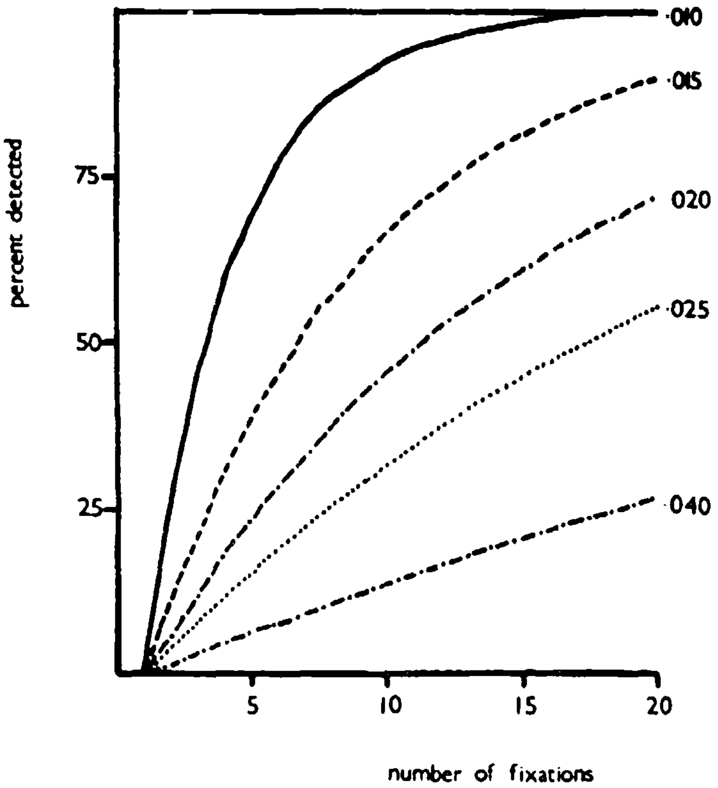


Figure 3: cumulative distributions for variations in m.

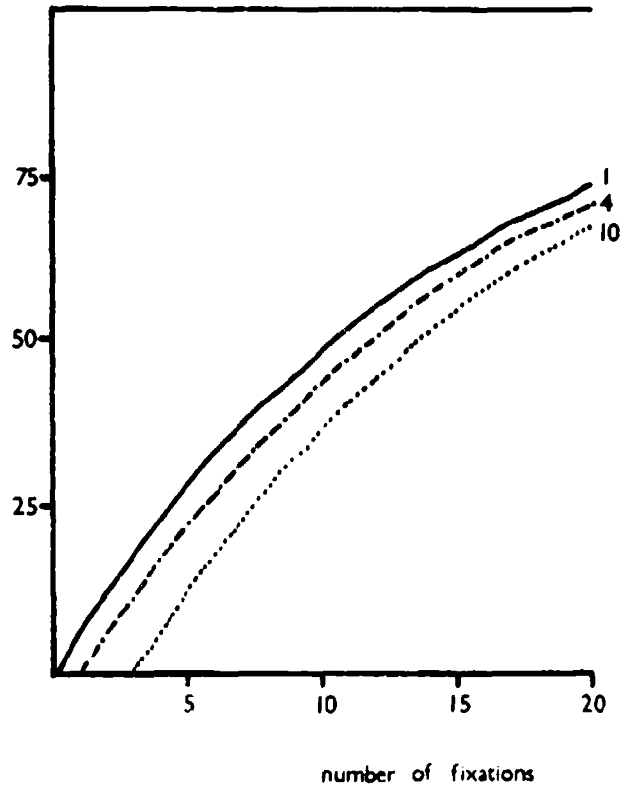


Figure 4: cumulative distributions for variations in y.

It was assumed that all the observer's fixations would fall on objects, whether targets or non-targets, but that otherwise they would fall at random. The actual positions were chosen by means of a pseudo-random number generator.

A further assumption was that the observer searched for both targets simultaneously. On each fixation the number of large lobe targets that fell within the visual lobe area was noted. Each time one of these targets occurred, a time delay was introduced: the delay represented the time needed for a response to the target to be made. Also on each fixation, a check was made whether the small lobe target was near enough to the centre of fixation to be seen. If it was not, the search continued. However, if it was found, the search trial was terminated and the time taken to locate this target was recorded. All the data reported here is in terms of this time. All times were measured in complete fixation units.

There were two small lobe targets (their lobe areas covered 5 and 13 positions in the display) and three large lobe targets (whose areas covered 25, 45 and 77 positions). 2 or 8 or 32 large lobe targets (of one particular lobe area) were presented. The length of the time delay was 1 or 2 or 4 fixations. Thus, there were 2x3x3x3 = 54 conditions. Each condition was simulated for 100 trials.

4. Results and discussion

(i) Variability of the data

In order to give an indication of the variability possible, the simulation was repeated ten times for one condition (small lobe target 5, large lobe target 25, number of large lobe targets 32, time delay 2). The resultant cumulative distributions are shown on figure 5. The spread of distributions is representative of those likely to be obtained for all conditions involving 32 large lobe targets. The spread would be less for those involving fewer.

(ii) Number of large lobe targets

There were 18 comparisons made for the three number conditions (one for each combination of small lobe target, large lobe target and time delay). In all cases, the small lobe target took longer to find the more large lobe targets there were present. Figures 6 and 7 show the effect for two extremes. With small lobe target 13, large lobe target 25, and the shortest delay 1, the fastest times for all three number conditions were achieved (as shown on figure 6). Whereas, the combination of small lobe target 5, large lobe target 77, and the longest delay 4, produced the longest times.

On both figures, as on the other 16 possible graphs, there was a considerable difference between the distributions for 8 and 32 large lobe target conditions, the effect being more marked as the small lobe area is reduced, and the large lobe area and the time delay are increased. The difference between distributions achieved with 2 and 8 large lobe targets is smaller for all the comparisons.

(iii) Variations in small lobe area

There were 27 comparisons made between the two small lobe areas selected. Those illustrated on figures 8 and 9 again shown the extremes of those conditions investigated. On figure 8 the comparison between small lobe areas 5 and 13 can be made, for all three number conditions, with large lobe area 25 and delay 1. On figure 9 a similar comparison is possible, again for all three number conditions, with large lobe area 77 and delay 4.

Both figures illustrate the considerable difference made by changing the similarity of the target to the nontargets (and, therefore changing the visual lobe area associated with the target). The effect is shown just as clearly for all possible comparisons, and is comparable to the effect shown in figure 2 in the first section of this paper.

(iv) Variation in large lobe area.

There were 18 comparisons of the effect of increasing the large lobe area on the time needed to detect the small lobe target. Figure 10 shows two of them. They are for 2 or 32 large lobe targets, small lobe target 5 and delay 4.

The time needed to locate the small lobe target is affected by variations in the large lobe area, but it is not a large effect. Some of the other 16 comparisons showed as large an effect as those of figure 10, but, for others particularly those combinations giving the shortest search times, no effect at all was noticeable.

(v) Variations in response time delay

There were 18 comparisons between response time delay. The largest differences achieved are shown on figures 11 and 12, both with small lobe target 5 and large lobe target 77. Figure 11 shows the differences for 2 large lobe targets, figure 12 for 32.

In both cases, the longer the response time delay, the greater the time needed to locate the small lobe target. Similar effects were obtained for most of the other 16 comparisons. The greatest effects of delays occurred with 32 large lobe targets. With 8 large lobe targets the effect is always present, if sometimes slight. While with 2 large lobe targets, it is less noticeable, and for the fastest time condition (small lobe target 13, large lobe target 25) it disappears altogether.

A change in the shape of the cumulative cumulative curves occurs in some cases as delay time is increased. It is illustrated in figure 12. Similar, though less pronounced changes were noted for the following conditions: small lobe target 5 with 32 large lobe targets of areas 45 and 25, small lobe target

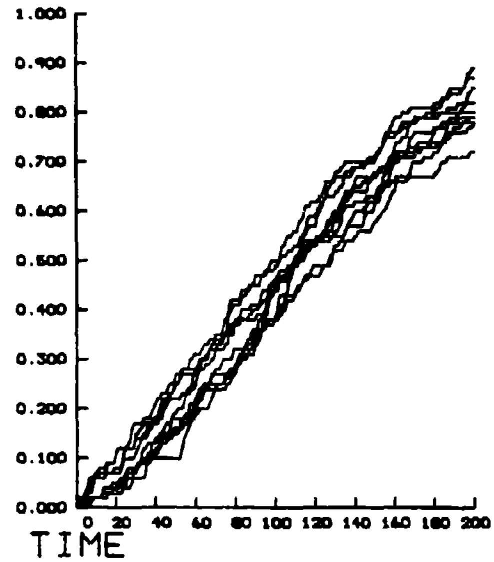


Figure 5: ten repeated simulations of cumulative distributions for target 5, with 32 of target 25 and delay 2.

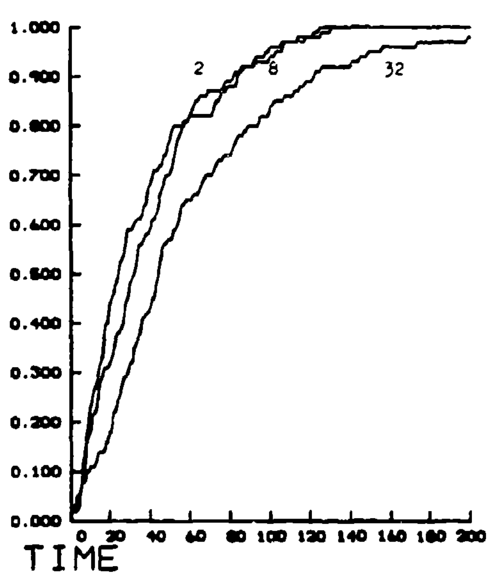


Figure 6: cumulative distributions with 2, 8 or 32 large lobe targets, for small lobe target 13, with large lobe target 25 and delay 1.

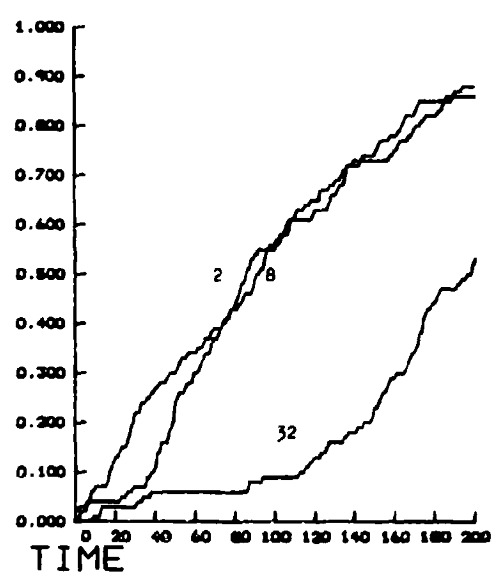


Figure 7: cumulative distributionswith 2, 8 or 32 large lobe targets, for small lobe target 5, with large lobe target 77 and delay 4.

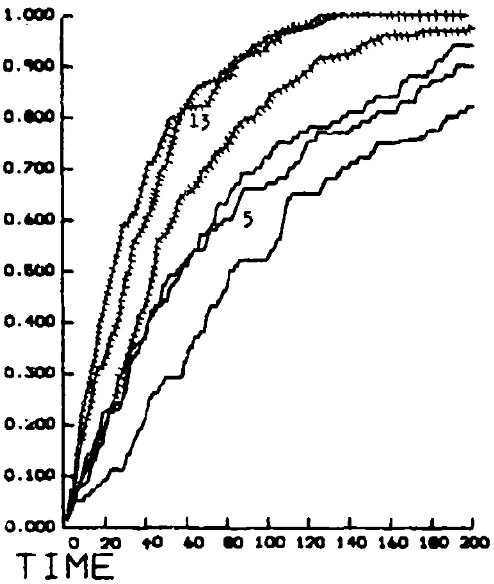


Figure 8: cumulative distributions for targets 5 and 13, with 2, 8 and 32 large lobe targets of area 25, and delay 1.

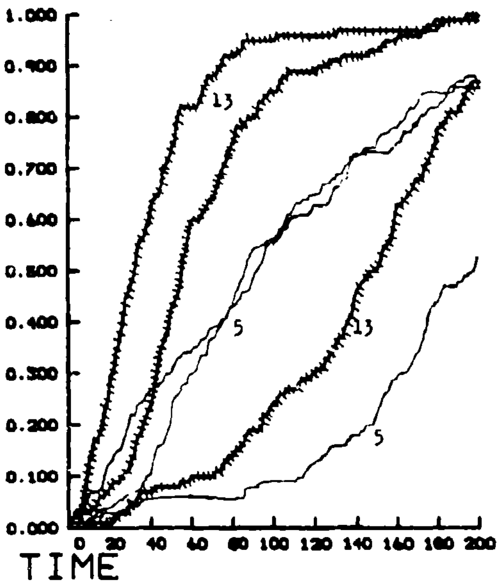


Figure 9: cumulative distributions for targets 5 and 13, with 2, 8 and 32 large lobe targets of area 77, and delay 4.

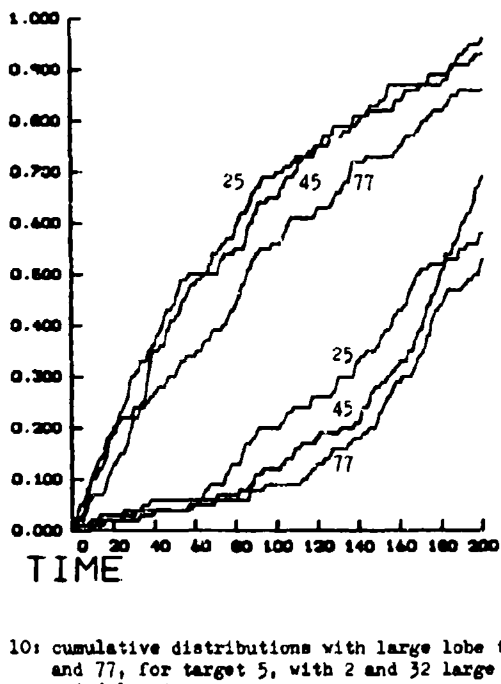


Figure 10: cumulative distributions with large lobe targets 25, 45 and 77, for target 5, with 2 and 32 large lobe targets and delay 4.

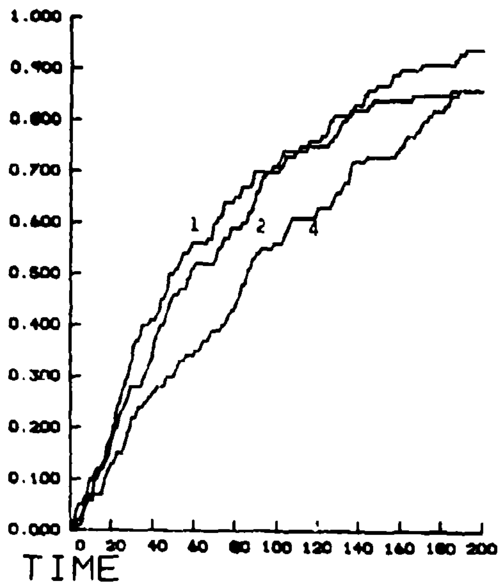


Figure 11: cumulative distributions with delays 1, 2 and 4, for target 5, with 2 large lobe targets of area 77.

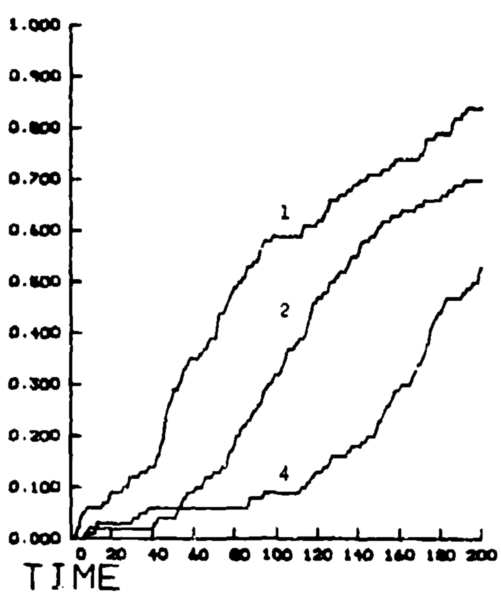


Figure12: cumulative distributions with delays 1, 2 and 4, for target 5, with 32 large lobe targets of area 77.

13 with 32 large lobe targets of areas 77 and 45. It is possible that a similar change in the shape of the cumulative distributions could occur with human observers.

In search situations that involve incomplete target information (i.e. where there is uncertainty about what the observer should look for) Bloomfield(7) suggested that observers can adopt at least two strategies. In the first, a scan pattern suitable for locating the easier targets is chosen. After it has been carried out, they adopt a pattern more suitable for targets slightly more difficult, and so on. With a strategy of this kind, there would not be the change in distribution shape obtained here: instead, with a fairly constant shape, it would merely be shifted along the time axis.

The second strategy is directed towards locating the most difficult target as quickly as possible. Easier targets would be found, as a matter of course, though the search times for them would be longer than if they were specifically searched for. The result of such a strategy, if applied to a situation like that simulated here, should be to produce a change in the shape of the distributions for difficult targets with increases in the time needed to respond.

(vi) Comment.

This simulation study investigates several variables likely to affect multi-target situations. We already know that it has not taken into account one important effect. There are suggestions from empirical work now in progress that an increase in the number of large lobe targets adversely affects the detectability of small lobe targets, so that sometimes they are not detected at all.

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DISCUSSION

Dr Vos (Netherlands)

How far is your work related to the practical situation of an out-of-cockpit search as opposed to a radar situation? I missed the concept of false responses in your argument when you were talking merely about the probability of detection.

Mr Dewey (UK)

Yes, it does in part relate more to radar or sonar displays, but does also fit data associated with one target in an unstructured field. Most of our experiments involve backgrounds with more than one target, however. False positive responses were exceedingly rare. Subjects were almost always right, and when they were wrong, they almost always corrected themselves quickly. So false responses were not incorporated, but we should now perhaps take the problem more seriously.

Dr Vos (Netherlands)

But at first sight of a picture, isn't there a fair chance of getting a false response?

Mr Dewey (UK)

Yes undoubtedly.

Dr Huddleston (UK)

Did you want to say a little about altering observers' criteria to see what happened to false responses?

Mr Dewey (UK)

This model is one purely in terms of a visual lobe with a hard shell. It's not a model in the tradition of signal detection theory where criteria and efficiency can be modified. Perhaps this should be incorporated. It would take time, however, since these simulations run on our quite slow machine. Our earlier model fits quite well without incorporating these refinements, however.

The Effect of Complex Backgrounds on Acquisition Performance

by

M.B.Brown
British Aircraft Corporation Ltd.
Guided Weapons Division
Filton House
Filton
Bristol
England

SUMMARY

The relationship between the subjective effect of structured target backgrounds on acquisition performance and physical attributes of the scene luminance structure is being investigated both theoretically and experimentally. This paper describes the theoretical attempts to classify various aspects of complexity and an experiment which was carried out using synthetic target material. The results showed that certain targets are more easily recognised than others for all the complex backgrounds used, and also indicated that recognition may be regarded as the detection of detail. A large variability between subjects was observed. Part of this variation can be attributed to eyesight differences and to experience.

INTRODUCTION

The Target Acquisition Group at BAC(GW),Bristol is engaged in a study of the acquisition of ground targets from low-flying aircraft. The investigation into the effect of complex backgrounds is a part of this study. This paper describes the theoretical and experimental efforts made so far in this continuing study. On the theoretical side, various aspects of complexity have been defined. This has been done for two main reasons: firstly, it helps to clarify the constituents of a complex background, and thus, it is hoped, leads to better understanding and communication of ideas; and secondly it makes experiments less ambiguous, since complexity classes can be studied separately. It is not claimed that the classes defined here are distinct. Certainly there must be interactions between classes, and the effects produced by these must not be ignored. However, it seems clear that an experimental approach based on seperate complexity classes gives the best chance of obtaining the problem solution.

COMPLEXITY

The term complexity is generally used in a rather loose way. If a useful scale for assigning a complexity value to a scene or acquisition task is to be obtained, complexity must be defined in relation to some scene or task which is acknowledged as being simple. A particularly appropriate set of data which could be used in this way are those from Blackwell's experiments using discs on a plain background (1). A complex acquisition is therefore one which produces threshold contrast/size values that differ from those predicted from Blackwell's infinite viewing time data using the same area and contrast values. (This definition assumes that both contrast and area can be defined. This may present some difficulties if the target or the background immediately surrounding it has a luminance structure. Both contrast and area may then have more than one possible value.) The definition given here means that an acquisition excercise can be complex either because the task conditions are different to those in Blackwell's experiment, e.g. dynamic viewing, finite search time, or because the stimulus is not a disc on a plain background, e.g. structured backgrounds, different shapes. It is convenient to distinguish between these two cases by labelling them task complexity and scene complexity respectively.

Having set up an origin from which to measure acquisition complexity, scene complexity must now be defined in terms of physical measures. The word complexity, when applied to a scene, describes the heterogeneity, or variety, or dissimilarity, of parts or dimensions of that scene. Since heterogeneity can exist with respect to a large number of variables (e.g. object size, shape, luminance, spacing, pattern, etc.) it may be considered that there are as many kinds of complexity as there are variables. However, for our purposes we shall define two classes which we believe are exhaustive. The first class describes a scene containing objects which are similar in size, shape, and luminance to the target, Fig. 1(a). These non-targets may be confused with the target, and thus we have labelled this type of complexity with the term confusibility. The other class, which has been termed complicacy, describes a situation where the target is 'embedded' in an area of varying luminance, Fig. 1(b). The target may also not be of a single luminance; this case is also included in complicacy.

(a) (b)

Fig.1 Examples of (a) confusibility and (b) complicacy

COMPLEXITY MEASURES

The complexity measures are separated into two classes, one containing subjective assessments, the other physical measures. The physical measures are the result of mathematical operations (or their optical or electronic analogues) on the scene luminance. Subjective measures can be obtained empirically. The basic subjective measure is that obtained from an acquisition task, as mentioned earlier. A second type of subjective assessment can be obtained from a ranking experiment in which scenes are ranked on the basis of target prominence.

There are a large number of ways of describing the scene luminance structure, e.g. entropy, mean scene gradient. One measure which expresses the degree of similarity of a target with its background is the cross-correlation function. Because of its relevance to the experiment described hereit will be treated in more detail. A more detailed treatment of mean scene gradient and entropy is given in (2), and other possible measures and their limitations are discussed in (3). The cross-correlation function is given by

$$C(x',y') = \iint_{-\infty}^{\infty} T(x,y)L(x-x',y-y')\,dx\,dy$$

where $T(x,y)$ and $L(x,y)$ are the target and background luminance structures respectively. The interesting property of $C(x',y')$ is that if the background contains an object similar to the target at x_n, y_n, then large values of $C(x',y')$ occur in the vicinity of $x'=x_n$, $y'=y_n$. The relationship between the object and cross-correlation planes is demonstrated in Fig. 2. It seems clear that the cross-correlation function has properties that makes it a candidate for a measure of confusibility.

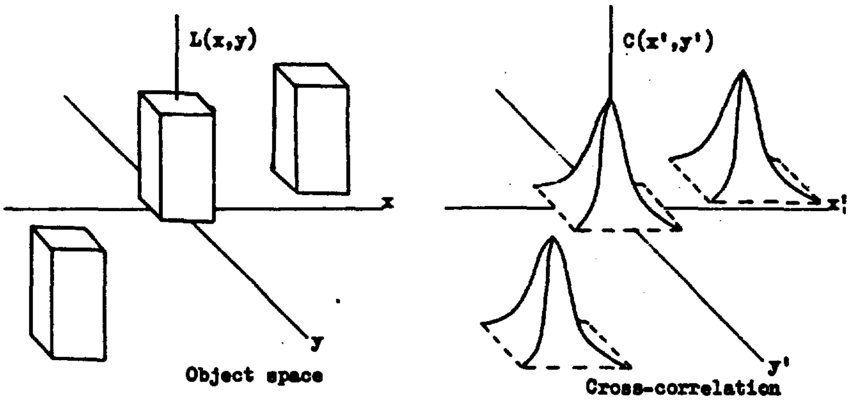


Fig.2 The relationship between Objects and Cross-correlation.

CONFUSIBILITY EXPERIMENT

An experiment was carried out to investigate the effects of confusibility on recognition performance. This experiment utilised the STill Acquisition Facility (STAF) at BAC, Bristol. Basically, this consists of a room at one end of which there is a large back-illuminated perspex screen. Target stimuli are presented on this screen to a subject (S) who sits in a motorised chair. The chair may be driven either forwards or backwards by the S. An acquisition is marked by the position of the chair when the S stops it. The target stimuli themselves are produced on photographic transparencies and fixed to the screen during an experimental run. The dimensions of the STAF room limit the maximum range to 23ft.

In the experiment the stimuli were scenes consisting of an array of relatively simple shapes. Four different targets (T's) were used, Fig. 3, and each T was embedded in an array of similar shapes (NT's). Each shape, including the T's, was constructed from six unit squares, with the constraint that each one must have a base of at least three units in a horizontal line. The NT's were arranged around the T in a 5x5 matrix. (24NT's+1T). The T was constrained to lie within the central 3x3 matrix, so as to eliminate edge effects. However, it was decided to present some scenes with T's on the edge so that the S's would not limit their search to the central area. The results for these particular scenes would not, of course, be included in the main analysis.

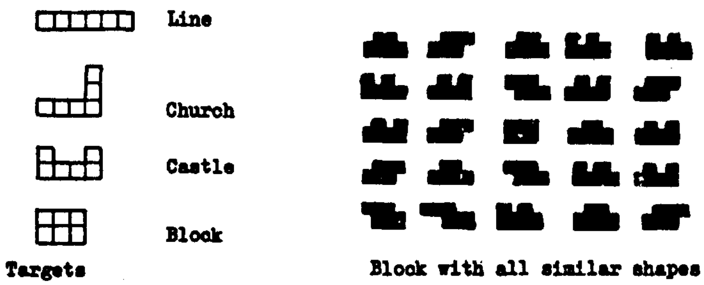


Fig.3 The Targets and a typical complex scene.

Different levels of confusibility were achieved by grading the NT's on a similarity scale independently for each T. The peak value of the cross-correlation between the T and NT was used for the grading. The NT's were divided into two sets, the members of one being classed as similar, members of the other being called dissimilar. For any T, similar shapes were arbitrarily chosen as having a peak correlation of 5.(the autocorrelation was 6), the rest being dissimilar. Scenes containing all similar NT's and all dissimilar NT's were constructed, as well as scenes containing a mixture of the two classes. These mixed scenes were constructed so that any effect due to the closeness of similar NT's to the T's would be found. This led to scenes which contained similar NT's near to the T with dissimilar ones further away, and scenes which had the reverse configuration, dissimilar near-similar far. A typical scene is shown in Fig. 3. One other variable was introduced into the experiment. This was packing density, that is the spacing between the NT's. Two levels were used, one being representative of a town scene, the other being similar to that which might occur in a country scene.

Before producing the experimental transparencies a pilot experiment was carried out to determine the size and contrast of the shapes to be used. The S's used here were several members of the Target Acquisition Group who would not be taking part in the rest of the programme. Sixteen S's were used for the main experiments, and they were chosen so that 8 could be classed as experienced and 8 as naive. The criterion for choosing experienced and naive S's was whether or not they had participated in previous STAF experiments or been actively engaged in visual acquisition studies. Any person engaged in any work concerned with the complexity problem was barred from the experiment.

The first experiment consisted of presenting four T's with either none, three, or four similar shapes closely grouped around them. The S's were also shown transparencies without a T, i.e. with only background shapes on them. The purpose of this experiment was to provide a comparison for evaluating the results for the complex situations. After this the S's were trained using the complex stimuli. The training consisted of presenting 8 transparencies similar to those which would be used in the experiment proper. Each of the four T's was presented twice, once at low and once at high packing. Also all the shape distributions were covered twice. After the training the S's were shown the 32 scenes containing 4 T's, 4 shape distributions, and 2 packing densities. Extra transparencies with T's on the edge of the 5x5 matrix were also included as mentioned earlier. The order of presentation was randomised to minimise any effects due to learning, fatigue, etc. The briefing for these two experiments consisted of a short description of the aims of the experiments and the target stimuli. The S's were then asked to 'look at the transparency, and as the chair moves forward to study the shapes until you can see the designated shape. As soon as you can see it press the switch to stop the chair, and then point out that shape which you consider to be the correct one.' The S's were not told whether they had made a correct recognition or not. After the experiment they were also asked to rank the T's in order of difficulty. General comments about the experiment were also solicited.

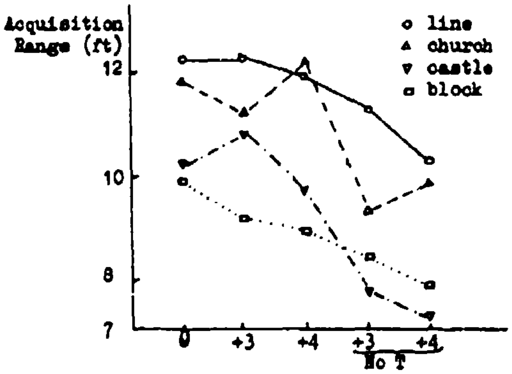


Fig.4 Results of the first experiment

EXPERIMENTAL RESULTS

The results of the first experiment are shown in Fig. 4. Here, 0, +3, +4, refer to the number of NT's surrounding the T. There was a considerable number of recognition mistakes, 67 out of a total of 320, and this meant that a full analysis could not be performed. Most of the mistakes, 51, occurred for runs where a T was not present. Also the mean recognition ranges were lower for the no-T runs. Although the S's were told that T's would not be present on some transparencies, they found it more difficult to decide that this was so than to recognise one of the T's. Fig. 4 has been plotted using estimated results for the incorrect recognitions. This has obviously greatly affected the results for the no-T cases.

The data obtained from the main experiment was divided into three sets for the analysis, all 16 S's, 8 experienced S's only, and 8 naive S's only. A test for normality was carried out, using a ranking method to estimate the probability of a particular range score, and using this the range scores were plotted on normal probability paper. These plots were linear over a 15-80% probability range, and it is fair to conclude that the range scores are normally distributed. The missing data due to false recognitions were estimated by a method of Bennett and Franklin (4). The missing cell entries were small compared to the size of the experiment, and the estimation of missing data was unlikely to confound the analysis. A four factor analysis of variance was performed for each of the three sets of S's. The results are shown in Table 1. All the main effects and most of the first order interactions were significant ($p<0.5$). Also the three sets were very similar, the main difference being the non-significant effect of packing density for the naive S's.

The four main effects are shown in Fig. 5. The experienced S's found the acquisition task significantly more difficult at the higher packing density, but no difference in packing was found with the naive S's. The reason for this is illustrated by the subject/packing density interaction. Fig. 6 shows that as the S finds the task more difficult the difference between the effects of packing becomes smaller. Since the naive S's in general obtained lower ranges than the experienced S's, the effect of packing was lower for the former set. These effects are thought to be a function of confidence level, and such trends are general throughout the results, the naive S's producing lower acquisition ranges than the experienced S's with differences in effects also being smaller.

The difference between the means of the two S sets was 2.1ft., or a 21.5% reduction in range for the naive set. If the maximum and minimum mean values are considered, the variation is 55% of the maximum value. Part of this variation may be due to differences in S's visual acuity (VA). The average VA (measured using Snellen letters) for the two groups were 6/6 (experienced) and 6/7.5 (naive). It is worthwhile noting that the ratio of the group mean recognition ranges (7.75/9.88=0.79) is approximately equal to the ratio of the group mean VA's (6/7.5=0.8). Also the maximum and minimum ranges were recorded for S's who had VA values of 6/5 and 6/10 respectively. In Fig. 7 VA has been plotted against mean S performance. A Spearman rank diff-

		All S's			Experienced				Naive		
Factors	DF	Ref.*	F	Level%	DF	Ref.*	F	Level%	Ref.*	F	Level%
I	1	IL	26.8	0.1	1	IL	50.6	0.1	IL	4.8	NS
J	3	JL	42.0	0.1	3	JL	22.5	0.1	JL	17.6	0.1
K	3	Res	10.1	0.1	3	Res	6.9	0.1	Res	5.3	0.5
L	15	"	82.8	0.1	7	"	58.3	0.1	"	72.3	0.1
IJ	3	"	14.3	0.1	3	"	12.8	0.1	"	5.1	0.5
IK	3	"	1.6	NS	3	"	-	NS	"	-	NS
IL	15	"	6.3	0.1	7	"	4.1	0.1	"	7.4	0.1
JK	9	"	2.2	2.5	9	"	2.4	2.5	"	1.5	NS
JL	45	"	2.0	0.1	21	"	2.9	0.1	"	2.0	2.5
KL	45	"	-	NS	21	"	-	NS	"	-	NS
IJK	9	"	3.0	0.5	9	"	6.8	0,1	"	-	NS
IJL	45	"	-	NS	21	"	-	NS	"	-	NS
IKL	45	"	-	NS	21	"	-	NS	"	-	NS
JKL	135	"	-	NS	63	"	-	NS	"	-	NS
Resid.	135				63						
Total	511				255						

I - Packing
J - Targets
K - Confusibility
L - Subjects

*The F-value was obtained using the variances listed under Ref.

Table 1

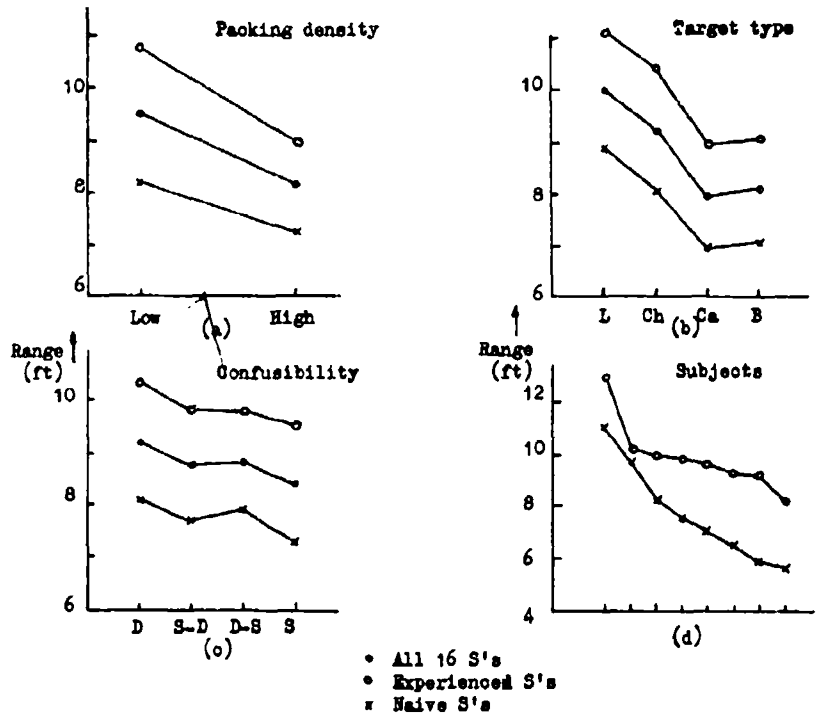
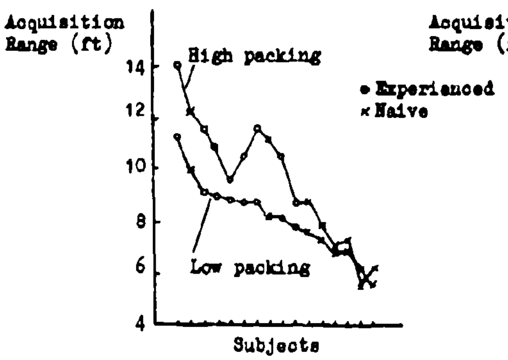


Fig.5 Main effects for experienced and naive subjects



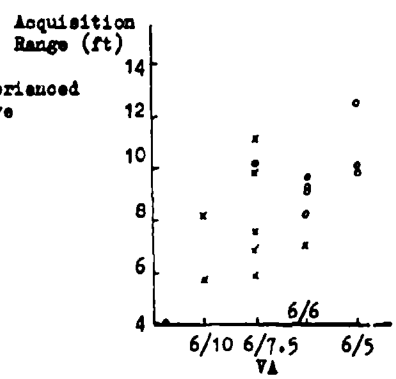


Fig.6 Variation of packing density effect with Subjects

Fig.7 Subject performance as a function of Visual Acuity erence analysis gave a correlation of 0.47, which is significant at the 5% level. Thus although the effect of packing density is highly significant, it is smaller than the variation in S's mean performance.

The effect of target type is shown in Fig. 5(b). The difference between the block and castle was not significant (>5%). Both sets of S's show a similar trend. A comparison with the results of subjective ranking of the T's in order of difficulty showed a high correlation between the two sets of results, the ranking producing the order (easiest first) line, church, castle, block. The ranking was very consistent between S's (see Table 2).

S	Debrief Rankings				STAF Performance			
	Line	Church	Castle	Block	Line	Church	Castle	Block
1	1	2	3	4	2	1	4	3
2	1	2	3	4	1	2	4	3
3	1	2	3	4	1	2	3.5	3.5
4	1	3	2	4	1	2	3.5	3.5
5	2	3	1	4	2	1	3	4
6	1	2	3	4	2	1.	4	3
7	1	2	3	4	1	2	4	3
8	1	2	3	4	1	3	2	4
9	1	2	3	4	1	2	4	3
10	1	2	3	4	1	2	3	4
11	2	1	4	3	1	2	3.5	3.5
12	1	2	3	4	1	2	3.5	3.5
13	2	1	3	4	1	2	3.5	3.5
14	2	1	4	3	1	[illegible]	4	3
15	1	2	3	4	1	3.5	3.5	2
16	3	2	4	1	1	3	2	4
Mean	1.38	1.88	3.0	3.7	1.19	2.03	3.44	3.24

Table 2

Confusibility as defined earlier also appeared as a significant effect, Fig. 5(c). Here there appears to be no significant difference between the stimuli with mixed confusibility, i.e. similar objects nearest the T with dissimilar ones farther away, and the reverse case. However there is a significant difference between all similar NT's and all dissimilar NT's. Also the confusibility factor had no effect for the church. It is useful to compare the results with Blackwell's for the detection of discs on a plain background, and also to some experimental results obtained from two trials involving the detection of ground objects from low-flying aircraft. In the first trial, called VS I, the aircraft was flown at an altitude of 1000ft. or less, and the T's were mainly in open terrain (N. Scotland). In the second trial, VS II, the aircraft was flown at 1000ft. altitude, and the T's were in more complex situations, e.g. in towns. Details of these two trials can be found in (5) and (6) respectively. In Fig. 8 contrast and size thresholds have been plotted for all these results, and Blackwell's 15-second search time data is also shown (Blackwell's published data has been factored to give a 95% probability of detection). The contrast/size thresholds from the complexity experiment lie close to the field trials for the more complex T's. If the size thresholds are reduced by a factor of six, the threshold values become very much closer to the Blackwell curve. This result would apply if the recognition task is to be considered to be one of detecting the individual blocks which comprise the shapes. Thus there is some indication that recognition may be regarded as the detection or discrimination of detail.

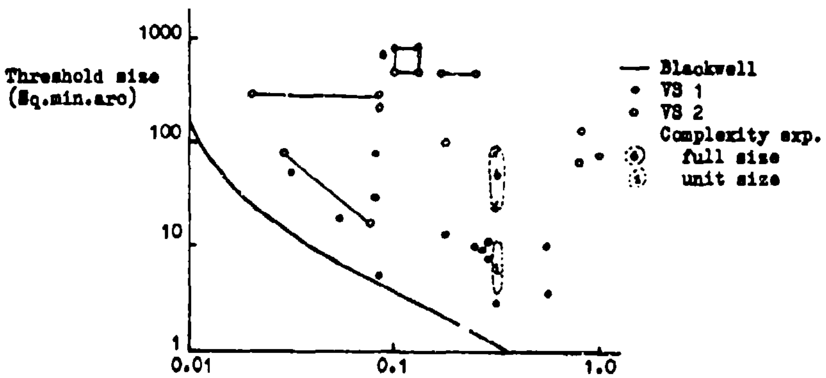


Fig.8 Threshold size/contrast values

SUBJECTS COMMENTS

The S's were asked to give their impressions of this acquisition task. One general comment concerned the search procedure used. At ranges large compared to the final recognition ranges the S's could isolate a few objects which they thought could be the T. They then concentrated on these until they could discriminate the T. They also expressed the view that this discrimination occurred rather abruptly. This subjective impression suggests that some function of the correlation of the T with the NT's might well be a good measure of confusibility. The S's also commented on interaction effects at the high packing density level. When the objects were closely packed it was difficult to distinguish them, i.e. a merging of the NT's took place. In some cases, discrimination between certain shapes was easier when they were closer together. Presumably, comparisons between shapes can be made more easily in this case.

CROSS-CORRELATIONS

The cross-correlation, as defined earlier, was found for each transparency. This was done by a manual computation, a digital representation being used. The levels were 0,......5,6, and a typical result is shown in Fig. 9. Here the larger squares show the position of NT's which were classed as similar, in this example there being 9. Now, the simplest description of confusibility would be based on the number of correlation peaks above a certain threshold value, and in this case a level of 4.5 would have to be used. In Fig. 10 the mean recognition ranges have been plotted against the number of correlation peaks greater than 4.5 for each T at low packing. The results for high packing were not used as the correlation for each NT overlapped with those from adjacent NT's. The line and block show a marked decrease in recognition range as

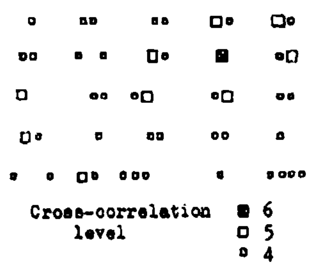


Fig. 9 Cross-correlation plane for castle with similar shapes near to the T

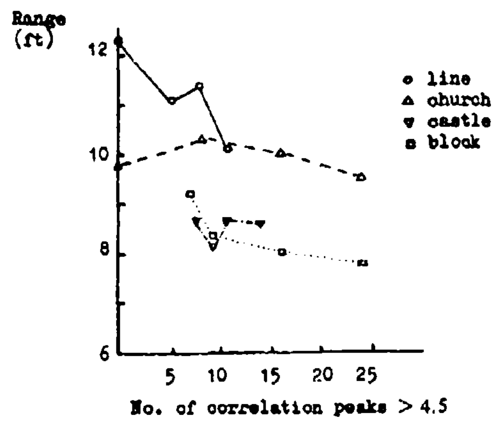


Fig. 10 Mean Ranges as a function of correlation peaks at low packing

the number of correlation peaks increases. The church and castle do not show such an effect, although the range of correlation peaks for the castle is very small. Thus there is some evidence that number of correlation peaks is linked with difficulty of recognition in a confusible scene, particularly with simply shaped T's, i.e. line and block. Obviously it does not explain the results for the two other T's. It is possible that the shape of the cross-correlation is also important. Also it must be pointed out that the range of correlation peaks obtainable using all combinations of the four T's with the NT's is very small. The minimum value of correlation peak, 3, is determined by the construction rule that constrained all shapes to have a base of at least three units, whilst the maximum value is 6, the autocorrelation level. Furthermore, the minimum value is only obtained when one of the two shapes being correlated is the line. In other cases the minimum value is 4, as in Fig. 9. Thus for the church, castle, and block, the difference between similar and dissimilar shapes is quite small in terms of cross-correlation peaks, and this is a possible reason for the small effect on recognition range of the confusibility factor.

CONCLUSIONS

The results of this experiment suggest that, when using stimuli consisting of a set of differently shaped objects, recognition may be regarded as the detection of detail. The part of the T which comprises the relevant detail will, of course, depend on the shapes of the objects surrounding the T. In fact, only objects which are most similar in shape to the T need be considered. Also, there is some evidence to suggest that recognition in the presence of confusible objects is related to the cross-correlation function of the T with the NT's. Detection and cross-correlation are related in as much as the larger a correlation peak becomes, the more similar are the T and NT, and thus the relevant detail which must be seenin order to distinguish the two objects becomes smaller.

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ACKNOWLEDGEMENT

I should like to thank Mr. P. Phillips for producing the target stimuli and conducting the experiment.

GENERAL DISCUSSION

Dr Huddleston (UK)

In opening the general discussion I don't want to push my own ideas too far. My questions are usually enormously unfair, and of the kind 'what large factors have you omitted from your model?' However, would it be reasonable to ask you to confess to any omission first, Dr Greening?

Dr Greening (US)

I do not feel the question is unfair, although that doesn't mean it is easy to answer. I've felt for some time that a major shortcoming has been an overemphasis on search and acquisition as an optical problem and an underemphasis on it as a cognitive problem. Behind the data I reported, for example, is an intelligent human being doing the searching, not an optical machine. He knows something about the object of his search, and we should try to account for this.

One of the reasons for my belief in the impact of personality on the problem lies in some work we did 5 years ago in forcing the person to say where the target was before he was prepared to commit himself. After he had indicated a likely location, we asked for a confidence estimate. This arose from an informal earlier observation that subjects would observe the target for an incredibly long time before pressing the "acquired" trigger; we wondered what was going on all that time. We found he was gradually increasing his level of confidence until he was ready to commit himself. One of the things humans don't like to do is to make foolish errors, and no matter how you instruct, they hold off from making a conspicuous error of judgement. This represents one of the kinds of things not handled well in our models.

Dr Huddleston (UK)

I wonder, Mr Overington, if I can now ask for a confession from you regarding the BAC model? I mention the childishly obvious supposition we all make that hue is so desaturated as not to come into the problem. However, I feel ill at ease too about the sharp edge, almost black/white contrast element at the crux of many models. Have you any comment?

Mr Overington (UK)

I could only make a personal one, and that is the basis on which I started the modelling I've reported. For some years I worried that most modelling could only cater for a sharp-edged object. This seemed to me to apply to recognition, the interrogation of specific objects, too. If one talks in terms of contrast and size as being predominant model features, this takes no account of a whole host of other relevant things. For instance, when you look at a simulation or a TV system or an image intensifier you have some degradation of imagery. Also, relevant to the observer himself, there are factors such as state of accommodation, pupil diameter, various other factors which change retinal image quality. This quality of retinal image is of course very important in all we do, detection and analysis of detail included. At BAC we, like many people, have tended to be over-naive in air-to-ground modelling in this assumption that it is the detection threshold that matters. I agree with Dr Greening that the ability to interrogate one of a number of possible objects at length, in a virtually no-search situation, is what really matters. But, still, quality is all too little considered.

Dr Huddleston (UK)

Still talking about modelling, Mr Silverthorn, if I had to confess illness-at-ease about model adequacy, I might have major misgivings about your definition and use of a hard shell visual lobe. Could you perhaps first clarify for the meeting what such a lobe is, and then mention what a soft shell model might imply, were there one?

Mr Silverthorn (UK)

In arriving at the hard shell lobe I made use of Dr Taylor's off-axis data, and generated what I call a target detectability profile. The probability of detection off-axis does not necessarily go up to 1. The lobe is merely a mathematical device for making the calculations simple. At $p = 0.5$ let us say, there will be a certain probability of off-axis angle and that is taken, quite simply, as the radius of the hard shell lobe. It's obvious that the concept of seeing the target inside, not outside the lobe, is again merely a mathematical device.

Imagine we have a search area with one embedded target which may be at any position. We are forced to speak of convolution; if we take my detectability profile across the search area an average probability of detection is found. This average is taken really in two ways, but as an average on glimpse distribution (a uniform, rectangular distribution in my model) the hard shell model makes sense.

Group Captain Whiteside (UK)

I want to ask simply what is the use of mathematical modelling? When considering men, with their changes in accommodation, arousal and so on, who are momentarily frightened with a consequently widened pupil, who alter their direction of gaze for a quite arbitrary and unpredictable reason and so forth, what use is a model? The aircrewman may have had a car accident or a police fine, or he may have an unhappy wife; how do you include all such factors and make sense of the modelling?

Mr Silverthorn (UK)

I don't spring to the defence of modelling, but heartily agree. It seems to me there are physical aspects of the problem and there are psychological aspects of the problem. The psychologists haven't a model of psychological man in the same sense that we have, for instance, visibility models. It seems to me we have taken the easy route through the physical side of modelling.

Dr Greening (US)

I can comment only to the extent of reiterating that we are leaving the human out of the model, unless we have him there as part of the variance. One of the few items of data I'm aware of that bears on your question directly was collected by the US Joint Chiefs of Staff (but is not otherwise available) on a Joint Task Force simulation using real personnel, real vehicles and real terrain. There were differences between those data and others from cinematic simulation in terms of probability and range effects, but, more importantly, there was immensely more variability in the real than in the simulated data. I feel the human being is represented in those very large variabilities. This is not an answer to your question, though; it is a confirmation of the basis for it.

Dr Huddleston (UK)

Mr Overington, I take it you are happy to start from adequate arithmetical descriptions of physical things such as retinal spread functions and eventually work through to these more nebulous areas with an accretion of precise models? In other words, you wouldn't agree that at the minute we measure the easy and omit the important?

Mr Overington (UK)

Well, I remain optimistic. We can come to terms, given that we start simply. We are still at the simple stage admittedly. My random search modelling, and recent simulation work not yet reported related to a photo interpreters type of task gives one confidence that the nebulous can be come to terms with eventually. Certainly, there is an awful lot of parameters to include in the modelling, each a source of variance and, indeed, of bias. It would be foolish to say we're close to accounting for them all at the moment.

Colonel Appleton (US)

I don't share your malaise about modelling work. What we're talking of is human performance (and the selection of personnel to perform) in the final analysis. Primary factors bearing on performance are sensory acuity, motivation and aptitude. We measure acuity to the best of our ability. We've pretty well given up on the measurement of motivation. I think what we're discussing here is largely to do with measuring aptitude. What appears to bother people is that the models don't mimic accurately; they probably never will very exactly. But that's not so big a problem. You end up with a situation, gadget, or whatever to measure up against people that you're going to select.

On the basis of intuition alone, if your model is close, without meeting the rigid criteria scientists tend to set themselves, it will be a most useful tool with which to assess aptitude. I encourage this kind of modelling; I see it as a great step forward. At the moment we're measuring acuity with a Snellen chart, knowing what a poor physical standard that is, and likewise for colour sense tests using pigments or lights. I think the modelling area is much more sophisticated, applicable and useful than simply measuring acuity, for example. Because you can shoot the models full of theoretical holes doesn't destroy their value.

Mr Silverthorn (UK)

I'm a little concerned that you base your views on operator selection. I, at least, model for operational roles and their description, in order to determine what aircraft stores to carry, for example. I don't think the model is good enough for that, yet.

When we varied target size, but not shape, and predicted by our model that range should be proportional to the scale used, we were quite wrong. Range and scale were independent, and the model came nowhere near. There must be a large factor we haven't come to terms with. In this sort of area we feel uneasy about the modelling we're doing.

Colonel Culver (US)

I was encouraged to hear of the importance of factors to do with the eye other than acuity, for instance accommodation, which Mr Overington mentioned. Do these factors need further clarification?

Mr Overington (UK)

I'm sure they do! We at BAC are one of many groups trying to tackle this.

Dr Vos (Netherlands)

Target recognition can be done by instrumental methods, looking through telescopes or whatever. Is that the kind of thing you make models for?

Dr Huddleston (UK)

Certainly a model can be applied to the aim of comparing physical aids, if that is what you mean.

Dr Greening (US)

We have done a good deal of modelling of TV, IR and other devices, and these models can be added on to the kind of models we've been discussing here. A human observer and physical detector are then in series, and the detector between him and the source brings another 20 or 30 variables with it. In my opinion this topic would justify another meeting.

Under USAF contract a few years ago, for instance, my Company examined low-light TV systems in just this way, namely, comparing 2 image intensification systems by reference to model parameters. Results show you can enquire usefully about parameters such as signal-to-noise, aperture, and so on, as they affect total system performance, man included.

Mr Overington (UK)

Modelling should be applicable to the comparison of equipments. Unfortunately, one quickly runs into the topic of image evaluation, which is beyond the scope of this meeting. I agree with Dr Greening that another session would be needed to cover it adequately. One of our objectives at Bristol is to model this man-equipment interaction, and we are optimistic.

PERIPHERAL ACUITY WITH COMPLEX STIMULI AT TWO VIEWING DISTANCES

by

Dr J R BLOOMFIELD

Department of Psychology, University of Nottingham,
University Park, Nottingham NG7 2RD, U K

SUMMARY

Visual acuity is defined in terms of the minimum resolvable visual angle or its reciprocal. This assumes, implicitly, that acuity is independent of viewing distance. In the current study, this assumption was tested for peripheral acuity using two viewing distances. A complex visual display was used for the acuity task. The display contained a regular 17 by 10 arrangement of discs. Its angular dimensions were $27^{\circ}1'$ by $16^{\circ}5'$ and $4^{\circ}2'$ by $2^{\circ}24'$, with the observer 7 ft (2.13 m) and 47 ft (14.33 m) away, respectively. The display was exposed for 0.25 seconds, with the observer fixating a particular point in it. Measurements were made of the threshold distance from the fixation point at which a single, smaller target disc could be detected. The data, obtained from eight observers, supported the assumption that peripheral acuity is independent of viewing distance; the threshold distance remaining unchanged for four sizes of target, in spite of the large change in viewing distance. This implies that performance in air-to-ground target acquisition should not be directly affected by variations in viewing distance.

A. INTRODUCTION

1. Visual search and peripheral acuity

Smith(1), Erickson(2) and Johnston(3) have shown that visual search and peripheral acuity are related. The further into the periphery that a particular stimulus can be seen, the faster are the search times associated with it. The smaller the observer's visual field, the slower he is at searching. Howarth and Bloomfield(4,5) made use of this relationship in order to relate search times directly to the physical characteristics of their search displays. They had some measure of success in predicting search times from peripheral vision performance, both for displays with a target among nontargets (Bloomfield and Howarth, 6) and for a single target in a plain background (Bloomfield, 7).

In many search tasks, the distance between the observer and the search area is not constant. In particular, for air-to-ground target acquisition, the observer is in continuous motion, and the distance between him and the target area is always changing.

Peripheral vision measures can be used to predict performance in search tasks with a constant distance between the observer and the display. But, what is the effect of viewing distance on peripheral acuity? And, can peripheral acuity be used to predict search performance when viewing distance varies? This study was designed to investigate the first of these two questions.

2. Foveal visual acuity and viewing distance

Visual acuity is, unfortunately, usually defined as the reciprocal of the minimum resolvable angle, measured in minutes of arc. In many ways, it would have been far better if it had been defined in terms of the minimum angle alone. However, the use of either definition entails the acceptance of the assumption that acuity is independent of the distance between target and observer.

In fact, with short viewing distances, i.e. below approximately six feet (two metres), foveal acuity decreases with decreasing distance. It has been suggested that, since convergence and accommodation necessarily co-vary with distance, either or both may account for this phenomenon. Tulving(8) discussed these possibilities and produced evidence indicating that, in the absence of any changes in the distance of the target from the observer and regardless of the state of accommodation, convergence alone influences acuity.

With longer viewing distances foveal visual acuity does appear to be independent of distance. Beebe-Center, Mead, Wagoner and Hoffman(9) reported that, at observation distances varying from about 30 feet (10 metres) to 2 miles (3.2 Kilometres), "for practical purposes visual acuity, defined in angular terms, may be considered to remain constant over this range of distances".

3. Definition of visual acuity

Before discussing the effects of viewing distance on peripheral acuity, it is worth detailing the difficulties caused by defining acuity in terms of the reciprocal of the minimum resolvable visual angle. This definition was introduced by Wertheim(10) and it has led to the view that peripheral acuity decreases rapidly at first as one moves away from the fovea, but then more slowly as the far periphery is reached. Both Low(11) and Weymouth(12) have pointed out that a much more accurate picture of peripheral acuity is achieved if the minimum resolvable angle itself is plotted against eccentricity. Figure 1 shows

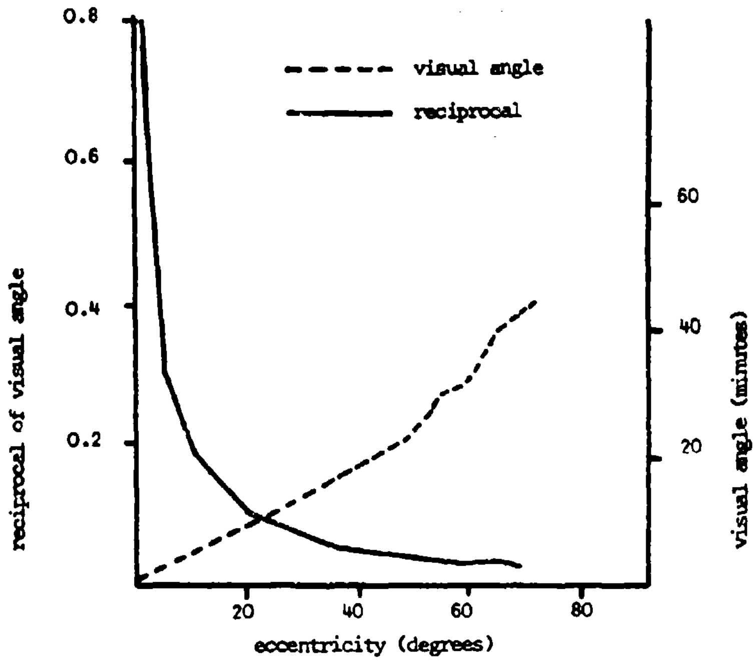

Figure 1: Wertheim's (1894) peripheral acuity data shown in terms both of the visual angle and of its reciprocal (adapted from Low, 1951).

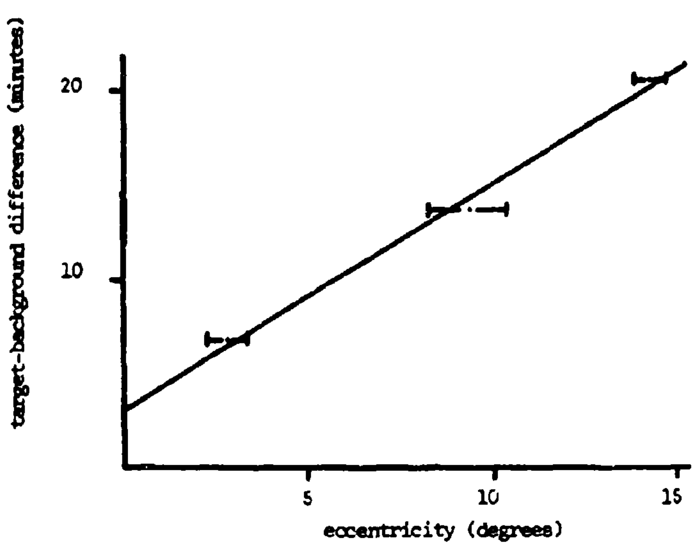

Figure 2: Bloomfield and Howarth's (1969) peripheral acuity data shown in terms of the difference in visual angle of the diameter of target and nontargets.

Wertheim's data plotted in both ways. After his careful and precise measurements revealed that acuity falls off gradually, and approximately linearly, as one moves from the fovea into the periphery and, then, in the far periphery falls off more rapidly, it is ironic that Wertheim represented his data in a way that actually seems to reverse this picture. Indeed, it is doubly ironic, since in doing this he moved from the kind of function - a linear one - that most researchers strive for, to a more complex function that is not easy to categorize mathematically.

4. Peripheral visual acuity and viewing distance

As a result of the use of the reciprocal function, the periphery of the retina has been assumed to be qualitatively different from the fovea. In fact, the linear relationship between minimum resolvable visual angle and angular eccentricity, leads to the expectation that similar principles to those that are true of the fovea might also hold in the periphery, particularly in the peripheral areas from 0° to 30° or 40° from the fovea.

One might, therefore, expect the effect of viewing distance to be similar. Again, in using angular terms, there is an implicit assumption that acuity is independent of distance. And, furthermore, for an isolated acuity target in a plain background, that the effect of reducing the angular size will be the same whether it is reduced by using a smaller target or by increasing the distance between the observer and the target.

Experiments testing this proposition have used short viewing distances and have produced all three possible results: i.e. that stimuli forming equal retinal images produced better peripheral acuity when placed near to the eye than when further away (Aubert and Foerster, 13; Jaensch and Kleeman, 14); that distance had no effect (Luckiesh and Moss, 15); and that acuity became worse for stimuli placed nearer to the eye (Freeman, 16). These experiments are discussed by Low(11). He points out that the observed acuity differences are both small and irregular and concludes that peripheral visual acuity, if measured with proper experimental safeguards, depends on the size of the retinal image.

No study that I know of has investigated the effect of viewing distance on peripheral acuity using distances of over six feet (two metres).

5. Peripheral visual acuity with complex stimuli

As mentioned earlier, Bloomfield and Howarth(6) obtained peripheral acuity measures using displays containing a target disc amongst a number of nontarget discs. They obtained a linear function relating the difference in diameter of the target and the nontarget discs to angular eccentricity. This is shown in Figure 2. It is similar to the linear function of Figure 1. Once more the use of angular terms entails the implicit assumption that peripheral acuity is independent of viewing distance.

The experiment reported here was carried out to test this assumption. In it, I used the type of display used in several studies of visual search (Bloomfield, 7, 17, 18) as well as in the experiment by Bloomfield and Howarth(6). The experiment differs from previous studies of visual acuity and viewing distance in that no attempt was made to have targets of equivalent angular size at the different distances. Instead, the linear dimensions of the target, the nontargets and the display were held constant. Under these conditions, if peripheral acuity was independent of viewing distance, we would expect to find that the linear threshold distance remained constant. (This is discussed more fully in section C.4.).

B. APPARATUS AND PROCEDURE

An overhead projector was used to project the display material onto a screen. A perspex sheet, with shallow holes drilled into it, was placed on the projector. Ball bearings were placed in these holes, their images appearing on the screen as discs. The perspex was masked off to give a rectangular display longer horizontally than it was vertically.

The observer sat near to the display (7 ft - 2.13 m) or far from it (47 ft - 14.33 m). His angle of view was identical at the two distances. The room was evenly illuminated. The ambient light level was 44 lm/ft². The walls of the room were matt white. The dimensions of the room were 48.25 feet long by 16.5 feet wide by 9.5 feet high.

The display used contained 170 large discs arranged in a regular 17 x 10 matrix. A fixation spot was provided for the observer. This fell on a spot coincident with the centre of the disc with two stimuli to its left, 14 to its right, four above and five below. The dimensions of the display, with the projector 6.5 feet from the screen, are given in Table 1.

The observer's task was to detect the presence of a single smaller target disc, which was placed on the horizontal row indicated by the fixation point and to the right of this point. Four sizes of target were used. Their dimensions and those of the nontarget background discs are given in Table 1.

In order to expose the display for a brief controlled interval a large aperture camera shutter was fitted to the overhead projector. The fixation point was provided by means of a slide projector, that also had a shutter attached to it. The two shutters were connected so that when one was open the other was shut, and vice versa. The fixation point was always visible, except when the display was exposed. The length of the exposure was controlled by the overhead projector shutter, and was constant at 0.25 seconds throughout the experiment.

Before each exposure the observer fixated the fixation point. The target was moved in towards the fixation point on successive exposures, until the observer was sure he could detect it. Its distance away from the fixation point was then recorded. Then, the target was moved out away from this point, until he was sure he could not detect it and, again, the distance was recorded. If, after any exposure, the observer reported that he was not fixating on the fixation point, the results of that run were ignored and the movement inward or outward was repeated.

Table 1: linear and angular dimensions of the display and stimuli

			Near	Far
Observer - display distance (feet)			7	47
Display	Linear Size (inches)		Angular Size	
Size	Unprojected	Projected	Near	Far
Horizontal	7.56	41.59	27° 1.4'	4° 2.0'
Vertical	4.50	24.75	16° 4.8'	2°24.0'

Diameter	(32nds inch)			
of Nontargets	10	55	67.0'	10.0'
of Targets	9	49.5	60.3'	9.0'
	8	44	53.6'	8.0'
	7	38.5	46.9'	7.0'
	6	33	40.2'	6.0'
Gaps between stimuli, and between edge of display and nearest stimuli	4	22	26.8'	4.0'

The contrast (C) of the dark (D) target and nontarget stimuli to the light (L) background, calculated from the formula

$$C = 100 \quad (D - L)/(D + L) \quad ,$$

was approximately 70%.

Each target was used twice at each distance in each session. All four were used at one distance, then all four at the second. Then, all four were again used at the second distance, and then again finally at the first. The targets were always presented in ascending or descending order. The four possible presentation orders are given in Table 2. Each session lasted between 1 and 1½ hours.

Table 2: four possible target presentation orders

	distance	targets	distance	targets	distance	targets	distance	targets
1	near	9876	far	6789	far	9876	near	6789
2	near	6789	far	9876	far	6789	near	9876
3	far	9876	near	6789	near	9876	far	6789
4	far	6789	near	9876	near	6789	far	9876

Eight observers were used. They all had normal vision (two - S3 and S8 - corrected). Each was tested alone in two or three sessions. For their first session, four observers (S1, S2, S3 and S4) were seated near to the display first (i.e. they had order 1 or 2), and for their second session they were far away at first (order 3 or 4). If they had a third session they were near at first again. This procedure was re rsed for the remaining four observers (S5, S6 S7 and S8).

C. RESUI , An DISCUSSION

__. Statistical treatment

Five observers (S1, S2, S5, S6 and S7) took part in three sessions, and three (S3, S4 and S8) in two. The first session was treated as practice for all observers. The raw data consisted of threshold distances from the fixation point. The target most different in size from the nontargets, target 6, could be detected at the edge of the display by four observers (S3, S4, S6 and S8) and, therefore, the threshold distances could not be measured for them for this target. Because of this the data have been analysed in two ways. Table 3 shows the results of a four-way analysis of variance with all eight observers, the three harder targets (9, 8 and 7), two viewing distances and with the inward and outward readings compared. Table 4 shows a similar analysis for four observers (S1, S2, S5 and S7) and all four targets.

Table 3: summary of four-way analysis of variance with all eight observers and three target sizes (9, 8 and 7)

Source	Degrees of Freedom	F	P
A. Observers	7	21.65	<.00001
B. Viewing Distance	1	0.12	-
C. Inward v Outward	1	77.28	<.0001
D. Target Size	2	130.61	<.00001
A x B	7	17.92	<.00001
A x C	7	2.31	<.05
A x D	14	6.07	<.00001
B x C	1	0.70	-
B x D	2	0.14	-
C x D	2	4.86	<.05
A x B x C	7	0.16	-
A x B x D	14	6.79	<.00001
A x C x D	14	0.71	-
B x C x D	2	1.94	-
A x B x C x D	14	0.32	-
Within	296		
Total	311		

Table 4: summary of four-way analysis of variance with four observers (S1, S2, S5 and S8) and all four target sizes

Source	Degrees of Freedom	F	P
A. Observers	3	120.26	<.00001
B. Viewing Distance	1	0.81	-
C. Inward v Outward	1	77.16	<.005
D. Target Size	3	54.65	<.00001
A x B	3	54.42	<.00001
A x C	3	2.11	-
A x D	9	14.46	<.00001
B x C	1	1.36	-
B x D	3	0.46	-
C x D	3	2.44	-
A x B x C	3	0.20	-
A x B x D	9	11.26	<.00001
A x C x D	9	0.58	-
B x C x D	3	1.49	-
A x B x C x D	9	0.15	-
Within	192		
Total	255		

Both tables show similar patterns of significance. All the main effects except that of viewing distance are highly significant. It was to be expected that the threshold distance would be significantly greater when the target was moved outwards than when it was moved inwards since this is an artifactual result dependent on the particular method of measuring the threshold. Similarly, from Bloomfield and Howarth(6) it was to be expected that, as the target came closer in size to the nontargets, the threshold distance would be reduced significantly. The third significant main effect in both tables was that of observers and, again, this was to be expected, being a typical finding in threshold experiments.

The first-order interactions, of viewing distance and of target size with observers, and the second-order interaction, of observers by viewing distance by target size, are highly significant. The main difference between the two tables is that the two interaction terms, of observers and of target size with inward v outward readings, with low levels of significance (.05) in Table 3, do not achieve significance in Table 4. Again, that interactions involving observers prove to be significant is not surprising.

The main interest in these analyses is centred on the fourth main effect: viewing distance. It is clear that we cannot reject the null hypothesis that the data taken at the two distances came from the same distributions, in this case. In fact, the high values of 'P' obtained for these (0.737 & 0.435 in the 1st & 2nd analysis respectively) constitute strong evidence for accepting the null hypothesis: ie. to accept that the linear threshold distance for each target is the same at 47 feet as it is at seven.

The significant interactions involving viewing distance are best interpreted in terms of differing trends amongst the observers. For some, there is a slight, but insignificant, decrement in performance as viewing distance is increased; for others, there is a slight, but insignificant, improvement; however, the difference between these two slight effects is significant.

2. Graphical representation

In reporting similar peripheral acuity data, Bloomfield and Howarth(6) plotted the difference in diameter of target and nontargets against eccentricity. However, eccentricity is probably not dependent on the absolute diameter difference but, rather, on the diameter difference relative to the diameter of the nontargets. Thus, it would be more appropriate to plot the relative difference against eccentricity.

The relative diameter difference remains unchanged as viewing distance is varied. Figure 3 shows the mean linear threshold distances for all eight observers for the three difficult targets as a function of the relative diameter difference. Figure 4 shows a similar plot for four of these eight observers with all four targets. The analyses reported in section C.1. indicated that the threshold distances obtained at the two viewing distances, which are compared in these two figures, were not significantly different and were, in fact, probably from the same distribution.

As the interactions of observer and viewing distance, and of observer by viewing distance by target size were significant, the data for each individual observer are shown in Figure 5. Here the linear threshold distance is plotted against viewing distance. The units on the two axes are the same, but the scale for viewing distance is 12.5 times greater than that for threshold distance. For most observers, there are changes in threshold distance with viewing distance. But, considering the difference in scales, these are not important for most observers. The largest changes occur for S5, who seems better at the far distance for targets 8, 7 and 6, and for S4 (targets 9, 7 and 6) and S8 (target 7) who seem better near to the display.

3. Possible source of error

As stated in section B, if the observer was not fixating the fixation point after the display had been exposed, the complete inward or outward sequence of presentations in progress was rejected. This was necessary on three occasions only, once each with observers S5, S6 and S8. However, it is possible that there were some small movements away from the fixation point towards the target that were not noticed by the observers. Since the same angular movement would be associated with a larger linear movement at the far viewing distance than the near, and such undetected movements may have had differential effects. It is not possible to state whether or not this occurred, and the possibility should be borne in mind when considering the implications of these findings.

4. The effect of viewing distance

This study was primarily undertaken to investigate the effect of viewing distance on peripheral acuity. On the evidence obtained using eight observers, one must conclude that the threshold distance from the fixation point remains constant for all four targets used when the viewing distance is increased from seven to 47 feet (though there is considerable variability among observers).

Beebe-Center et al.(9), measuring foveal acuity in minutes of arc over a range of distances from 30 feet to 2 miles, found that acuity was constant. If the effect of viewing distance (V_D) on peripheral acuity was analogous to this, one would expect that targets of constant angular dimension (δ) would be detected at constant angular eccentricity (θ) as V_D was varied. The result obtained here was that, for targets of constant linear dimensions (D), the linear threshold distance from the fixation point (T) was constant.

The obtained result and that that might be expected by analogy are, in fact, formally equivalent; viz

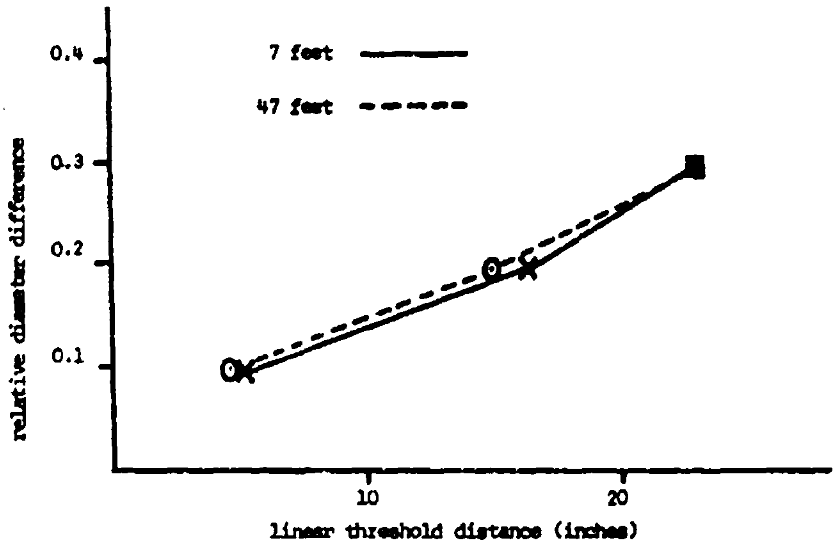

Figure 3: mean linear threshold distance for all eight observers with targets 7, 8 and 9, as a function of the relative diameter difference.

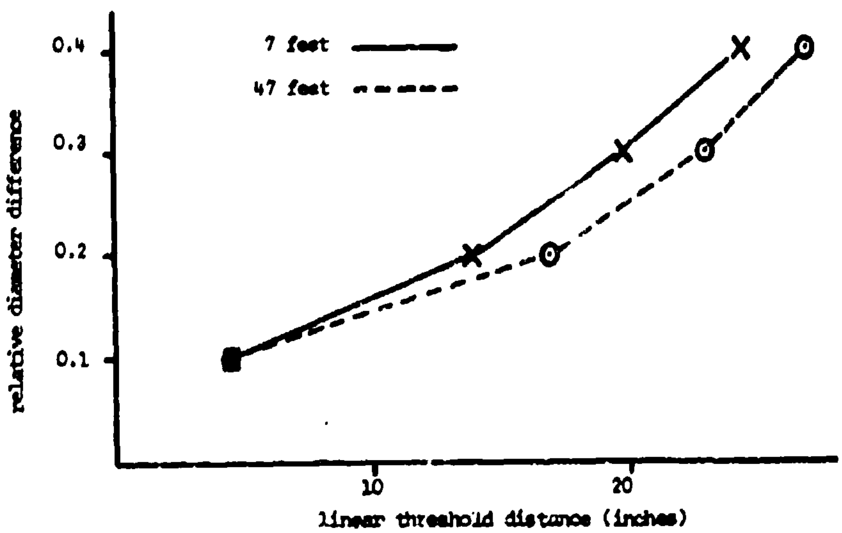

Figure 4: mean linear threshold distance for four observers (S1, S2, S5, S7) with all four targets as a funct of relative diameter difference.

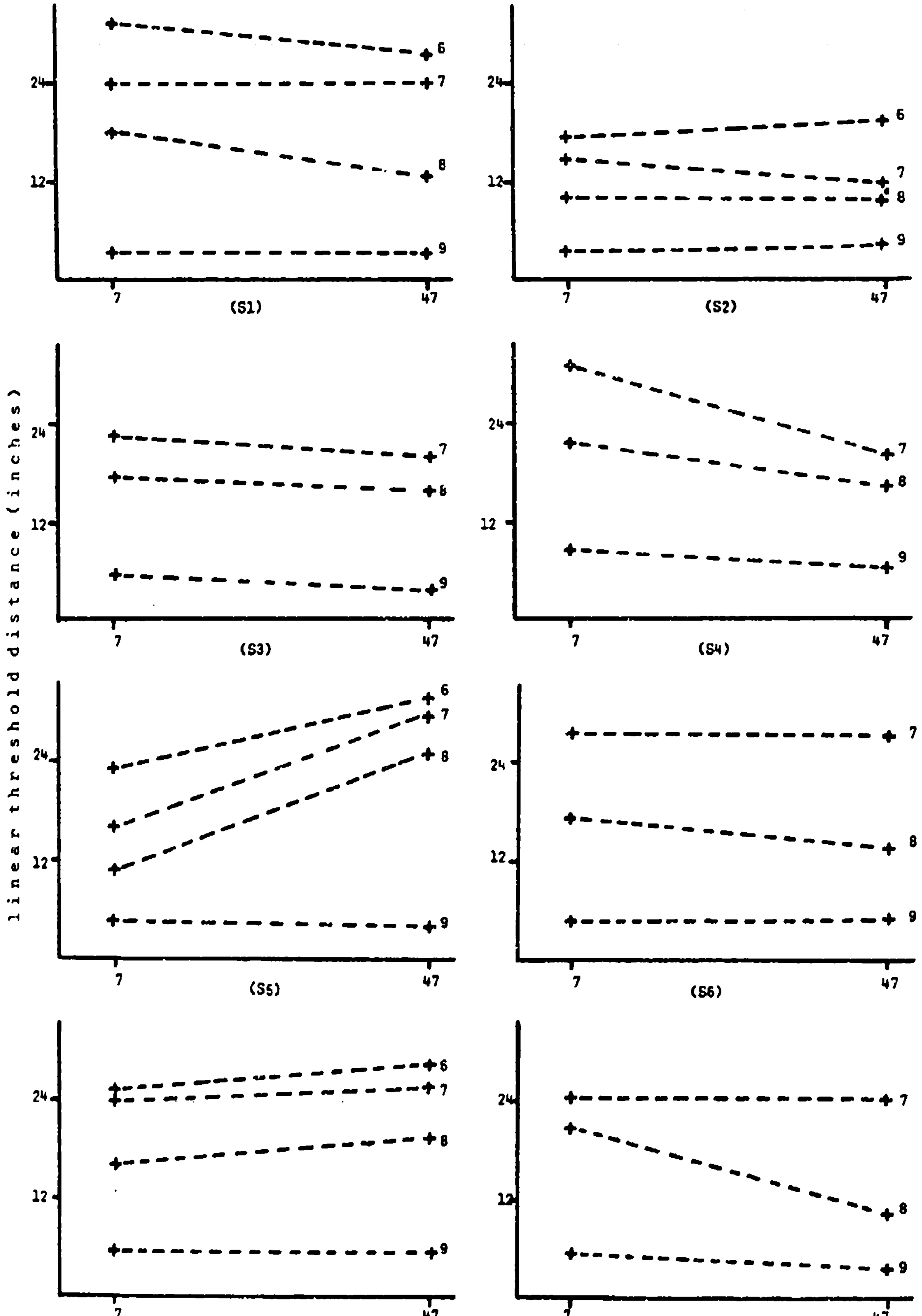

Figure 5: linear threshold distance as a function of viewing distance for all eight observers.

$$\theta = T/V_D$$

$$\text{and } \beta = D/V_D \text{ , both by simple geometry}$$

$$\therefore T = V_D \cdot \theta \quad (1)$$

$$\text{and } D = V_D \cdot \beta \quad (2)$$

The obtained results with varying V_D was

$$D/T = \text{constant} \quad (3)$$

$\therefore$, by substituting 1 and 2 in 3 ,

$$\beta / \theta = \text{constant, and this is the expected result.}$$

A particularly notable feature of the main result of this study is that, not only is it in line with expectations based on work on foveal acuity, but also it was obtained using a complex visual display containing many nontarget stimuli.

5. Implications for target acquisition and visual search

The second question posed in section A.1. was can peripheral acuity be used to predict search performance when viewing distances varies? Since it does appear to be independent of viewing distance, it seems likely that it can. Because of the relationship of peripheral acuity to visual search, one would expect viewing distance to have no direct effect on search or target acquisition, for distances of over approximately six feet.

If search or target acquisition does become more difficult as viewing distance increases, this is likely to be because of secondary variables. For example, with longer viewing distances more interesting, irrelevant objects may come into the field of view, drawing the observer's attention away from the search area. We do know that, with increased viewing distance, the search area may become so small that the observer finds it difficult to place all his glimpses within its boundaries. Enoch(19) found that, while only 10% of his observer's fixations fell outside his search displays when they were 9° square or more, as many as 50% fell outside his 6° display and 75% outside that of 3°.

The display used in the current study had, at the longer viewing distance, angular dimensions of $4^\circ 2'$ by $2^\circ 24'$. On the basis of Enoch's data, one would expect a high proportion of fixations to fall outside this display, if it was used for search with an observer 47 feet away. This may result in wastage, which one would expect should lead to longer search times at this distance compared with those at seven feet. In fact, from preliminary work, this does seem to be the case.

At the present time, one would expect that providing (a) the search display always has angular dimensions of 9° or more, (b) viewing distance is greater than six feet (two metres) and (c) viewing distance is not so great that the observer is unable to resolve the target, then variations in viewing distance should have no effect on target acquisition or visual search performance.

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DISCUSSION

Mr Ericson (US)

Did your observers have difficulty maintaining fixation while you took the measurements?

Dr Bloomfield (UK)

Subjects sat 7 or 47 feet from the screen, and fixated a point. When they were ready, the fixation point was removed and a stimulus flashed on for ¼ sec, during which time they should still have been fixated. We asked them to tell us if they weren't doing this. In fact, I was one of the subjects (S3) and remember having no problem. But I agree there was no actual check on whether subjects' eyes had moved.

Mr Ericson (US)

I tried to do a test like this with 22 pilots in 2 sessions. In the first session I didn't tell them I was watching their eyes, and in the second session I told them I would say when I saw their eyes move off. What I could describe as cheating then dropped from 20 to 1 per cent or thereabouts.

Dr Bloomfield (UK)

I don't know whether our subjects were cheating. They seemed to try to help us. Obviously we would have liked to have had a way of checking fixation, but with out viewing distances and without specialised optical systems such as split prisms this was not possible.

Incidentally, like many subjects, I had the distinct feeling I was much worse further from the screen, though this turned out not to be the case when the data were analysed.

Mr Overington (UK)

Foveal acuity doesn't change much beyond 6 feet, as you say in your paper. I'm at a loss to see why your experiment was from 6 feet outwards. For the fovea, those effects that there are are from 6 feet inwards.

Dr Bloomfield (UK)

When asked to do the investigation, it was quite clear I was expected to find an effect, if only the subjective one I mentioned. I agree the literature makes the discovery of a large distance effect unlikely. Peripheral acuity was in this case expected to decrease as viewing distance increased, and this expectation was from a previous practical finding, not from the literature.

Mr Overington (UK)

From the physical optics stand point, any distance effect on acuity should be due to the imaging optics of the eye. The periphery already has a poorer image and is more grainy than the centre area of the eye, so effects of distance should be even harder to pick up than they are for foveal viewing from 6 feet inwards. I might expect peripheral effects to be insignificant even at these short distances.

Dr Bloomfield (UK)

I think we now agree.

Mr Overington (UK)

Two of your observers might well be considered 'rogues' in a small sample experiment. How were they screened visually? One of them could be short sighted (S5) and the other long sighted (S4). Did you do any analysis excluding these 2 subjects? The A x B interaction you report might then be insignificant.

Dr Bloomfield (UK)

I agree the interaction would go. As to screening subjects out, this depends on what one is trying to do. I wanted to follow this study up with one on visual search at the 2 viewing distances.

Mr Overington (UK)

Agreed, but it's only chance that S5 and S4 balanced each other in your overall results. You could have had 2 'rogues' in the same direction which would have given an apparent main effect.

Dr Bloomfield (UK)

No. We would still have isolated the Observer X Viewing Distance interaction.

A Model for the Inherent Contrast Conditions in Full-Form Objects

Dr.-Ing. habil. Max R. Nagel, Scientific Coworker
Deutsche Forschungs- und Versuchsanstalt für
Luft- und Raumfahrt e.V.
D-8031 Oberpfaffenhofen, Germany

Summary. The concept has been developed of a simple model that is representative of the luminance and contrast conditions on full-form objects. A reasonably realistic approach is a sphere that is exposed to the irradiation from the entire sky, the sun, and the ground, taking into account the considerable variation of the luminance in the sky. Based, primarily, on measurements of the sky luminance in the Pikes Peak region of Colorado, U.S.A., calculations were made of the inherent contrast in such a model when it is viewed from any direction with fields of view of various sizes. Other calculations were concerned with the model object's contour contrast against its background, and with its color. Representative results of these calculations are shown and discussed.

List of symbols

λ = azimuthal distance of a point of the model sphere from the sun vertical

φ = latitudinal distance of a point of the model sphere from the horizontal equator of the sphere

α = azimuthal distance of a point of the sky from the sun vertical

β = latitudinal distance (elevation) of a point of the sky over the horizon

β_Θ = elevation of sun over the horizon

w = wavelength of light, in nm

$\bar{y}(w)$ = relative sensitivity of the eye for light of wavelength w, with reference to sensitivity at w = 555 nm

$H(w)$ = solar energy in W/m^2 just outside the terrestrial atmosphere, perpendicular to direction from the sun, for wavelength w

$a(w)$ = attenuation coefficient per unit air mass, for wavelength w

m = effective air mass

ϵ_Θ = angular distance of point (λ, φ) from point ($\lambda = 0, \varphi = \beta_\Theta$) on the sphere, directly under the sun

B = brightness of sky in the vicinity of point (α, β), in lm/m^2

A = area of small portion of sky having an average brithtness B, in steradian

ρ = reflectance of ground

ρ_K = reflectance of model sphere

E = total illuminance in lm/m^2

ΔE_{SD} = portion of the total illuminance attributable to direct radiation from the sun, in lm/m^2

ΔE_{HD} = portion of the total illuminance attributable to direct radiation from the sky, in lm/m^2

ΔE_{SR} = portion of the total illuminance attributable to reflected radiation from the sun, in lm/m^2

ΔE_{HR} = portion of the total illuminance attributable to reflected radiation from the sky, in lm/m^2

V = ratio of solar and sky components of illuminance

Λ = azimuthal component of a viewing direction with respect to the center of the sphere and sun vertical

ϕ = latitudinal component of a viewing direction with respect to the center of the sphere and the horizon

ω = center angle determining radius of a field of view on the sphere surveyed by an outside observer

Θ = angle determining location of a point at the boundary of the field of view

L_K = luminance at a point of the sphere at the boundary of the field of view

L_G = luminance of the sky next to a point of the sphere at the boundary of the field of view.

1. Introduction

One of the primary factors governing the visual detection and identification of ground features from an aircraft is the inherent contrast of these objects, either within themselves or against their backgrounds. In fact no ground object can be detected, much less identified, without an inherent contrast either in terms of luminance or in terms of the spectral composition - or color, respectively - of the radiation emitted or reflected from its surface. This statement applies to any photo-electronically supported observation as well; and problems around the inherent contrast conditions in outdoor objects continue, therefore, to hold considerable interest for a great number of everyday-public, industrial, scientific and military disciplines. As a consequence, a need is felt to establish a set of sufficiently detailed data on the inherent object contrast which, based on measurements under actual conditions, can be realistically associated with a variety of environmental, meteorological and operational situations and which, in turn, can serve as a model for further calculations, for duplications and simulations, and for predictions of object contrasts assuming changed conditions.

2. Discussion of the Model Concept

Physically, the concept of such a model envisages a smooth sphere located outdoors, initially under a clear day-time sky, and illuminated by skylight, sunlight, and the reflecting ground. Both the sphere and the ground are considered completely opaque, neutral gray in color and diffusely reflecting, the ground having a reflectance ρ ; and the sphere, ρk. The size of the sphere is small and its altitude above the grounds is such, that its shadow does not cover a material portion of the ground and affect the amount of light (or radiation, respectively) that is reflected from the ground upon any part of the sphere. This sphere is viewed from the outside by an observer from any direction; and the observer is, again. small or distant enough from the object sphere and its surrounding ground so as not to interfere with the light distribution on them. To fill the condition of an "inherent" contrast, the environment is assumed to be such that the contrast is neither attenuated nor augmented by the medium between the observer and the sphere. It is also assumed that no atmospheric attenuation (scattering, absorption) occurs in the space between the observer and the sphere. Furthermore, both the sphere and the ground will in the case of visible radiation, not emit any light of their own.

This concept of a model object has already been proposed in an earlier publication (1), and, inevitable shortcomings notwithstanding, still appears suitable and appropriate for the above-stated purposes. The following arguments in favor of this concept are essentially repeated from that publication:

1. It reduces an object to a mathematically easily accessible spherical shape. In particular, it facilitates interpretation of basic data obtained through its application and makes it possible to easily translate locations on the model into more general terms of surface orientation. The assumption of a three-dimensional full-form system permits the execution of a series of considerations that cannot be performed with models concerned with specific surface orientations only. In particular, the adventages of full-form models come to bear, when questions of optimalization, location of minima and maxima, etc., are to be dealt with, as is the case, for example, in connection with the problem of detection and recognition of objects.
2. Physically, the convex, unobsured portions of the surface of an object, that are the characteristicum of a sphere, are usually also the ones most responsible for the photometric, spectroscopic and colorimetric appearance of an object.
3. The condition of a smooth surface necessarily narrows the applicability of the model to gross-form considerations and will often lead to minimum contrasts, which can be desirable or undesirable, depending on the task at hand. Generally, this condition will tend to be best approached in small objects, but it is for practical purposes usually sufficiently satisfied in significant portions of the surface of complex objects as well.
4. The assumption of a gray coloration of sphere and ground, and the condition of perfect diffusion simplify the theoretical considerations and at the same time enable further application of the results to colored surfaces. While, admittely, such a simplification neglects the influence of colored natural ground covers, it must be remembered that, by and large, natural objects usually reflect through the

entire visible spectrum. They also change their spectral appearance through the year so as to make generalization - which is the purpose of a model - extremely difficult. Furthermore, many manmade outdoors features distinguish themselves from natural ones by their - sometimes, as for example in the case of camouflage, deliberate - neutral coloration. This present article will therefore consider - to some small extent - only the coloration of an object introduced by the solar and celestial radiations.

Since the time of the previous publication, several sets of new, more detailed data have been published and more elaborate computation capabilities have become available, which now permits expansion of the scope of the earlier study.

3. Computations

In order to determine contrast and color of a model object, it is first necessary to know the basic components of the total illuminance occuring on its surface. These are primarily the contributions made by the direct radiation from the sky and the sun, and those made by the radiation reflected from the ground. In the case of the model considered in this study, the radiation impingent on the ground is identically the same, in amount as well as spectral composition, as that on the upper pole on the sphere. In the process of reflection, only the amount of reflected radiation changes in accordance with the reflectance of the ground, while the spectral composition - represented here by the ratio V of solar to celestial radiation - is maintained.

For the calculation of the celestial radiation, the data from the ground-based measurements during the 1956 Infrared Measurement Program (IRMP'56) of the Wright Air Development Center by Bennett, Bennett and Nagel (2-3) were employed. Unlike similar sets made at the same and other occasions by an airborne group of the Scripps Institution of Oceanography Visibility Laboratory (4-8), the chosen data refer to a ground-based station and several sun altitudes from 4 to 55° during one generally clear afternoon and seem, therefore, particularly suitable as a point of departure for future correlation of less easily interpretable measurements.

Lacking adequate solar irradiation measurements - a set of pyrheliometric data obtained during the IRMP by D.J. Portman and F.C. Elder (9) yielded unrealistically high values -, the calculations of the solar component of the illuminance on the point directly under the sun were made using Moon's values for the solar radiation (10) after adjusting them slightly to an extraterrestrial irradiance of 1401 W/m^2 to conform with the International Pyrheliometric Scale.

That portion ΔE_{S0} at a point (λ, φ) on the sphere, which is attributable to the direct radiation from the sun, is given by

$$(1) \quad \Delta E_{S0}(\lambda,\varphi) = \sum_{w=0}^{\infty} 680\,\bar{y}(w) \cdot H(w) \cdot 10^{-a(w)m} \cdot \cos \varepsilon_0 \ \text{lm/m}^2$$

where λ, φ the longitude and latitude coordinates, respectively, of the point on the sphere, with reference to the sun vertical $\lambda = 0$ and the horizontal equator of the sphere, $\varphi = 0$; w = wavelength of light; 680 lm/Watt = international mechanical light equivalent; $\bar{y}(w)$ = relative sensitivity of the eye; H(w), in Watt/m^2, = solar irradiance just outside the terrestrial atmosphere incident on a surface perpendicular to the direction to the sun, after Moon (10); a = attenuation coefficient per unit of air mass; m = air mass according to Bemporad; ε_0 angular distance of point (λ, φ) from the point of the sphere $(\lambda = 0 \ \varphi = \beta_0)$ directly under the sun, β_0 = altitude of sun over the horizon. It is also

$$(2) \quad \cos \varepsilon_0 = \sin\varphi \sin\beta_0 + \cos\varphi \cos\beta_0 \cos\lambda$$

This equation is valid within $0 \leq \varepsilon_0 \leq 90^{\circ}$, which condition defines the sunlit half of the model sphere, and $\Delta E_{S0} = 0$ for the rest of its surface. It may here also be inserted that Eq (1) still tends to result in somewhat high value of ΔE_{S0}, probably due to the rather unsecured value for the mechanical light equivalent.

The component of illumination ΔE_{H0} (λ, φ) in a point (λ, φ) of the sky due to direct skylight is given by entire visible spectrum. They also change their spectral appearance through the year so as to make generalization - which is the purpose of a model - extremely difficult. Furthermore, many manmade outdoors features distinguish themselves from natural ones by their - sometimes, as for example in the case of camouflage, deliberate - neutral coloration. This present article will therefore consider - to some small extent - only the coloration of an object introduced by the solar and celestial radiations.

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where λ,φ the longitude and latitude coordinates, respectively, of the point on the sphere, with reference to the sun vertical $\lambda = 0$ and the horizontal equator of the sphere, $\varphi = 0$; w = wavelength of light; 680 lm/Watt = international mechanical light equivalent; $\bar{y}(w)$ = relative sensitivity of the eye; H(w), in Watt/m^2, = solar irradiance just outside the terrestrial atmosphere incident on a surface perpendicular to the direction to the sun, after Moon (10); a = attenuation coefficient per unit of air mass; m = air mass according to Bemporad; ε_{θ} angular distance of point (λ,φ) from the point of the sphere $(\lambda = 0\ \varphi = \beta_{\theta})$ directly under the sun, β_{θ} = altitude of sun over the horizon. It is also

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This equation is valid within $0 \leq \varepsilon_{\theta} \leq 90^{\circ}$, which condition defines the sunlit half of the model sphere, and $\Delta E_{S0} = 0$ for the rest of its surface. It may here also be inserted that Eq (1) still tends to result in somewhat high value of ΔE_{S0}, probably due to the rather unsecured value for the mechanical light equivalent.

The component of illumination ΔE_{H0} (λ,φ) in a point (λ,φ) of the sky due to direct skylight is given by to the determination of location where such conditions occur.

As an example, Fig. 4 shows the locations of the minimum and maximum illuminance, when the ground reflectance changes. Particularly interesting is here the transition of the point of maximum illuminance from a latitude well above the point directly under the sun for zero ground reflectance, to much lower latitudes at increasing reflectances.

5. Surface Contrasts

Three types of contrast were investigated as further examples of the utility of the model sphere concept in practical applications:

1. The inherent contrast within a field of view of given size, as seen from an outside observer (surface contrast)

2. The contrast of the sphere along the edge of the field of view in relation to the background of the sphere, i.e. against the ground or the sky (contour contrast)

3. color variations on the sphere

For this purpose, an observer or a camera is imagined to look from outside the sphere toward its center in a principal direction (Λ, Φ). The coordinate system of these directions is oriented like that for the sphere surface (λ, φ) itself, so that the surface point (λ, φ) is the nadir point with respect to the observer. The observer is then thought to be able to survey a circular area on the sphere which is centered at (λ, φ) and whose radius is determined by an angle ω subtended at the center of the sphere (see Fig. 5). $\omega = 90°$ will therefore describe a situation where the entire half sphere facing the observer is visible to him. Smaller fields of view are of importance for the study of situations where large objects are involved, such as in the case of navigation over mountainous terrain, or when the field of view is narrowed by optical instrumentation, photographic cameras, microscopes, telescopes, or the like. In operations involving visual observation, the object contrast may then define the probability of detecting an object; in the photographic application it will, for example, determine the required exposure range of the film, etc.

For the present study, the relationship

$$(8) \qquad C = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}$$

was used to define a contrast. Here Emax and Emin are the maximum and minimum irradiances, or luminances, respectively, within the field of view. For reference and comparison, Appendix 1 contains a number of values for various other definitons in common use.

Fig. 6 illustrates the case when an observer sees the entire sphere ($\omega = 90°$). The lines indicate viewing directions from which the inherent surface contrast within the field of view remains the same. The star at the meridian $\Lambda = 0$ indicates the direction of the sun.

Of special interest is here the upper section of the presentation which contains the directions applicable to aerial observation and other situations where the observer looks downward on the subject. In the case shown - that is, for a sun altitude of 55° and ground reflectance 20 % - a large section of that upper half is blank and marked 82, indicating that for all the directions pertaining to this section the inherent surface contrast stays at that level; primarily because, looking at the object from any of these directions, both the sphere point having the greatest illumination and that having the smallest one are within the field of view of the observer. For all directions outside the blank area, the surface contrast diminishes and is lowest from a direction about opposite that of the sun, commonly referred to as a situation of "backlighting".

Fig. 7 demonstrates the use of the model in a study on the influence of the ground reflectance on the surface contrast in the observer's field of view by showing the displacement and deformation of the line for directions from which a surface contrast of 0.7 is maintained. By means of illustrations of this kind, an observer from an unspecifiable direction and at different seasons of the year, i.e. bare vs snow covered ground. (Other conditions, - in particular, illuminance levels, sun altitude and background - remaining equal, a greater number of observation directions should be available for detecting an object when the ground is bare.)

Of course, when the field of view becomes smaller, there are fewer chances of seeing the two locations of absolute minimum and maximum sphere illuminance simultaneously. Therefore, the contrast within a given field of view will tend to be small in a small field of view, or at a small ω , respectively. Vice versa, there will be fewer directions from which an object appears above a minimum contrast; and Fig. 8 illustrates the dependency for three fields of view of differing size at the standard 53.5° solar altitude and a ground reflectance 0.2. In the illustration, the hatched side of the lines shown indicate the viewing directions from which the contrast in the object is smaller than the required one of, in this case, 0.7.

Fig. 9 elaborates on this statement in the, perhaps, more practical, application when an object is imagined to be observed from an aircraft during a direct overflight within the sun vertical. Three different fields of view with half-angle ω are assumed; the geometry is indicated in the insert. It can be seen, that the contrasts not only become smaller with a diminishing field of view, being smallest when the object is viewed approximately from the direction of the sun. They also fluctuate the less during the overflight, the larger ω becomes; a fact, that may become of interest for the visual observer as well as for example, a photographer or engineer engaging films or detectors having a limited dynamic range.

6. Contour Contrast

At times - particularly during the night, at overcast sky conditions, or within clouds or fog - it is the contour contrast rather than the surface contrast that dominates the detection and, even more so, the recognition process of a surveillance or reconnaissance task. A set of calculations was made, in order to obtain an indication of the trends and magnitudes involved.

For this study, an observer was again envisaged to view the object sphere in a principal direction (Λ,Φ). Contrary to the earlier proposition, the observer is now located at a fixed altitude $H = R(\sec\omega - 1)$ above the point (λ,φ) of the sphere, however, where R is the radius of the sphere. From that altitude, the observer is able to survey on the sphere a circular field of view, whose radius sustends, as before, the angle ω at the center of the sphere. The contour contrast is then determined, on one hand, by the luminance L_K of the sphere, and, on the other hand, by the luminance L_B of the background as seen by the observer, when both luminances are measured at adjacent points along the circumference of the observer's field of view. The location of these points with respect to (λ,φ) is given by an azimuthal viewing angle Θ , with $\Theta = 0$ oriented as shown in Fig. 8. The numerical magnitude of the contour contrast was defined to be

$$C_C = \frac{L_K - L_B}{L_K + L_B} \tag{9}$$

and the locations pertaining to L_K and L_B are given as follows

a) location on the sphere:

$$(10)\quad \begin{cases} \sin\varphi(\Theta) = \sin\omega\cos\varphi\cos\Theta + \cos\omega\sin\varphi \\ \sin(\lambda - \lambda(\Theta)) = \dfrac{\sin\Theta\sin\omega}{\cos\varphi(\Theta)} \end{cases}$$

b) associated location in the background

$$(11)\quad \begin{cases} \sin\beta(\Theta) = \cos\omega\cos\varphi\cos\Theta - \sin\omega\sin\varphi \\ \sin(\lambda - \alpha(\Theta)) = \dfrac{\sin\Theta\cos\omega}{\cos\beta(\Theta)} \end{cases}$$

When $\beta(\Theta) < 0$, the associated background luminance L_B is that of the ground; otherwise, that of the sky at $(\alpha(\Theta), \beta(\Theta))$. The condition for the natural horizon as seen from the observer is

$$(12)\quad \cos\Theta = \operatorname{tg}\omega \cdot \operatorname{tg}\varphi$$

The sky luminances were taken from the appropriate sky maps (Fig. 1) or from the computed ground illuminations, multiplied by the ground reflectance ρ , which, in the executed examples was assumed to be 0.2, while the sphere was assigned a reflectance $\rho = 0.03$, simulating a rather dark camouflage point.

Fig. 10 shows the contour contrast along the circumference of the observer's field of view on the sphere, as a function of the azimuthal viewing angle Θ , for three fields of view of differing size or three observer altitudes, respectively, corresponding to the angular radii ω = 30; 60 and 90°. The graph for $\omega = 90^\circ$ is again associated with a field of view covering an entire half-sphere and accordingly with a very great distance of the observer from the object. The example assumes a principal viewing direction ($\Lambda = 0$ $\phi = 0$), meaning a horizontal view of the sphere, with the sun in the back and above the observer. Only the absolute values of the contrast are given. Under the assumed conditions, all contrasts are in reality negative, due to the low reflectance of the sphere. The vertical break in the graphs is caused by the discontinuity of the background luminances at the horizon due to the brightness difference between the sky and the ground. Contrary to the conditions regarding the surface contrast, it is only incidental to the viewing direction chosen in the example, that a small ω results in small contour contrasts. Also, the symmetry of the graphs will disappear if the observer's location is outside the sun vertical, or when Λ is other than zero, respectively.

The other graph relating to the contour contrast, Fig. 11, illustrates the conditions when an observer is imagined flying over an object at great heights and viewing it from a variety of directions ϕ' within the sun vertical, for two sizes of the field of view. Of these, the case for $\omega = 90^\circ$ can be taken to represent the contour contrast conditions, for example, in a typical downward-vertical wide-angle (120°) scan of a scene consisting of many small objects. The directions ϕ' from which these objects are viewed are then varying within the 30° to 150° range considered in this graph. The plots being symmetrical, only one half is shown.

Except for the rather gentle bend where the edge of the field of view crosses the boundary of the half sphere directly irradiated by the sun, no abrupt discontinuity appears, as was the case in Fig. 10 . This is so, because the natural horizon is outside the range of the field of view, and the uniformly illuminated ground forms the only background within the scene. At $\omega = 90^\circ$, this bend will under the assumed condition always occur at $\Theta = 90^\circ$, corresponding to the diameter of the object sphere which is at right angle to the sun vertical.

While the contour contrasts in Fig. 11 are high in comparison to the surface contrasts appearing in the earlier illustrations, this is due only to the high ratio of the ground reflectance to sphere reflectance assumed in this particular example. The conditions for other reflectance ratios can be easily derived using the values in the table of Appendix 1.

7. Color

Only little space can here be given the discussion of the color contrast in the object that is caused by the three components of radiation acting on its surface. Each of these components - radiation from the sun, radiation from the sky, and radiation impinging from the direction of the ground - has its own spectrum, or color, respectively; and the color in each point of the model sphere is a mixture of these three colors as determined by the percentages by which each component contributes to the total illuminance in that point. Leaving the treatment of the rather complex case of colored ground coverings to a future special publication, a neutral ground is here assumed, which reduces the active color components to those due to the sky and the sun.

The procedure of determining the color is described in detail in the previous article (1). It involves the determination of the ratio V of the two illuminance components for every point on the sphere; the calculation of the combinded spectrum of the sun and sky as a function of V ; the conversion of spectral irradiances to visual illuminances; the computation of the chromaticity coordinates and of the dominant wavelength, which together with the purity factor determines the color impression, as a dependency of V ; and, finally, plotting lines of equal dominant wavelengths on the sphere.

The following graphs illustrate the principal steps of this procedure as applied to the standard case for a sun altitude of 53.5°, which should be fairly representative for the conditions at medium solar elevations. The spectral data for the solar and celestial radiations used are the same ones employed in (1) and are based on Moon's (10) and Herrmann's (11) respective publications. They are shown in Fig. 12, while Fig. 13 represents the relationship between the ratio V and the dominant wavelength with respect to the chromaticity locus of the standard illuminant C of the International Commission on Illumination (C.I.E.) as derived in (1).

The distribution of the ratio V on the model object, calculated through Eq (1) to Eq (6) is plotted in Fig. 14 showing lines of equal ratios; and Fig. 15 depicts the locations of equal dominant wavelengths on the subject based on Fig. 13.

Of course, these equal-dominant wavelength lines follow closely the pattern of the lines of equal V , and a range of V from 0.6 to 7.62 occurs on the object under the sample conditions, corresponding to a range of dominant wavelengths from about 540 to 570 nm; that is from a blue-green to a yellow-green hue. The cross-hatched line in the graph connects the points of minimum V or the smallest dominant wavelength, respectivly, along each meridian line of the sphere. Accordingly, it represents the locus of surface orientations on an object where the color tends most to become bluish-green and may therefore appropriately called its "blue line", although, of course, the color along its length changes.

Fig. 16 , finally, demonstrates how, under the same conditions, the line for V = 3, corresponding to a dominant wavelength of about 570 nm, would shift locations on the object, if the ground reflectance would change.

Even though color differences such as demonstrated in the last two illustrations are quite conspicuous in bright - for example, snow-covered - scenes, the human eye cannot discern them readily in dark or colored objects. On the other hand, many non-physiological sensors, including certain types of wavelength-selective detectors and most commercial color films, respond strongly to such differences, which then manifest themselves in apparent radiometric derivations and anomalies, or, in the case of films, in the form of color casts that may, in turn, give rise to misinterpretations.

It has also a variety of scientific-metrological and technical implications, how - in fact: that - a change in ground reflectance causes not only a change in the distribution of illuminance in an object; but as Fig.16 shows, a change of illuminance is always accompanied by a change in the distribution of color, even though the ground itself is neutral gray.

8. Conclusion

In conclusion, it is hoped that the examples cited in this paper of application of the discussed concept of a model for the illuminance, contrast and color conditions in outdoor objects have demonstrated its potential utility in a number of disciplines involving visibility tasks. It is intended to develop it further, covering, for example, spectral regions outside the visible range; the influence of colored ground covering; and situations where the illumination conditions are modified by the geometry of the objects vicinity, such as the presence of a nearby wall.

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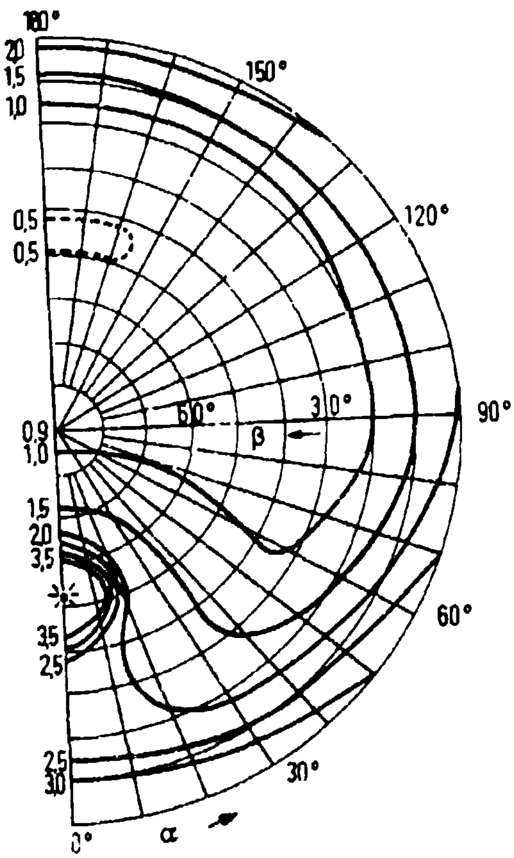


Fig. 1 Map of the luminance distribution in a clear sky at solar altitude 53.5°, measured at an elevation of 1870 m, in units of 10^4 lm/m^2.

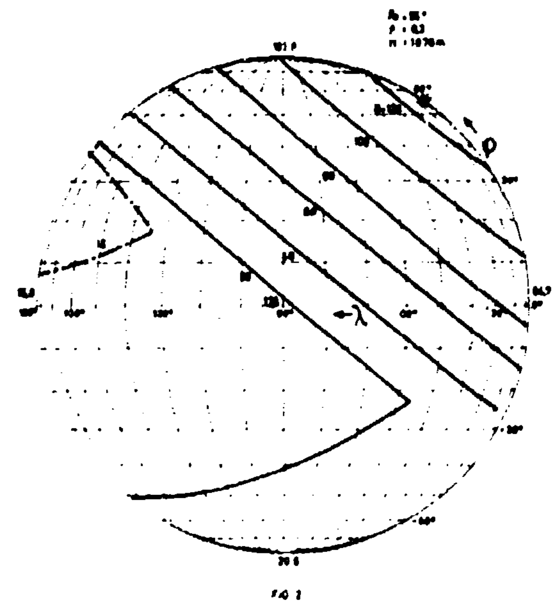


Fig. 2 Lines of total illuminance on the surface of a sphere, for a sun altitude of 55°, ground reflectance 0.2 and elevation 1870, in 1000 lm/m².

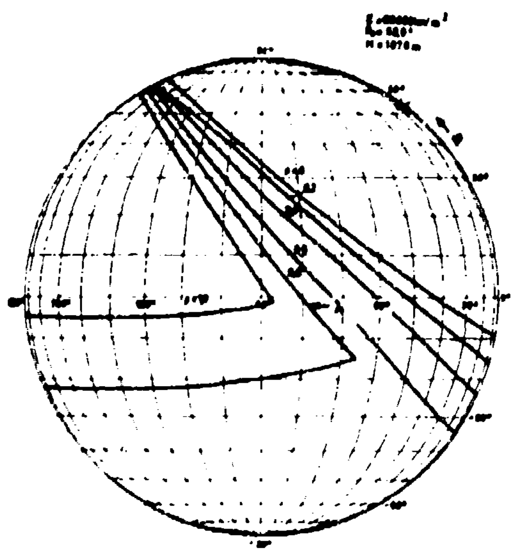


Fig. 3 Showing displacement of the equal-illuminance line for 60.000 lm/m², when ground reflectance ρ changes. Sun altitude 53.5°, elevation 1870 m.

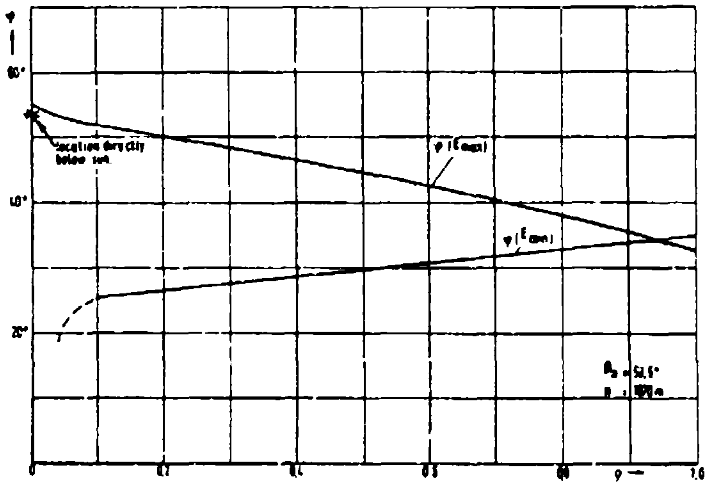


Fig. 4 Location of maximum and minimum illuminance on a sphere, in degrees above the equator of the sphere in the sun vertical, as a function of the ground reflectance. Sun altitude 53.5°, elevation 1870 m.

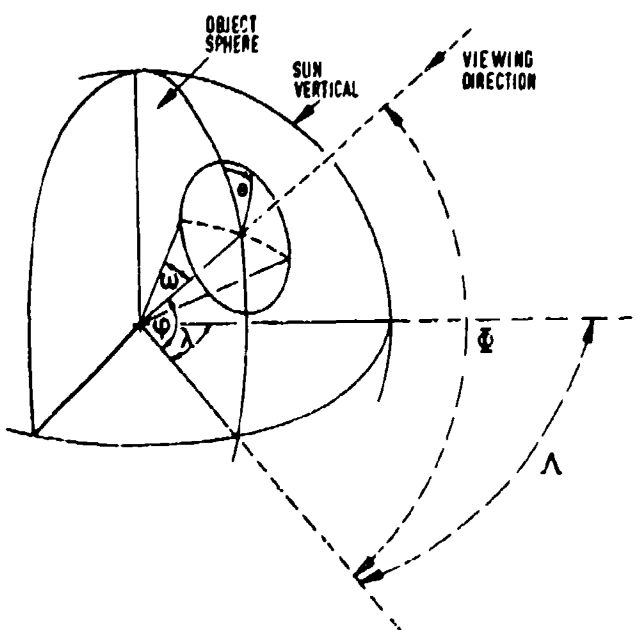


Fig. 5 Defining symbols used to describe viewing geometry.

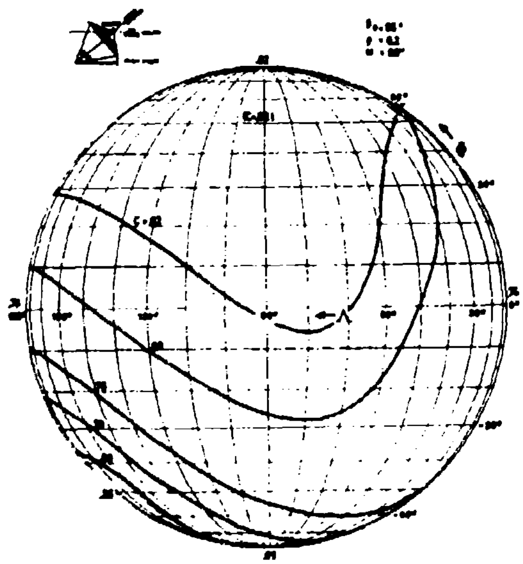


Fig. 6 Lines of viewing directions, from which the field of view on the sphere shows equal surface contrast. Solar altitude 55°; ground reflectance 0.2; angle ω defining radius of field of view = 90° (entire half sphere is visible).

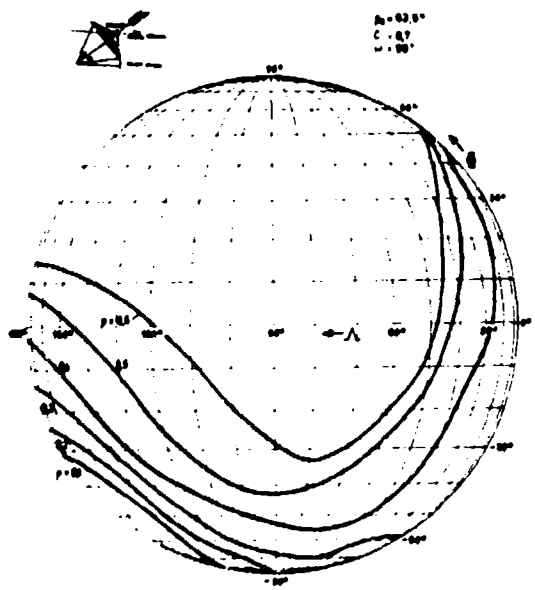


Fig. 7 Showing displacement of lines of viewing directions in which equal surface contrast 0.7 exists in the field of view, as a function of ground reflectance. Solar altitude 53.5°, ω = 90°.

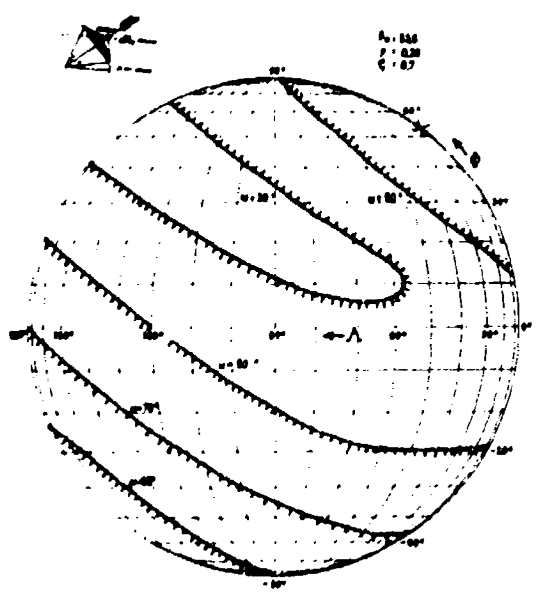


Fig. 8 showing bundles of viewing directions in which equal surface contrast 0.7 exists in the field of view, when the size of the field of view changes. Sun altitude 53.5°, ground reflectance 0.2.

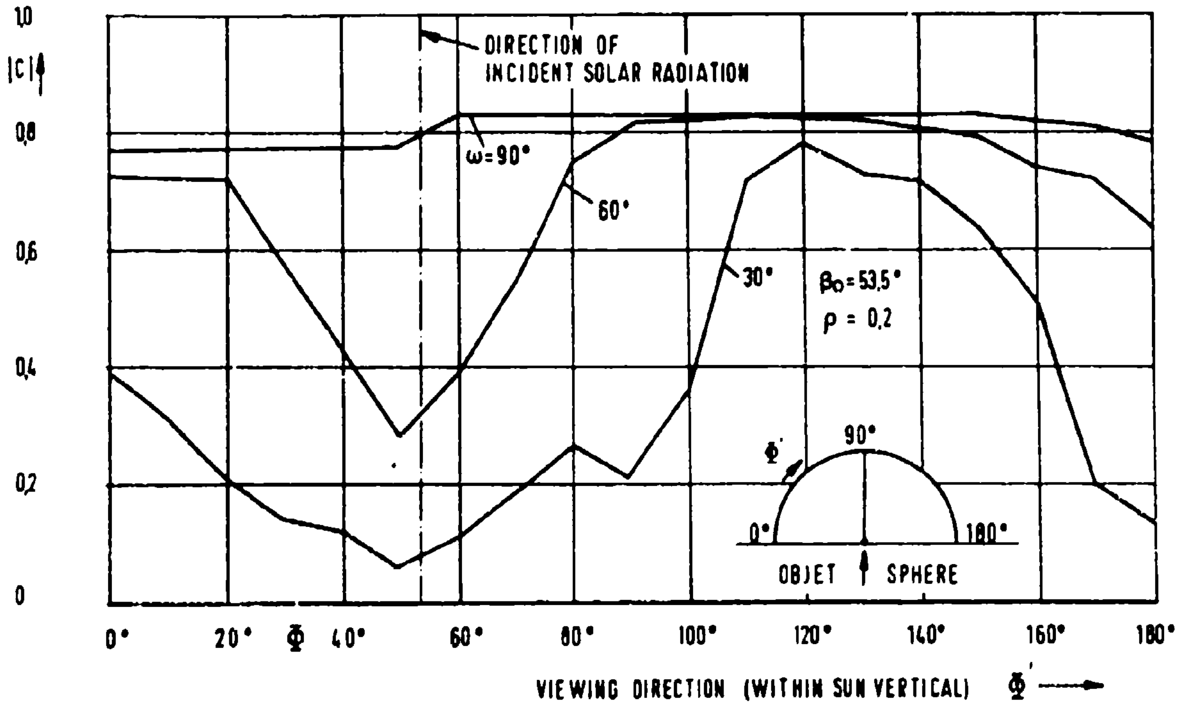


Fig. 9 Surface contrast within the field of view, when flying over an object in the plane of the sun vertical, for three sizes of the field of view. Sun altitude 53.5°, ground reflectance 0.2.

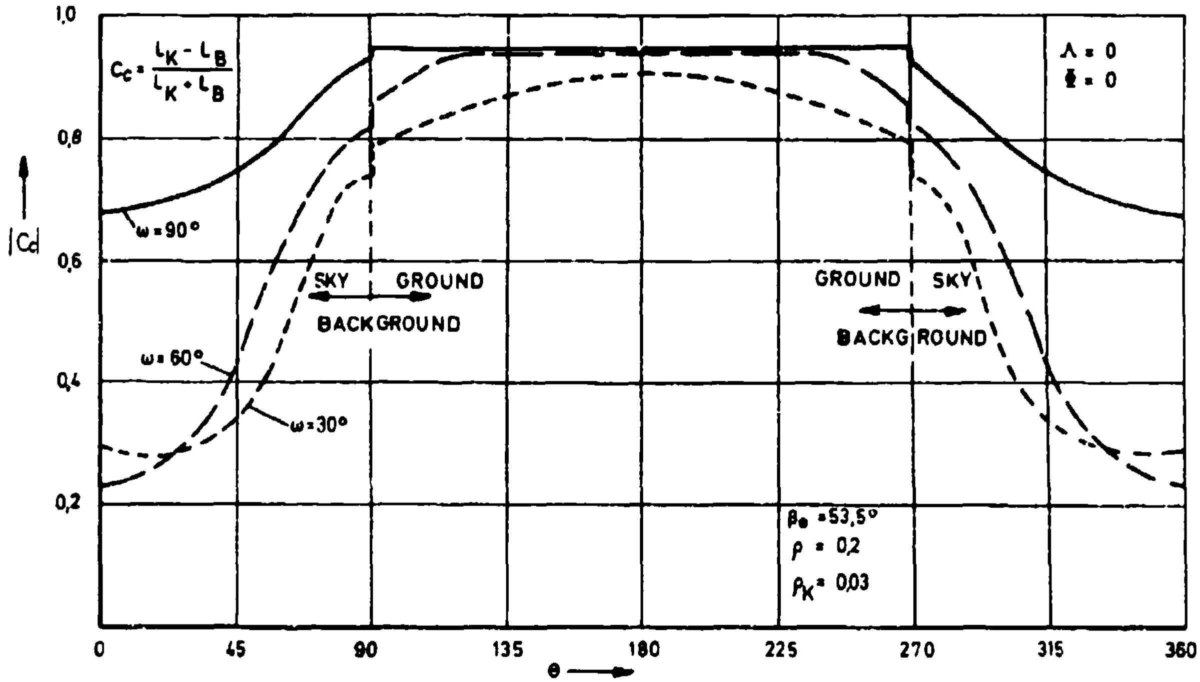


Fig. 10 Contour contrast along the boundary of the field of view for three sizes of the field of view. Viewing direction horizontal, sun above and behind the observer. Sun altitude 53.5°, ground reflectance 0.2, sphere reflectance 0.03.

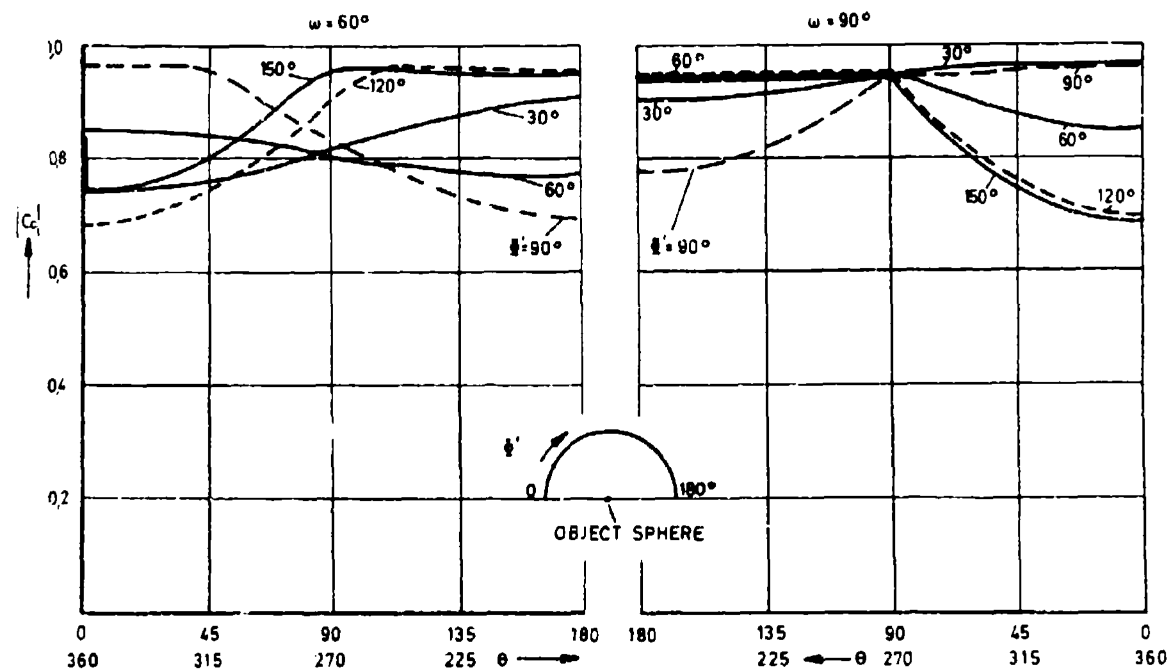


Fig. 11 Contour contrast along the boundary of the field of view for two different sizes of the field of view (ω = 60° and 90°), for five different viewing directions in the plane of the sun vertical. Solar altitude 53.5°, ground reflectance 0.02, sphere reflectance 0.03.

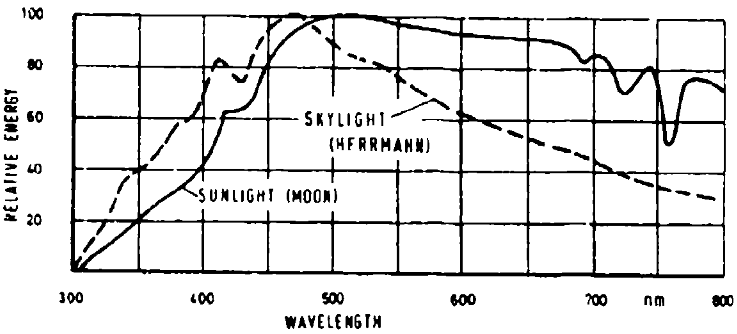


Fig. 12 Spectrum of the sun and sky for medium sun altitudes, in relative units.

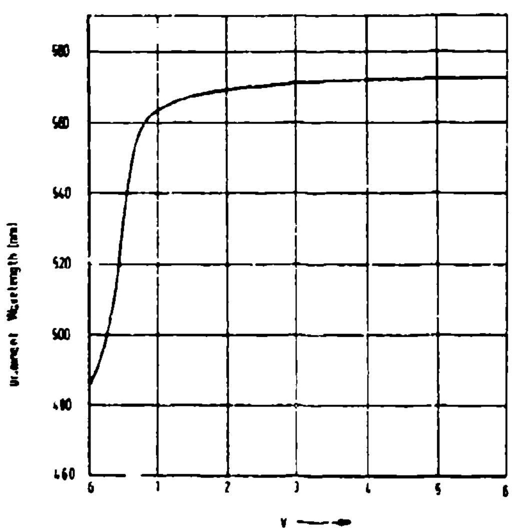


Fig. 13 Dominant wavelength in nm as a function of the ratio V of solar and sky contributions to the illuminance.

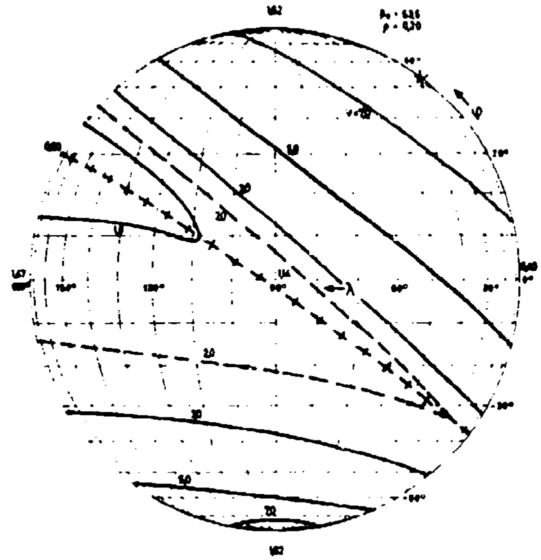


Fig. 14 Distribution of the ratio V of solar and sky contributions to the illuminance on the surface of the sphere. Crosshatched line is the "blue line".

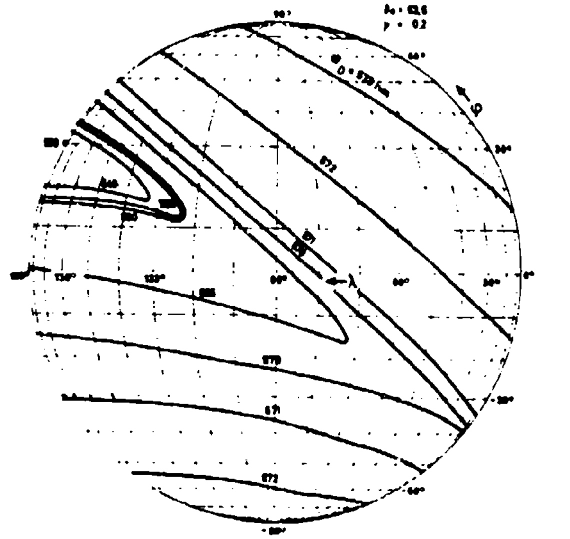


Fig. 15 Distribution of the dominant wavelength over the surface of the sphere. Solar elevation 53.5°, ground reflectance 0.2.

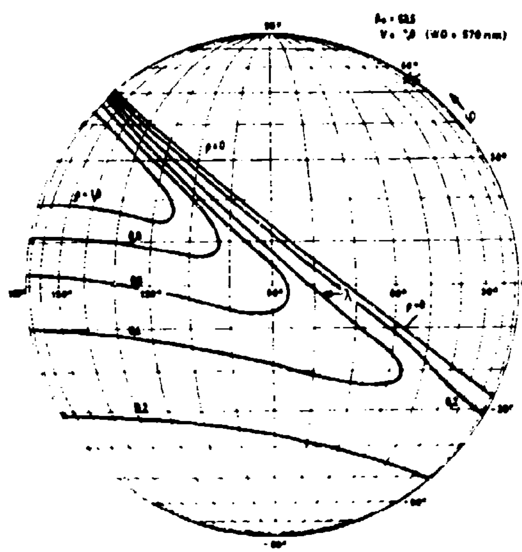


Fig. 16 Displacement of line of equal V = 3.0, or dominant wavelength 570 nm, respectively.

Appendix 1

Conversion of Contrast Values+)

C = $\frac{E_{max}-E_{min}}{E_{max}+E_{min}}$	log C	$\frac{E_{max}}{E_{min}}$	log $\frac{E_{max}}{E_{min}}$	$\frac{E_{max}}{E_{max}+E_{min}}$	$\frac{E_{min}}{E_{max}+E_{min}}$
1.00	0.000	-	-	1.00	0.00
0.95	-0.0223	39.0	1.591	0.975	0.0250
0.90	-0.0458	19.0	1.279	0.950	0.0500
0.85	-0.0706	12.3	1.091	0.925	0.0750
0.80	-0.0969	9.000	0.954	0.900	0.1000
0.75	-0.1249	7.000	0.845	0.875	0.125
0.70	-0.1549	5.667	0.753	0.850	0.150
0.65	-0.1870	4.714	0.673	0.825	0.175
0.60	-0.2218	4.000	0.602	0.800	0.200
0.55	-0.2596	3.444	0.537	0.775	0.225
0.50	-0.3010	3.000	0.477	0.750	0.250
0.45	-0.3468	2.636	0.421	0.725	0.275
0.40	-0.4979	2.333	0.368	0.700	0.300
0.35	-0.4559	2.077	0.317	0.675	0.325
0.30	-0.5228	1.857	0.269	0.650	0.350
0.25	-0.6198	1.667	0.222	0.625	0.375
0.20	-0.6990	1.500	0.176	0.600	0.400
0.15	-0.8239	1.353	0.131	0.575	0.425
0.10	-1.000	1.222	0.0872	0.550	0.450
0.05	-1.3010	1.105	0.0435	0.525	0.475
0.00	-	1.000	0.0000	0.500	0.500

+) In the case of contour contrasts, exchange $E_{max} \rightarrow L_K$ and $E_{min} \rightarrow L_B$

AIR-TO-GROUND VISIBILITY OF LIGHTS AT LOW BACKGROUND LEVELS

John H. Taylor
Research Psychologist
Visibility Laboratory
Scripps Institution of Oceanography
University of California
San Diego, California 92152
U S A

SUMMARY

After sunset and before sunrise the visual task of the airborne observer becomes radically different from that which he must perform during the daylight hours. The scene is characterized by low levels of prevailing luminance, and the most common object which he may discern on the ground is likely to be an angularly small, self-luminous, and usually man-made light. The range at which any such target will be seen depends upon the physical properties of the source, such as its intensity and color, the length of time for which it is exposed to view, the transmissivity of the atmospheric path of sight, and the visual performance capabilities of the observer. This paper describes some new data which apply to this problem, and suggests that the relationship between visibility and flash duration may be somewhat more complex than has usually been assumed. The results have application to both aggressive and defensive needs, and are of interest to the signalling community in general.

INTRODUCTION

During the hours of twilight and darkness the airborne visual observer must perform the critical task of detecting and interpreting a great variety of ground-based lights. These lights may be either steady or flashing, and color may be an important clue to their identity and interest. Many examples come readily to mind, such as vehicle lamps, highway lights, beacons, flares, aircraft landing aids, aids to navigation, ships' lights, and a great variety of civil and military ground installations. They may, obviously, be either friendly or unfriendly.

From the standpoint of the visual process these lights are almost invariably so small in their angular dimensions that they may be treated as point sources. This is to say that the subtended angle at the observer's eye is below the resolution limit of his visual system, and that the lights in question may be considered to obey the inverse-square law of illumination. In consequence of this property the detectability of a distant light will be governed by its inherent intensity and its distance from the observer. In the simplest case, neglecting atmospheric attenuation, the illumination reaching the eye is directly proportional to the intensity of the source and inversely proportional to the square of the distance from source to eye. In addition to the reduction in illumination attributable to the inverse-square relationship, the energy is usually further reduced by atmospheric absorption and scattering, and by anything which lies before the observer's eye, such as optical instruments, aircraft windscreens or goggles.

A significant reduction in the visibility of lights may occur if the time available for observation becomes brief. If the exposure time is shorter than a second or two, as is frequently the case with flashing lights or at relatively high aircraft speeds, the required intensity for detection at a given range is higher or, conversely, the detection range for a given intensity is reduced.

The general problem of seeing brief pulses of light has been recognized and studied for many years, and approximately six hundred existing publications attest to the continuing high interest in the phenomena associated with it. Many of these papers reflect attempts to quantify the relationship between flash duration and visibility, and many have explored such other stimulus parameters as color, pulse shape, adapting luminance, and position in the visual field. In spite of this seeming wealth of available data it has become evident that very little of the published information is applicable to the practical case. This unhappy state of affairs results primarily from the fact that many studies were restricted in their range of conditions, imposed special experimental constraints (such as artificial pupils, monochromatic light, and uniocular viewing), or were addressed to the support of a particular theoretical position. This is not to be taken as criticism of these studies; it serves only to point up the relative paucity of useful data in a seeming plethora of available papers. Certain general features of the time-intensity relationship in human vision have, nonetheless, been established beyond possible doubt. It is undisputed that the detectability of extremely short flashes, in the millisecond and microsecond range, is determined by the product of the time and the intensity, and that this holds true rigorously for any pulse shape and for trains of successive flashes.

At the other end of the duration continuum it is usually assumed that the detectability is independent of duration and is determined by intensity alone. If so, we may now say that the time-intensity function, or the curve relating the amount of energy required for detection to the duration of the flash, is described by the equation $I \cdot t = C$ at the shortest flash lengths and by the equation $I = C$ for very long pulses. On a logarithmic grid the data fall on two straight lines with slopes of minus one and zero, respectively, as indicated in Figure 1.

The form of this function in the transition zone has for many years been the subject of investigation and debate, but there has rarely been argument about the limiting asymptote at the shorter durations and the approach to $I = C$ has the sort of common-sense appeal that the vast majority of investigators have found irresistible. (One notable exception is seen in the quantum theory, which predicts that $I \cdot t^{½} = C$ at long durations, giving a limiting slope of minus one half.) By far the most familiar formulation of the time-intensity function is that of Blondel and Rey (1,2), who believed that the transition must be gradual and who found their data to be reasonably well fit by an equation of the form:

$$I_e = \frac{I \cdot t}{a + t}, \tag{1}$$

where I_e is the effective intensity and a is a constant which varies considerably with experimental conditions but is often taken to be about 0.2 second. The Blondel-Rey equation as given in (1) is strictly applicable only to square-wave pulses, and they subsequently gave an integral form to handle any pulse shape:

$$I_e = \frac{\int_{t_1}^{t_2} I\,dt}{0.21 + (t_2 - t_1)} \tag{2}$$

The Blondel-Rey formula, then, describes the time-intensity function as a curve with the shape shown in Figure 2, which has been drawn with $a = 0.2$ second in accordance with the recommendation of the Commission Internationale de l'Eclairage for the threshold case.

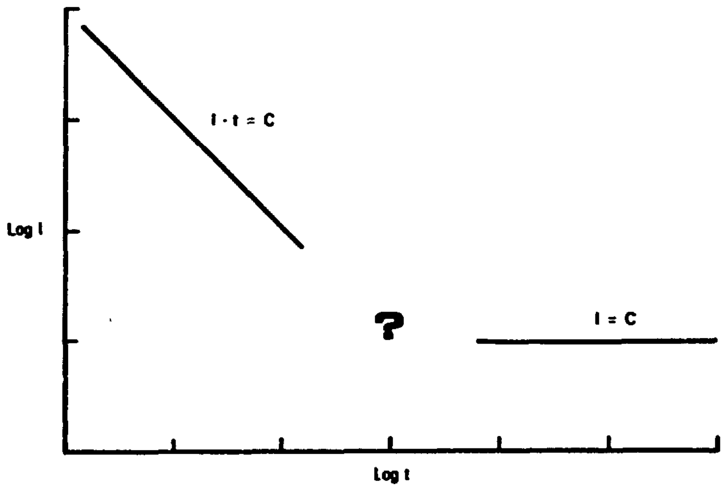


Figure 1. The assumed limiting slopes of the time-intensity function. At very short exposures detectability is determined by the product of time and intensity, while at very long ones further time does not result in a lower threshold.

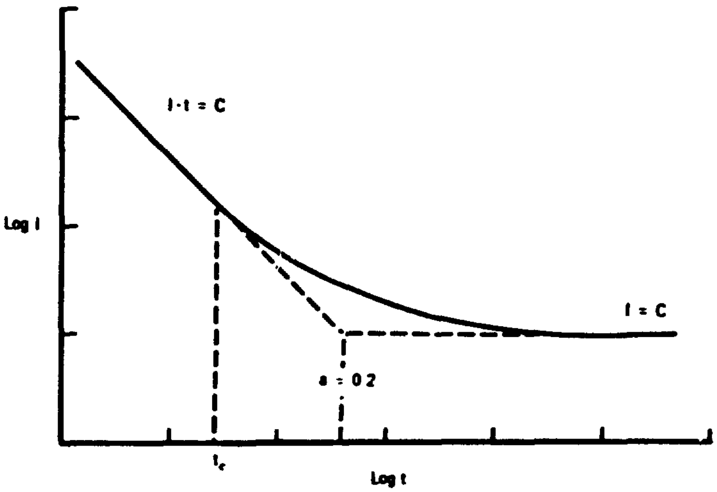


Figure 2. The shape of the time-intensity function as predicted by Blondel and Rey. The value of a is taken to be 0.2. The point at which the curve departs from the linearity of $I \cdot t = C$ is called the critical duration, t_c

In the years following the work of Blondel and Rey a number of studies have been performed which sought to confirm or to modify their formula, to extend the experimental conditions to include colored stimuli, larger sources and non-square-wave pulse forms, and to apply their concept in the evaluation of the effective intensity of flashing lights of many kinds under threshold as well a suprathreshold conditions. As better and better experimental techniques became available the data became ever more extensive and precise, and during the last decade or so a number of experiments have been reported which allow us to make a critical assessment of the time-intensity relationship.

By no means do the results of these investigations agree in confirming the adequacy of the Blondel-Rey formulation to describe the time-intensity relationship. A recent survey by Kishto (3) of 22 papers published between 1887 and 1969 clearly shows that the transition zone may be either sharp or gradual, and that the value of a is found to range from less than 0.1 to about 0.6. These wide differences are ascribed to variations in experimental method, the relative goodness of fixation, and to the methods of statistical treatment of the data. In 1970 the United States Coast Guard, in an attempt to reconcile some of these differences and to develop an optimum method for the evaluation and specification of navigational aids lights, sponsored a meeting at the Visibility Laboratory of the University of California at San Diego. This meeting, which lasted for five weeks, was attended by Mr. Charles A. Douglas of the U. S. Bureau of Standards, Dr. Hans Joachim Schmidt-Clausen then of Philips Research Laboratories, Dr. Bhoopendranath Kishto then of the Road Research Laboratory of the U K (now, unfortunately, deceased) and the author. Although the deliberations of this meeting did not result in the hoped-for concordance of opinions and did not produce the desired elegant system for the evaluation of lights, it was generally agreed that the major points of difference might be resolved by a series of experiments addressed specifically to a more adequate definition of the time-intensity function. In consequence of this need, a series of experiments have been performed at our Laboratory which shed new light on this old problem, and which, we believe, show that the time-intensity relationship is by no means as simple as we once thought. In this paper I will report upon some of our results and discuss their application to the visibility of lights from the air.

EXPERIMENTAL DESIGN

The transition region of the duration function has, as we have indicated, attracted the interest of many experimenters. The debate over whether the curve is sharp or gradual has been vigorous and extensive, and there are data in the literature which may be shown to support either argument. Only fairly recently, however, has the assumption of the limiting asymptote at long exposure times been called into question. Adherents to the quantum theory of vision predict that the limiting slope must be minus one-half, as shown in Figure 3, although it seems most unlikely that the downward trend of the curve could continue indefinitely. A detailed treatment of the quantum hypothesis as applied to flashing lights may be found in Bouman (4). Quite aside from this, there is now a growing body of evidence from experimental studies which, in my view, compels us to doubt either the I = C or the square-root asymptote.

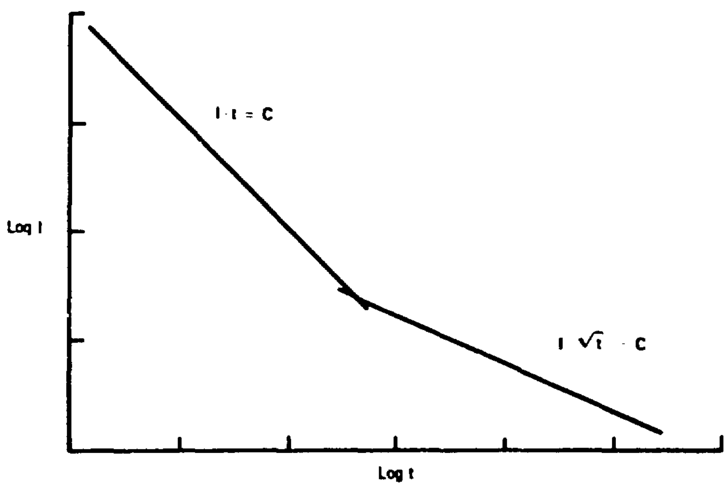


Figure 3. The form of the duration function as predicted by the quantum hypothesis. (Cf. Bouman)

With very few exceptions the assumption that I = C at long durations has pervaded the literature. Indeed, in many instances we find that experimenters have simply stopped their studies as soon as a pair of points were found with about the same threshold intensity. In at least one widely quoted study the data were "smoothed" in order to make them conform to the I = C notion, even though this required that considerable violence be done to the obtained values of threshold. There are other reasons, however, why the true form of the duration function might be obscured, quite aside from any theoretical bias. First, if there were an insufficient number of different flash durations tested, there is danger that any fine structure which the curve may have will not be detected. Second, if only one or two observers are involved, as is frequently the case, there is a danger that idiosyncratic effects may influence the apparent shape of the function. Third, if the data from a number of observers showing the same function but with different threshold values are averaged, there is a high likelihood that the average curve will show a smooth transition. Fourth, if the experimental method is less than optimal and the number of observations is small, it is possible that the data will be so noisy as to obscure the fine structure of the function and preclude any meaningful analysis of the data.

Some clarification of the problem is provided by a study by Clark and Blackwell in 1959 (5), who studied the duration function with an improved psychophysical method, used seven observers, and covered the range from less than a millisecond to one second using as many as 22 different durations. Their data clearly showed that the function was doubly inflected, as suggested in Figure 4, and that the lower limiting asymptote had not been reached even at their longest exposure times.

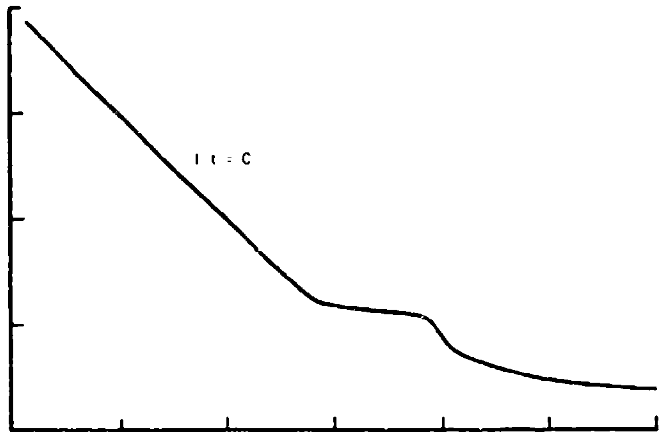


Figure 4. The general shape of the duration function as reported by Clark and Blackwell (Ref 3), for circular targets subtending 18.2 minutes of arc against a background of zero luminance.

The experiments of Clark and Blackwell were conducted using background luminances of zero and 34 nits (0 and 10 ft-L) in order that any differences in the duration function due to the change from scotopic to photopic vision might be demonstrated. While these cases are of considerable theoretical interest, they do not represent the intermediate range of adaptation conditions which are frequently found in the real world. The experiments to be described here apply to the case of a mesopic adaptation level that was shown by a number of photometric surveys to be quite typical of certain twilight and nighttime conditions in the field. Until now we have completed work on only one value of background luminance, 0.003 nit (0.0008 ft-L). This is the luminance, for example, of the sea surface when the sun is about ten degrees below the horizon, or the land surface when the contribution of illumination from sky and moon, together with certain reflectance properties of the terrain, combine to produce such a level. Finally, at this adaptation level, the eye is approximately equally sensitive from the fovea to the near periphery.

Our stimuli were physiological point sources; they subtended an angle of one arc minute at the viewing distance of 3.1 meters (122 in.). Three colors were used: white, red, and green. The trichromatic coordinates of the targets are indicated in Figure 5. They are representative of the colors used by the international signalling community, and are therefore believed to be among the cases most likely to be encountered in the field.

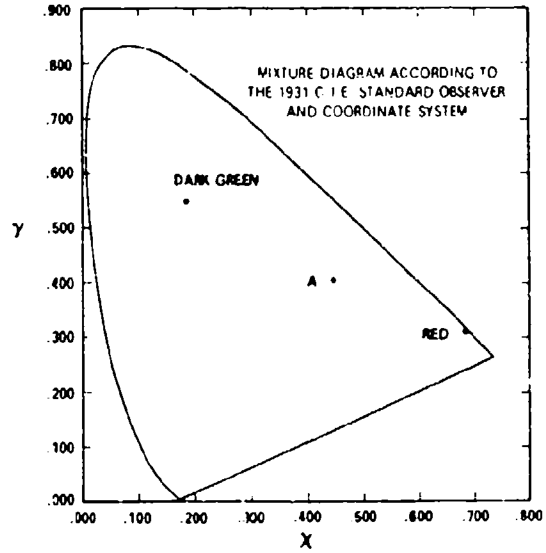


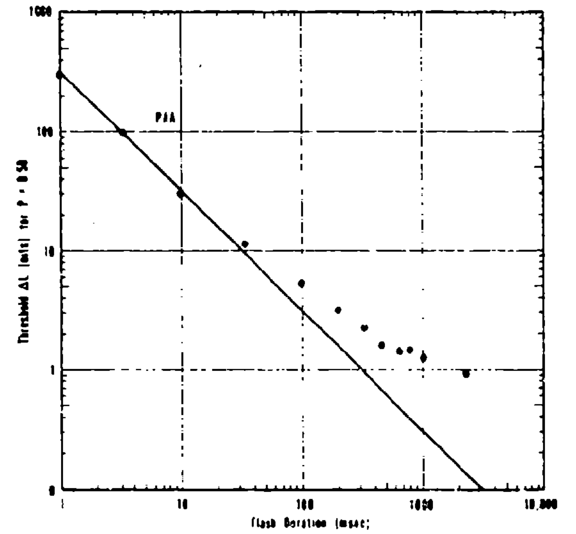
Figure 5. Loci of the three point source stimuli on the CIE chromaticity diagram, relative to white light at 2854°K (Illuminant A)

Using five young observers with good visual acuity, we measured the detectability of these point sources as a function of the flash length, using the psychophysical method of temporal forced choice. The observers were required to guess which one of four aurally marked time intervals contained the flash on each trial. This method has a number of advantages, but the one which is paramount for practical problems is that the obtained probabilities of detection (which are, from statistical sampling considerations, usually taken at P = 0.50) may be easily converted to any other desired probabilities by a simple mathematical operation. In order to achieve a satisfactory degree of precision in the data it is necessary, however, to make many observations. In our study each single point on an individual observer's curve has been determined by 500 separate observations. The data to be shown are based upon approximately 72 500 trials, and were recorded only after about 9000 training trials had been completed. In all cases the pulse shape was square, although the study will eventually embrace those shapes which are characteristic of switched lamps, rotating beacons, and multiflick discharge tubes. It is also planned to study additional background luminance levels.

EXPERIMENTAL RESULTS

Since the data of these experiments are quite extensive, I will present only enough examples to show the general nature of our results. Complete data will be furnished on request to the Visibility Laboratory, as will the results of subsequent studies.

It is appropriate to discuss the white light results first, since the greatest number of lights which are likely to be encountered are polychromatic in nature and very likely to exhibit the continuous spectral energy distribution which is characteristic of tungsten lamps. The white light stimuli we used were adjusted to match a color temperature of 2854°K, or CIE Standard Illuminant A. There is no *a priori* reason to believe that the data would differ in any significant manner had we chosen a higher or lower color temperature. In all cases the plotted values refer to the 0.50 level of detection probability, and the duration functions show the obtained values of target luminance (nits, or candelas per square meter) for the range of flash lengths from 0.001 to 2.33 seconds. Target luminance refers to the added flux which must be superimposed on the 0.003 nit constant background, and is therefore designated ΔL in the graphs. The straight lines of minus one slope represent the case of perfect temporal summation, when the product of intensity and time is constant. Figure 6 shows the white light data for two observers. Although no attempt has been made to fit a smooth empirical function to the points, it can be seen that the curve shapes are probably similar to the Clark and Blackwell form and cannot be fairly represented by either the Blondel-Rey or the quantum functions mentioned earlier.



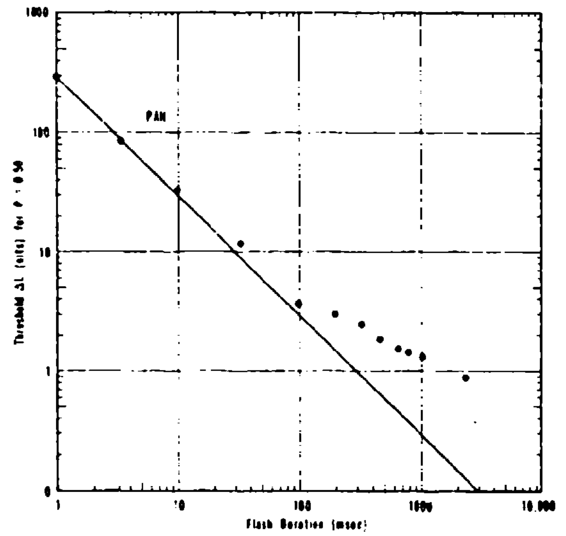


Figure 6. Experimental data from two observers in the white light experiment. The straight line represents Bloch's Law reciprocity

The red light stimuli yielded data which are typified by the two curves shown in Figure 7. It was thought that, on account of the extremely high spectral purity and long wavelength of this stimulus, it might be found that the shape of the duration function might give a clearer basis for support of either the Blondel-Rey or the quantum formulations. Obviously there again appears to be an inflection in the function, indicating that we are dealing with a complex curve.

Finally, the green light data, shown in Figure 8, also suggest that the duration function is doubly inflected. In none of the data so far collected have we yet approached the lower limiting asymptote where I = C, although future work with longer pulse lengths will probably indicate this limit. (The units on the ordinates of the red and green curves are irrational; they are merely the result of integrating the transmissions of the filters used with the photopic sensitivity curve of the eye and the spectral energy distribution of the source.)

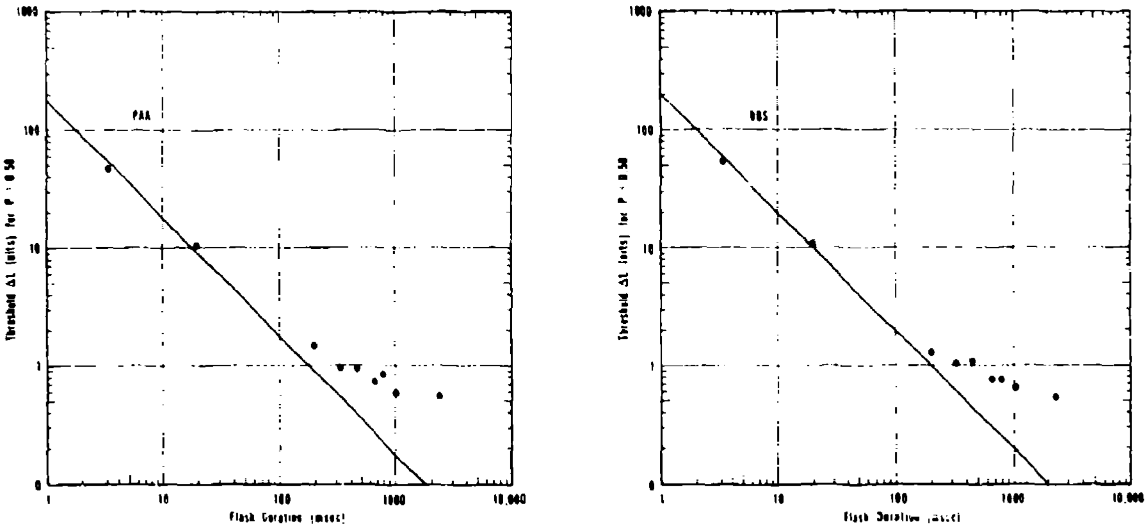


Figure 7. Experimental data from two observers using red light

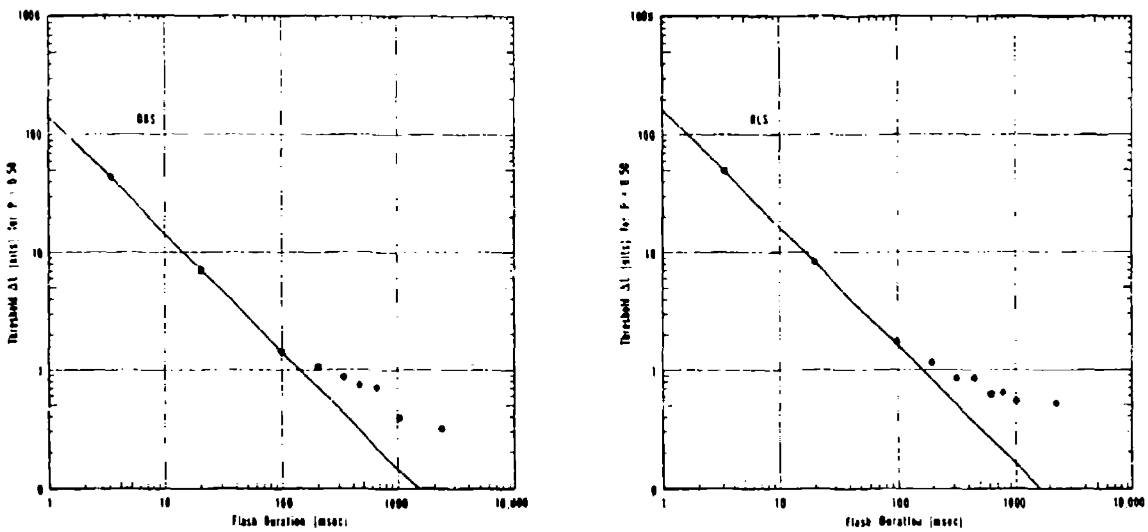


Figure 8 Experimental data from two observers using green light

APPLICATIONS OF THE DATA

In the context of this meeting the laboratory results which have been shown have direct application to the problem of air-to-ground detection of angularly small sources whose effective viewing times may be quite short, either because they are inherently of brief duration or because the dynamics of the flight path, intermittent obscuration of the lights, or other factors allow only brief glimpses of such lights. Perhaps equally important is the finding that the use of the Blondel-Rey equation can lead to errors of estimate – the man on the ground may be less secure from aerial surveillance than he thought, while the airborne observer enjoys a concomitant advantage. In a friendly situation, it is possible that a certain amount of power conservation could be achieved if that were desirable or necessary, as it frequently is in aeronautical and maritime signalling in remote areas.

Before these new data can be incorporated into visibility nomograms or other utilitarian forms, however, it is necessary to perform at least two operations. The first of these is the conversion from the 0.50 level of detection probability to some field-realistic level such as 0.90, 0.95, 0.99, or whatever may be judged appropriate for the situation. This is possible owing to the fact that the seeing frequency data collected by the method of temporal forced choice exhibit a remarkable constancy in the relation between the value of threshold ΔL at $P = 0.50$ and the σ of the normal probability integral which is fitted to the obtained data points for each observing session. The ratio σ/M (where M is the obtained threshold) we have called V, the coefficient of variation. The method for converting probabilities has been outlined by Blackwell and McCready (6), and we may use their method for this purpose. Our average value for σ/M was found to be 0.510 for red, 0.519 for white, 0.527 for green, and 0.519 for all three colors, based on more than 300 individual frequency-of-seeing ogives. In the general case, then, the desired probabilities are obtained by use of the following factors, Z, which are to be used as direct multipliers on the thresholds shown for the P = 0.50 laboratory case:

P	Z
.90	1.67
.95	1.86
.99	2.21

Values of Z for any desired probability can easily be computed. In very general terms, it can be seen that doubling the obtained laboratory values which have been shown will result in a detection probability between 95 and 99 percent.

The atmosphere which intervenes between the airborne observer and the ground-based light will always act to attenuate the strength of the signal reaching his eye. In the case of point sources, therefore, we must account not only for the loss due to distance, but also for the transmissivity of the atmosphere. In the case under consideration here, where the background luminance is very small relative to the target luminances, it is possible to apply Allard's law directly. Allard's law, which was enunciated almost a century ago (7), gives the relationship between the sighting range of a luminous signal and the effects of distance and transmissivity: $E_m = IT^V/V^2$, where E_m is the threshold illumination at the eye, I the intensity of the source, T^V the transmissivity over the path of sight V. Some approximate transmissivities are shown in Table I. The consequences of Allard's law are shown graphically in Figure 9. Further attenuation of the optical signal will occur owing to the presence of an aircraft windscreen, protective glasses, or any intervening optical aids. Unlike the atmospheric losses, which may change dramatically as the path of sight changes in angle and weather conditions vary, these tend to be invariant and may be measured or predicted with fair confidence.

Visibility Description	Transmissivity (T per mile)	Meteorological Optical Range (miles)
Exceptionally clear	>0.90	30+
Very clear	.90	30
Clear	.74	10
Light haze	.55	5
Haze	.22	2
Thin fog	.05	1
Light fog	.0025	1/2
Moderate fog	$10^{-5.2}$	1/4
Thick fog	$10^{-10.4}$	1/8
Dense fog	$10^{-20.8}$	1/16
Very dense fog	10^{-69}	100 ft.
Exceptionally dense fog	10^{-137}	50 ft.

Table I. Transmissivities and meteorological optical ranges for various visibility descriptions.

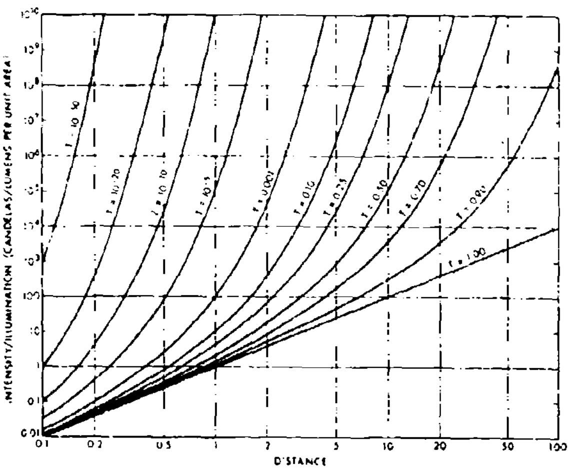


Figure 9. Allard's law for several values of transmissivity.

One of the best ways in which the data may be used in predicting the visibility of lights is by constructing nomograms such as those prepared during World War II, and described by Middleton (8). These charts allow rapid estimation of sighting range for a wide gamut of source intensities, background luminances and atmospheric transmissivities, but apply only to steady burning lights seen without limits being put on observing time. At the Visibility Laboratory we are hoping to prepare new nomograms which will enable the prediction of sighting range for the case of brief flashes and restricted viewing times.

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Photometric errors mean that figures on the ordinates of Figures 6, 7 and 8 must be multiplied by 0.327.

DISCUSSION

Mr Ericson (US)

Would you comment on any individual differences you noted? Also, would you discuss the differences between using a cumulative probability-of-seeing curve versus starting with the 50 per cent threshold and multiplying it by appropriate factors?

Dr Taylor (US)

The individual differences are not easy to describe at this moment, that is, our data are not sufficient and not complete. By adjusting for absolute threshold in the range you know, that is Bloch's Law area, you can slide the data together on the ordinate so that they seem to fit. But even now, we are down from 6 to 5 test subjects, and complete data for 6 would hardly be adequate.

As regards using probability integrals rather than operating directly on the observed frequencies-of-seeing, you have a good point. You could, for example, have a range of 5 stimuli so that one was so dim it was never seen and at the other extreme one so bright it was always seen, and draw a best fitting curve on the data in between. We tried all sorts of curves; special N Poissons, logarithmic cumulative Gauss, linear normal integrals, etc. and, overwhelmingly, standard normal Gaussian integrals are the best fit. That could cheer the physiologists a little!

Conventionally, one works at the point of inflexion of the curve, where the best estimate is. If I went up to the 95% point a little error on one axis would lead to a huge uncertainty on the other. If you believe in cause and effect, this is all then simply mathematical, you do not have to go to individual curves, and the best fit is an iterative process, derived from probit analysis. That is the reason for operating on Z-curves rather than on individual curves.

AIR-TO-GROUND TARGET ACQUISITION WITH FLARE ILLUMINATION*

ROBERT L. HILGENDORF
MAJOR, UNITED STATES AIR FORCE
FLIGHT ENVIRONMENTS BRANCH
HUMAN ENGINEERING DIVISION
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

SUMMARY

Despite the advent of many exotic sensors for detecting targets at night, a significant portion of airborne tactical activity is carried out via direct vision, usually involving some type of artificial illumination, with air-dropped parachute flares. The use of flares constitutes one of the most difficult visual requirements for aircraft crew members attempting to detect targets at night. Efforts by the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, have involved simulating various illumination sources, and requiring subjects to detect scaled-down targets under different terrain and illumination conditions.

This paper is concerned with the results from three recent experiments. Experiment I dealt with the effect of shielding a 25,000,000-lumen flare source and determining the optimal number of flares to be used for a given target area. No statistically significant effect was found due to flare shielding. For the given target area simulated, it appeared that there was no additional benefit derived from igniting more than two flares over a simulated area of about 1.5 kilometers by 5 kilometers. Experiment II dealt with shielding of a 60,000,000-lumen source, and again, no statistically significant effect was found due to the flare shielding. Experiment III dealt with the "visual acuity" under simulated flare light. In this experiment, each of eight groups of five subjects performed at a different simulated observer altitude ranging in 152-meter increments from 152 to 1,219 meters. For the slant ranges simulated (1,029 to 1,587 meters), 610 meters was the best altitude for visual performance. Like the other findings, this could have significant impact on tactical planning for night missions. The parameters of this study have now been "blown-up" to real-world size and the Aerospace Medical Research Laboratory, in conjunction with the Air Force Armament Laboratory, is conducting flight tests to validate the altitude date of the experimental simulations.

INTRODUCTION

One of the most difficult visual requirements for aircraft crew members involves detecting targets at night. Despite the advent of numerous exotic sensing devices, the majority of night-time aerial activity is carried on under air-dropped, parachute illumination flares. Specific problems encountered by crew members utilizing flare illumination include: restricted fields of view, visual discrimination at low levels of illumination, difficulty in tracking, terrain avoidance, visual whiteout, flare flicker and oscillation, contrast reversal, loss of depth perception, and vertigo.[1] It has also been reported that during low level flight at night, the large and frequent changes in adaption impair visual performance.[2]

There is very little literature relevant to this general problem of vision under flare light. Laboratory investigations[3] into aspects of visual air reconnaissance have been conducted and mathematical relationships for predicting performance in actual operations have been suggested. However, it has been pointed out that applications of these predictive methods to practical detection problems can lead to "great complexities".[4] An example of these "complexities" is given by Blunt and Schmelling.[5] Based upon hypothetical diffuse target-reflectance, inherent contrast, target area, range, and atmospheric effects, it was calculated that a flare of 1,445,000,000 lumens would be required to produce enough illuminance to be able to detect an armored tank located on dry sand at a range of 2,743 meters. (The most commonly used flare in the present inventory, the Naval Mark 24, produces 25,000,000 lumens). Blunt and Schmelling further point out these requirements may be increased by as much as five times when combat factors are considered (i.e., psychological stress, etc).

Therefore, it is not surprising that visual problems are encountered during night, air-to-ground tasks and that this is a difficult problem for research. Using laboratory-established relationships in their present form does not always end in reasonable recommendations for the field and attempts have been made at both laboratory simulations[6] and field studies.[7] Hamilton[6] attempted to determine night visibility distances for military targets using a scale-model simulator. Viewing paths were ground-to-ground rather than air-to-ground. It was found that visibility was poorest when targets were placed against foliated backgrounds and when the durations of illumination were short. In Wessner's[7] field study, ground targets were placed in a 2.6 square-meter area and six aerial observers flew at altitudes ranging from 762 to 1,676 meters with ranges from ground zero of 1,000 to 6,000 meters. Thirty-three flares, varying in intensity and burn-time were dropped singly. Fifteen percent of the stationary targets and five per cent of the moving targets were detected while only one percent of both types of targets were identified.

Initial simulations by the Aerospace Medical Research Laboratory used three different groups of subjects performing target acquisition (detection and recognition) tasks under simulated Mark 24 flare light, simulated Briteye flare light (a recently developed flare which produces 60,000,000 lumens), and simulated sunlight.[8,9] Generally, target acquisition took significantly longer under four simulated

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Mark 24 flares dropped a simulated distance of 0.4 kilometer apart and ignited at a simulated altitude of 610 meters. This compared with significantly shorter times under the simulated Briteyes deployed similarly and still shorter times under simulated sunlight (simulating those light conditions characteristic of a "partly cloudy" day). However, with the simulated Briteyes, there appeared to be a much more pronounced direct glare problem which was apparently associated with the more intense flare source. In an effort to alleviate this potential problem, efforts have been made to develop shielding techniques for flare sources.[10,11,12]

The early simulations involved attempts at scaled-down reproductions of real-world characteristics without regard to the scientific investigation of the visual system in terms of such concepts as visual acuity. Whether visual acuity is generally defined as the capacity of the eye to resolve detail, or specifically defined as the ability to discriminate black and white detail at various distances, there are many problems associated with taking purely clinical or laboratory visual acuity measurements and applying them to the field. For example, direct application of the normally accepted methods of measuring visual acuity to the field is difficult in a visual search task from an aircraft because: the eye, the platform, and the target are not static; the scene involves color; and the illumination level can be measured only generally. On the other hand, in varying the factors included (i.e., illumination, etc.), the researcher can be accused of not really measuring "visual acuity" at all, or of using a concept that was not intended to serve as a criterion bridge between laboratory and field, but rather as a precise clinical tool for determining the visual capacities of individual subjects and patients.

Yet the gap between laboratory simulation and in-flight validation must be bridged. Utilizing high fidelity terrain models can be successful. However, there is great difficulty in duplicating and controlling features similar to the terrain model in the real-world validation. The apparent alternative is to take accepted acuity measures and "modify" them for laboratory simulation and eventually "blow them up" for in-flight validation.

This paper is concerned with the results from three recent simulation experiments. Experiment I[13] was an attempt to determine the behavioral effect due to flare shielding utilizing a 1:1,000 scale terrain model and simulated shielded and unshielded flare sources. In addition, there was a concern with optimal number of flares to be used for a given target area for both shielded and unshielded Mark 24 flares. Twelve groups of subjects were used. Each group searched the terrain model under from one to six simulated flares in either the shielded or unshielded configuration. While the illuminance from a shielded flare is greater at the center of an illumination pattern, the illuminance from an unshielded flare is greater at 40 degrees from the center and beyond. Therefore, strictly from a visual performance point of view, it was necessary to determine what effect these different patterns of illumination could have on target acquisition.

Experiment II was also concerned with flare shielding. However, in this experiment simulated 60,000,000-lumen flares were used. This seemed to be a reasonable follow-on effort since an earlier study[9] had indicated that the direct-glare problem may only be associated with the more intense flare and, also, a 60,000,000-lumen flare which burns for 5 minutes is now being introduced for limited use. In this experiment, two groups of 15 subjects each searched the terrain model under two simulated flares in either the shielded or unshielded configuration.

Experiment III[14] was concerned with the optimal observer altitude for performing visually under Mark 24 flare light. (An earlier study established 610 meters as the optimal altitude for flare ignition.)[15] Another concern involves the type of measurement of visual performance. Required is a measure which is usable in the laboratory, yet expandable to real-world validation. Each of eight groups of five subjects performed at a different simulated observer altitude under simulated flare light. The simulated altitudes ranged in 152-meter increments from 152 to 1,219 meters. Landolt rings and acuity gratings were used as targets. In addition, four different brightness contrasts were used.

METHOD

Subjects

The subjects were male college students with normal color vision and 20/20 acuity or better. Color vision was tested by the Dvorine Psuedo-Isochromatic Plates. Visual acuity was tested by a Bausch and Lomb Master Ortho-Rater. Sixty, thirty, and forty subjects were used in Experiments I, II and III, respectively.

Apparatus

The main feature of the apparatus was the simulation of the flare source. The Naval Mark 24 is a commonly-used parachute flare and it produces 25,000,000 lumens for three minutes. Simulation of this flare is accomplished by use of a standard No. 47 pilot lamp.[8] Operating this lamp at appropriate voltage reasonably simulates a Mark 24 on a scale of 1:1,000. Operating a standard No. 45 pilot lamp at appropriate voltage reasonably simulates the 60,000,000-lumen flare. For experiments I and II the simulated shields consisted of modified flashlight reflectors coated with opaque white paint.

The flare simulator (Figure 1) is composed of six mechanically-driven and electronically-controlled No. 47 pilot lamps mounted on a framework suspended from the ceiling of a laboratory dark room. Each simulated flare can be manually positioned within the length and width of the framework. The descent of each flare is controlled by a 28 Volt DC motor. The voltage to each motor is a ramp function to simulate the constantly decreasing velocity in the descent of a parachute flare due to its mass loss and heat generation while burning. All six of the flares were used in Experiment I, two were used in Experiment II, and one in Experiment III.

The terrain model (Figure 2), used as the background over which the subjects searched for targets in Experiments I and II, is on a scale of 1:1,000 and presents a realistic portrayal of actual terrain. It measures 1.5 meters by 5.5 meters, which represents a terrain of about 5.5 kilometers long by 1.5 kilometers wide. The model simulates the color and reflectance properties of the real world within the visible portion of the electromagnetic spectrum and contained among others, the following features which were used as

FIGURE 1 - FLARE SIMULATOR IN OPERATION

targets for Experiment I: road, river, village, paddy area, bridge, parked truck, moving truck, moored sampan, and anti-aircraft site. Three parked trucks, three villages, and the moving sampan were used as targets in Experiment II.

In order to "fly" the subject by the terrain model in Experiments I and II, he was placed in an optometrist's chair and required to keep the back of his head against the head pads. Through the use of the chair's elevation feature, the eyes of each subject were maintained at 61 centimeters above the terrain model to correspond to a simulated altitude of about 656 meters. The chair was placed on a motorized trolley which propelled the subject along the model at a simulated speed of about 215 kilometers per hour. The non-dominant eye of each subject was covered by an eye patch since, at the actual ranges which were simulated, there would be no stereoscopic distance/depth cues.

In Experiment III, the targets used were Landolt rings and acuity gratings.[16,17,18] The Landolt ring measures minimum separable acuity or gap resolution and involves the tasks of resolution and recognition. During testing, the ring was rotated so that the gap was in one of four positions: up, down, right, or left. The acuity grating also measures minimum separable acuity and involves the task of resolution. It consists of three parallel bars with the distance between the bars equal to the thickness of a bar. The length of the bars is equal to the width of the entire configuration. During testing, the acuity grating was located in either a "horizontal" or "vertical" position.

Both the gap in the Landolt ring and the gap between the parallel bars of the acuity grating were equal to .19 centimeter. Although the use of larger targets was attempted, it was found that this size (.19 centimeter) provided the necessary discriminations among conditions for the viewing distances in this study. The targets were silkscreened with a co-polymer viscous solution onto four gray-scale shades of Kimberly-Stevens Kacel paper, Type 100 (.9 gram/square meter). This paper is a laminated material having an inner net or scrim of non-woven threads with surfacing material bonded to both sides. The backgrounds were mounted on one square foot artboard for ease of handling. Table 1 shows the brightness of the four backgrounds and the resulting brightness contrasts. These measurements were obtained with a Spectra-Brightness Spotmeter Model "SB" under indoor ambient light conditions. The brightness contrast percentages

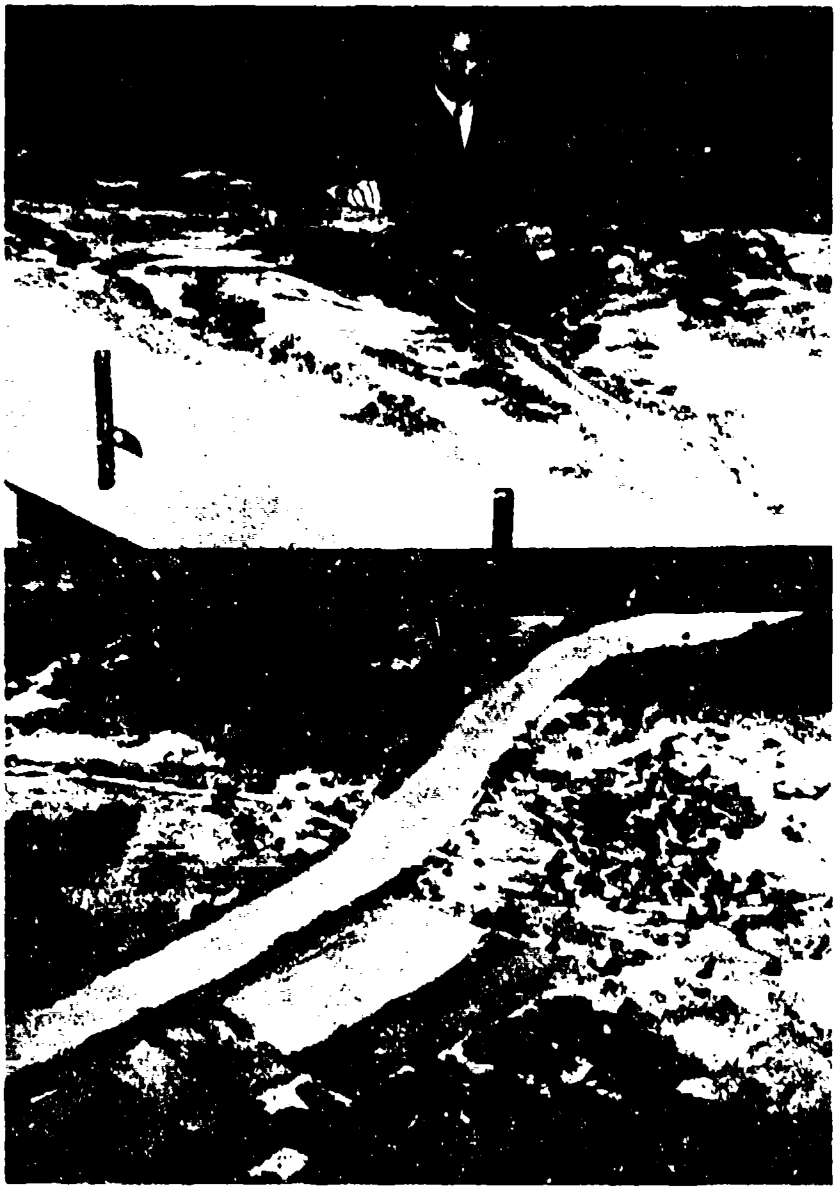

FIGURE 2 - TWO VIEWS OF TERRAIN MODEL USED IN EXPERIMENTS I AND II

were computed by the following formula:[18]

$$\text{Per Cent Contrast} = \frac{B_b - B_t}{B_b} \times 100$$

Where: B_b = Brightness of the Background

And B_t = Brightness of the Target

The slight differences in the target brightness from background to background were due to the required additions of the co-polymer because of changes in viscosity of the solution necessary to completely cover the various shades. The negative percentage of brightness contrast in Table 1 merely shows that the one target was brighter than the background.

TABLE 1

LUMINANCE IN CANDELA/SQUARE METER (cd/m^2) AND CONTRAST PERCENTAGES FOR BACKGROUNDS AND TARGETS FOR EXPERIMENT III

BACKGROUND BRIGHTNESS (cd/m^2)	TARGET BRIGHTNESS (cd/m^2)	BRIGHTNESS CONTRAST PERCENTAGE
115	30	74
67	24	64
30	24	20
9	26	-200

Each subject was placed in the motorized optometrist's chair and was required to keep the back of his head against the head pads. Through the use of the chair's elevation feature, the eyes of each subject were maintained at 15.25, 30.50, 45.75, 61.00, 76.25, 91.50, 107.75, or 122.00 centimeters above the target surface to correspond to the simulated altitudes of about 152 through 1,219 meters. Table 2 shows the visual angles, actual and simulated altitudes and slant ranges for the eight conditions. The visual angles were computed using the following formula:[18]

$$\text{Visual Angle} = 2 \arctan \frac{L}{2D}$$

Where: L = Size of the target gap or separation.

And D = Distance from the observer's eye to the target.

Again, the non-dominant eye of each subject was covered with an eye patch since, at the actual altitudes which were simulated there would be no stereoscopic distance/depth cues. The study was also conducted in a laboratory darkroom.

The visual angles expressed in Table 2 assume that the targets were perpendicular to the observer's eye. However, the targets were actually perpendicular to the flare source. The incident angle for the observers' eyes varied from 39°8' for simulated 1,219 meter altitude to 81°6' for the simulated 152-meter altitude.

TABLE 2

VISUAL ANGLES AND SIMULATED AND ACTUAL DISTANCES BY EXPERIMENTAL CONDITIONS FOR EXPERIMENT III

CONDITION	VISUAL ANGLE (Min & Sec)	SIMULATED ALTITUDE (Meters)	ACTUAL ALTITUDE (Centimeters)	SIMULATED SLANT RANGES (Meters)	ACTUAL SLANT RANGES (Centimeters)
1	6'25"	152	15.25	1,027	103
2	6'12"	305	30.50	1,061	106
3	5'52"	457	45.75	1,114	112
4	5'31"	610	61.00	1,185	118
5	5'10"	762	76.25	1,270	127
6	4'50"	914	91.40	1,367	137
7	4'30"	1,067	106.75	1,473	147
9	4'8"	1,219	122.00	1,587	158

Procedure

The subjects were divided into 12 groups of 5 subjects each in Experiment I. Table 3 summarizes the conditions for each group of subjects.

TABLE 3

SUBJECT GROUP CONDITIONS FOR EXPERIMENT I

SUBJECT GROUP	NUMBER OF FLARES	IGNITION INTERVAL (SECONDS)	MODE	DISTANCE BETWEEN FLARES: ACTUAL (CENTIMETER)	DISTANCE BETWEEN FLARES: SIMULATED (METERS)
1	1	N/A	Shielded	N/A	N/A
2	1	N/A	Unshielded	N/A	N/A
3	2	20	Shielded	183	1,829
4	2	20	Unshielded	183	1,829
5	3	15	Shielded	137	1,372
6	3	15	Unshielded	137	1,372
7	4	12.5	Shielded	109	1,097
8	4	12.5	Unshielded	109	1,097
9	5	10	Shielded	91	914
10	5	10	Unshielded	91	914
11	6	5	Shielded	79	792
12	6	5	Unshielded	79	792

After initial screening and preliminary explanations, each subject was trained to identify the ten targets listed earlier. This was accomplished by repeatedly pointing the targets out on a smaller terrain model located in the subjects' preparatory room.

For consistency, during the experimental runs, the moving truck and sampan were always started from their respective starting points. The simulated flares were ignited at the different intervals, indicated in Table 3, to simulate a flare aircraft flying a track parallel to the simulated flight of the subject. Due to the high learning rate associated with the targets on the terrain model, each subject was used for only one experimental run.

Three types of data were recorded for each subject: total number of valid targets found; errors (i.e., identifying a truck when none was in the area); and time elapsed from ignition of the first flare to a subject's verbal response that he had detected, identified and located a target. Concerning this last variable, for any of the ten targets not detected during a run, the subject was given a response time score of 180 seconds since this was the shortest elapsed time for any of the flare conditions.

The procedure for Experiment II was similar to that for Experiment I, except two groups of 15 subjects each were established to correspond to the shielded and unshielded conditions. In addition, only two flares, placed 183 centimeters apart, were used. Concerning response times, for any of the seven targets not detected during a run, the subject was given a response time score of 300 seconds since this was the elapsed time for the 60,000,000-lumen flare.

In Experiment III, 40 subjects were used. The subjects were divided into eight groups with five subjects in each group. Each group was exposed to one observer altitude condition. In addition, all groups were exposed to the two types of targets (Landolt rings and acuity gratings) and the four brightness contrast conditions (Table 1).

After preliminary explanations and a trial run, each subject proceeded with the task of determining the position of the gap in the case of the Landolt ring or determining the orientation of the acuity grating. The order of presentation for the target and brightness contrast combinations was random. Between sessions, the subject wore opaque goggles to promote dark adaptation and also to prevent seeing target placements. The data recorded for analysis consisted of the time elapsed from ignition of the flare to a subject's correct verbal response concerning the gap of the Landolt ring or orientation of the acuity grating. If a subject was unable to determine the orientation of a target, he was given a response-time score of 180 seconds, since that was the duration of the burn time of the single simulated flare.

Design

In Experiment I, for number of targets and errors, the experimental design was a 2 x 6 factorial. The first factor refers to shielded versus unshielded modes (two levels) and the second factor refers to number of flares (six levels). For the response-time scores, the design was a 2 x 6 x 10 factorial with repeated measures on the last factor which refers to targets (ten levels).

In Experiment II, for number of targets and errors, the statistical design was a *t*-test with 15 subjects in each of the two groups (shielded flares and unshielded flares). For the response time scores, the design was a 2 x 7 factorial with repeated measures on the second factor which refers to targets (seven levels).

In Experiment III, the experimental design was an 8 x 2 x 4 factorial with repeated measures on the last two factors. The first factor refers to observer altitude (eight levels), the second factor refers to type of target (Landolt ring or acuity grating), and the third factor refers to brightness contrast (four levels).

RESULTS

Experiment I

The descriptive results consisting of overall means for the effects due to shielding Mark 24s are summarized in Table 4.

TABLE 4

OVERALL MEANS FOR SHIELDING VERSUS NON-SHIELDING MARK 24s

	SHIELDED FLARES	UNSHIELDED FLARES
Targets Found	6.93	7.13
Error	.77	.80
Response Time (Seconds)	97.62	97.65

In terms of overall grand means for the entire experiment, the average subject acquired about 7 (7.03) targets, took about 98 (97.64) seconds to find an average target, and committed about .8 (.83) error during an average run. The mean response-time score is very close to the overall mean (91.4 seconds) for Mark 24 flare light obtained from an earlier study[8] involving much more austere methods. None of the three variables revealed any statistically significant effects due to the flare shielding versus the non-shielding. Further, for the data consisting of number of targets acquired, there were no statistically significant effects at all. For the response time data, Table 5 reveals a statistically significant main effect due to type of target and also a significant interaction between type of target and number of flares used. These results necessitated the search for the simple main effects of number of flares for each type of target and this analysis is summarized in Table 6, which reveals that only the village, the moving sampan, and the parked truck contributed statistically significant main effects. For this reason, these three types were the only targets used in Experiment II. The zero mean square for the anti-aircraft site is attributed to the fact that it was not detected by any of the subjects in any group. The Newman Keuls tests for differences on all ordered means for the three main effects generally showed that performance with just one flare is significantly poorer than with two or more flares, but that increasing the number of flares above two does not increase visual performance for the type of target layouts used in the experiment. The data consisting of errors also revealed a statistically significant effect due to number of flares used.

TABLE 5

SUMMARY OF ANALYSIS OF VARIANCE FOR RESPONSE TIME SCORES FOR EXPERIMENT I

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F
Between Subjects	101,118.900	59		
A (Shielding)	0	1		
B (No. of Flares)	7,012.000	5	1,402.400	
AB	10,643.400	5	2,128.180	
Subj w/groups	83,463.500	48	1,738.820	
Within Subjects	2,376,134.100	540		
C (Target)	1,629,618.400	9	181,068.711	150.37**
AC	10,850.400	9	1,205.600	1.00
BC	154,050.500	45	3,423.344	2.84**
ABC	61,412.700	45	1,364.727	1.13
C X Subj w/groups	520,202.100	432	1,204.172	

** $p < .01$

TABLE 6

SUMMARY OF ANALYSIS OF SIMPLE EFFECTS OF NUMBER OF FLARES FOR DIFFERENT TARGETS FOR EXPERIMENT I

SOURCE	SUMS OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARES	F
B for C_1 (River)	2,427.600	9	269.733	
B for C_2 (Road)	1,541.483	9	171.276	
B for C_3 (Village)	23,100.740	9	2,566.749	2.13*
B for C_4 (Bridge)	10,387.490	9	1,154.166	
B for C_5 (Paddy)	5,906.000	9	656.222	
B for C_6 (Moving Truck)	8,941.400	9	993.489	
B for C_7 (Moving Sampan)	69,719.490	9	7,746.610	6.43**
B for C_8 (Parked Truck)	25,393.090	9	2,821.454	2.34*
B for C_9 (Moored Sampan)	13,645.150	9	1,516.128	1.26
B for C_{10} (Anti-Aircraft)	0.0	9	0.0	
C X Subj w/groups	520,202.100	432	1,204.172	

* $p < .05$ ** $p < .01$

Experiment II

Since the target problems presented to the subjects were considerably more difficult and it was hoped, more sensitive, than those presented in Experiment I, the results from Experiment II are not comparable, for example, with the results in Table 4. For the shielded condition, the average subject acquired 4.13 targets, took 171.77 seconds to find an average target and committed 1.27 errors. For the unshielded condition, the average subject acquired 4.07 targets, took 181.15 seconds to find an average target and committed 1.93 errors. Statistical t-tests for the targets found and errors and the analysis of variance for the response time scores revealed no statistically significant differences due to the shielding versus unshielded condition for the 60,000,000-lumen flare.

Experiment III

Table 7 shows that considerable response time variability was found between different simulated altitudes. Table 8 shows the summary of the analysis of variance for these data.

TABLE 7

OVERALL MEAN RESPONSE TIMES BY SIMULATED ALTITUDE FOR EXPERIMENT III

SIMULATED ALTITUDE (METERS)	MEAN RESPONSE TIME (SECONDS)
152	69.49
305	29.96
457	31.74
610	5.92
762	11.41
914	8.90
1,067	30.24
1,219	35.75

TABLE 8

SUMMARY OF ANALYSIS OF VARIANCE FOR RESPONSE TIMES FOR EXPERIMENT III

SOURCE OF VARIATION	SOURCE OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F RATIO
Between Subjects	221,956.31	39		
A (Altitude)	117,305.30	7	16,757.90	5.12***
Subj w/Groups	104,651.01	32	3,270.34	
Within Subjects	523,150.82	280		
B (Type of Target)	4,125.63	1	4,125.63	12.23***
AB	6,910.64	7	987.23	2.93**
B X Subj w/Groups	10,793.63	32	337.30	
C (Brightness Contrast)	143,125.33	3	47,708.44	23.53***
AC	78,832.68	21	3,753.94	2.24***
C X Subj w/Groups	160,528.[illegible]	96	1,672.17	
BC	5,226.04	3	1,742.01	1.89
ABC	25,339.90	21	1,206.66	1.31
BC X Subj w/Groups	88,288.69	96	[illegible]	

** p < .05   *** p < .01

From the analysis of variance for response times, Table 8, the statistical hypothesis that there are no significant differences in response times among the eight groups is not tenable at the .01 level of confidence. The Duncan's New Multiple Range Test[15], at the .10 level of confidence indicated the results summarized in Table 9. In this table an asterisk indicates a statistically significant difference.

TABLE 9

SUMMARY OF STATISTICAL TESTS ON ALL ORDERED PAIRS OF MEANS FOR EXPERIMENT III

SIMULATED ALTITUDE	(METERS)	610	914	762	305	1,067	457	1,219	152
	MEANS	5.920	8.20	11.41	29.96	30.24	31.74	[illegible]	69.49
610					*	*	*	*	*
914								*	*
762								*	*
305									*
1,067									*
457									*
1,219									*

* p < .10

Also, from the analysis of variance for response times, Table 8, the statistical hypothesis that there are no significant differences in response times due to type of target is not tenable at the .01 level of confidence. Rather, the data tend to indicate that the acuity gratings required significantly longer times than the Landolt rings. In addition, the statistical hypothesis that there are no significant differences in response times due to brightness contrast levels is also not tenable at the .01 level of confidence. The Duncan's New Multiple Range test at the .01 level of confidence indicated that brightness contrasts of 64 and 74 percent were associated with shorter response times than the contrasts of 20 and -200 percent. However, neither of these pairs was significantly different from one another. Finally, there was a statistically significant interaction between altitude and type of target at the .05 level of confidence and an interaction between altitude and brightness contrasts at the .01 level.

DISCUSSION

That there were no statistically significant differences due to simulated flare shielding was somewhat surprising. However, there are several other factors concerning shielding other than those involving the dependent variables used in this experiment. For example, the visual performance in this study was restricted to that associated with area search for targets of opportunity. Also, though the shield may not enhance visual performance for this type of tactical task, it will prevent illumination of the aircraft from the flare, an important consideration. An earlier study[9] indicated that the full benefit of flare shielding may not be realized until the candlepower of the flare reaches 60,000,000 lumens. Therefore, the results from Experiment III which also revealed that there was no statistically significant main effect due to flare shielding constituted a further surprise.

The results concerning number of flares are in close agreement with our earlier study[15] which disclosed no significant differences in performance when simulated .4, .8, 1.2, and 1.6 kilometer separations between flares were used. Discounting flare failure rates and other tactical maneuvers, there is no rationale for igniting more than two flares over a target area represented by the scaled-size and target features of the terrain model utilized in the experiment.

The differences attributed to type of target were anticipated. In Experiment I, most subjects detected and identified the road and river within a few seconds while the anti-aircraft site was never detected. However, for this experiment, the important targets were those which provided variability for the different experimental factors. The village, the parked truck and the moving sampan were the targets associated with this variability. For this reason, emphasis was given to these types of targets in Experiment II. That no subject detected the anti-aircraft site was not a total surprise, since Southeast Asia returnees reported that these sites are seldom detected unless they are firing.

It is apparent from Tables 7 and 8 that for the slant range angles of this study, observer altitudes in the range of 610 to 914 meters are superior to other altitudes. Specifically, while 610 meters did not result in significantly different performances from 762 and 914 meters, the 610 meter altitude was the only one significantly better than all of the other altitude conditions. This problem now awaits field validation via an in-flight study. It is evident from the results from Experiment III that these acuity targets (1,000 times larger), placed on a controlled ground point will provide reasonable criterion measures for the inflight validation.

However, it was surprising that the acuity gratings generally were associated with poorer performance than the Landolt rings. Riggs[16] reports that in the case of acuity gratings, each single element (i.e., a single line) of the grating pattern would be clearly identifiable if it were presented alone. However, the presence of contours (i.e., other lines) makes it difficult for the observer to discriminate the separate elements of the pattern. It is reasonable to assume that even with the Landolt ring gap equal to the separation width between the grating bars, the two targets do not necessarily present the same level of difficulty in discriminating performance. In addition, Shlaer[16] found that two functions resulting from the use of these two targets to be quite dissimilar, with the Landolt ring resulting in higher visual acuity with increases in illumination. However, he concluded that both are admissable measures of visual performance.

Since visual acuity appears to be a form of brightness discrimination,[16] the significant main effect due to brightness contrast bears some importance. The results of this main effect were anticipated except for the relatively poor performance in the condition where the target was brighter than the background (BC = -200 percent). However, the general reflectances from these target/background combinations were quite low (See Table 1). In addition, traditional empirical data have shown that, for dark objects on a bright background, acuity is maximal for the highest degree of contrast between test object and background.[16] The converse may not necessarily be true.

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DISCUSSION

Major Perry (UK)

A comment, really, from some unpublished UK results of practical operational interest. We used 3 different gun-fired or air-dropped light sources, and helicopters going down range looking for tanks. Prime data were detection ranges as they varied with 3 light sources, from 3 million candle power at 4,000 feet to artillery star shells.

Surprisingly, the smallest source, the star shell, proved to be best, while the high powered high level source was reduced in value by all sorts of factors such as colour and area of terrain covered.

Major Hilgendorf (US)

Individual light source variability is of great importance here. Based on a University of Denver study, it can be concluded that to see most of the targets which our personnel in South East Asia are seeing would require a flare of about 115 million candle power a few feet off the ground! The standard flare produces only 0.2 foot candle at 1000 feet altitude, about 100 times more than moonlight in fact. Clearly our model data are deficient here.

AIR TO GROUND TARGET ACQUISITION

by

Robert W.Bailey, Colonel, MSC, Commanding Officer,
US Army Aeromedical Research Laboratory,
Fort Rucker, Alabama 36360

It has been our experience in the application of aviation medicine research that many systems (including the aircraft) are operator limited, both by task loading placed upon the crewmember and an inadequate interface between the operator and his machine. In addition to problems between man and his flying machine there are increasing demands on man's perceptual and motor capabilities when this task of flying from A to B is complicated by a visual target acquisition and weapon delivery application task. These weapons are always employed in a high threat environment and invariably require flight profiles that are unforgiving if the pilot fails to perform all his tasks effectively, accurately and expediently.

In an effort to make a portion of this task easier and to reduce the task loading a method for visually coupling the pilot to his weapon system has been in the research and development stage for over a decade. The advantages of such a system are that it should allow complete hands free direction of weapons system, a heads-up display, feedback from firing and displays to null out pointing errors, wide field of fire limited only to weapons system flexibility for "off-axis" targets and most important very rapid target acquisition while using the natural perceptual and control abilities of the operator. The research and development funding by US Army, Air Force and Navy for such a system has been considerable and it has resulted in operational hardware. In spite of these achievements there are unresolved hardware problems, e.g., reticule design and helmet coordinate control that require considerable engineering improvement to reduce cost, complexity, safety and efficiency. It is my purpose today to present to you some of the biomedical problems with the helmet mounted sight and visual target acquisition system that are unresolved. There are biomedical problems, for which assistance is unsolicited, but are the basis of deficiencies in the man/machine interface that still exists with these systems. For example, so far in this helmet sight technology head movement only has been measured and used for control, when in fact man uses his head and eyes together in almost equal amounts to perform a natural target acquisition task. Current systems force the man to employ an unnatural tracking task (using only the head) in a vibrating, bouncing aircraft that during turns or evasive maneuvers may produce sufficient G loading on the head and neck to physically restrict or prevent this necessary head movement. Although analogies are dangerous it is my impression that an analogous psychomotor task would be to tune one's television set by using only the elbow. In both of these situations only gross muscle groups are employed and the degree of difficulty and resultant accuracy are physiologically comparable. Hughes and Nicholson[23, 33] reported a pointing accuracy of 1° using this technique in the quiet laboratory environment and 2.0° average error during in-flight testing[33]. This sighting was within a 12° zone (6° either side of the longitudinal axis of the aircraft); the doubling of errors in flight were attributed to mild turbulence. When the target is presented as a moving target, degradation of accuracy is relatively small at velocities up to 8 degrees per second. Nevertheless, a target moving at a l`ne normal to the longitudinal axis of the aircraft at 8 degrees per second increases the sighting error by a factor of 4 as compared to a stationary target. At 25 degrees per second the error is again doubled[33]. Perhaps one physiological reason for this increase in error can be found in the work of Sugie and Wakakuwa. Their studies revealed that although target fixation is accomplished by a combination of head and eye movements the visual tracking of a target tends to be independent of head movement. In the case of the helmet mounted reticule this complication to normal tracking is also degraded further by the vestibulo-ocular reflex. This reflex tends to null the system so that head motions automatically result in a compensatory eye movement to keep the fixated target stationary. To successfully operate the current design of helmet sight, that eliminates eye movements as a part of the control system, it is necessary to overcome this non-linear reflex function. This is not always possible and therefore may produce disassociation between the sight system and observer.

A controversial and yet unresolved visual problem associated with current models of helmet mounted sights is the potential effect of such an optical device upon a depth and spatial perception. Current models of the helmet mounted sight, or visual target acquisition system use a semi-silvered mirror mounted on front of either the right or left eye to receive the collimated reticule image. This results in differences in retinal illuminance between the two eyes. Pulfrich first reported in 1921 that distortions in space perception are introduced when a stimulus object is in motion relative to a fixed field and viewed binocularly with one eye darkened by a filter, or if one eye is illuminated more than the other by veiling glare. Munster in 1941 discovered that an object in motion was not necessary, but rather space shifted about a vertical axis. This was confirmed by Cibis and Haber in 1951, and Ogle in 1952. This steroscopic effect of the rotation of space about a vertical axis in the objective fronto-parallel plane can be detrimental to flight safety and mission accomplishment. Lit (1959) conducted research to determine the effect of illuminance level on this phenomena and reported the effect to be large at low illuminance levels and decreasing as illuminance levels are increased.

The attachment of the helmet mounted sight components to the helmet is a third source of bioengineering concern along with the total weight of the helmet. This is no new problem and historically appears to have been empirically studied by German Aviation Medicine Specialists in World War II. The conclusion reached is quoted as follows, "One of the parameters of head protection, which is physiologically most important especially with regard to accelerations, is to limit weight of the helmet to about 1 Kg, or 20 percent of the weight of the head". Deceleration research on cadavers by Haley and Turnbow reported a severe displacement of the fifth cervical vertebra during a test of the Army APH-5 weighing about 4 pounds (1.8 K). It was their opinion that, "a single decelerative pulse at a level of 40 G for 0.10 seconds would cause irreversible injury to the cervical spine if a 4 pound helmet was worn". Work done by a joint effort between the Naval Aerospace Medical Research Laboratory and USAARL have caused us to also be concerned about the centre of mass of the helmet and its relationship to the center of mass of the head. Briefly our data, using live human volunteer subjects, revealed that a 9 G deceleration pulse measured at the seat at time of impact was amplified to 12 G at the cervical-thoracic junction, 18 G at the bregma and over 36 G at an accelerometer mounted on a bite bar at the subject's mouth. Therefore our medical position is to restrict total helmet weight to a maximum of 3.5 pounds. Mounting of the sight upon the helmet can also destroy the load distribution capability of the outer shell.

What can be done to eliminate these bad features of current helmet mounted sights?

(a) First two techniques can be employed to reduce weight and potential Pulfrich phenomena complications. A technique for projecting from a light emitting diode to a very small (1.5 mm diameter) semi-silvered mirror attached to the visor has been produced. If this technique is considered operationally unsatisfactory a parabolic visor with similar collimated lens and light emitting diode can be used to present the reticule. This also solves the weight problem as well as spatial distortion since such a system weighs only an ounce.

(b) Ultrasonic techniques can be employed to sense helmet movement rather than current systems using filtered light or hardware linkage to measure the positional relationships between helmet and the aircraft. Ultrasonic surveys of current helicopters reveal no appreciable amount of ultrasonic noise in the helicopter cockpit.

(c) These corrections do not resolve the elimination of eye movements from the system. Therefore, one should not expect point target accuracy for such a system, but rather expect to use such a system primarily for target acquisition. The helmet mounted sight slaved to a stabilized optical sight combined with a weapons system is an ideal system for a pilot to handoff a target to the co-pilot/gunner, or vice versa. This system can also be seriously degraded when nearby targets are passing at high angular rates. For area weapons systems the helmet mounted sight is a fine system for acquisition and fire control. After firing is initiated and observed the system becomes a closed loop system and a better chance for direct hits is possible.

In summary, the current helmet mounted sights offer an ideal method for man/machine interface and currently offer certain advantages; they can be improved, but in any event they should be employed with full knowledge of their biomedical deficiencies.

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DISCUSSION

Major Hilgendorf (US)

Would Colonel Bailey give us a global, off-the-cuff judgement as to whether the helmet-mounted device is really going to become operational?

Colonel Bailey (US)

It is operational now. What makes it successful is our use of it with a stabilised optical sight, a fine piece of optical engineering, the SOS system. It has some human factors problems still, like switches being in reversed sense, but once on target it is a fine system.

My concern is the system accuracies people are trying to specify and design in, to enable, theoretically, first hits at long ranges. I just do not think it is physiologically possible to achieve that. Used in conjunction with other systems, it offers tremendous advantages. I am certainly not shooting down the concept, however, but merely emphasising the biotechnological constraints on its use.

A DESIGN CONCEPT FOR A DUAL HELICOPTER NIGHT SCOUT SYSTEM

William J. Kenneally - Electronic Engineer

US Army Electronics Command
Avionics Laboratory
Fort Monmouth, New Jersey 07703

SUMMARY

Limited but promising operational experience with helicopter borne-night vision systems (both low light level TV and forward looking infrared) has spurred an interest in the application of night vision technology to second generation airborne systems. The limited quantitative performance data on these first generation systems, coupled with the significant advances in night vision technology made during the intervening period, place severe restrictions on the system designer attempting to make logical system tradeoffs. The scope of the paper is to examine various relevant data on the subject and to develop a design concept for such a second generation scout system.

INTRODUCTION

The limited but conceptually proven capability of airmobile scout helicopters to operate in periods of darkness has fostered considerable interest in extending this capability to the mid-intensity[8] battlefield. The basic problem is that of establishing a conceptual design of such a scout helicopter system that will accomplish the tactical mission of mobile target detection, recognition, and identification.

The major distinction between these earlier efforts and the proposed advanced design task is that the emphasis in these first generation systems was on fielding the best system available within severe constraints of time and possible aircraft modifications. Since these early systems, rather significant advances have been made in increasing night-vision device capability (range, resolution) while reducing the size and weight. Additionally, rather significant increases in predicted MTBF have been achieved. In short, the system designer has available to him considerable design freedom in specifying desired night vision sensor characteristics. The question then is how to accomplish equivalent system level tradeoffs with respect to other aspects of the problem (e. g. installed weight, endurance, type crew compartment, stabilization requirements, navigation/sensor integration, etc.).

Tactical Context

To bound the scope of this paper we shall confine our interest to that of real-time self-contained battlefield reconnaissance systems. Specifically, we are concerned with the detection, recognition, identification, and position fixing of mobile targets (tanks, personnel carriers, support vehicles, and troops) in a fluid mid-intensity battlefield environment. Conceptually, since the scout helicopter will be lift capability restricted with respect to ordnance (with possibly a mini-gun for some[9] suppressive fire capability) it is reasonable to expect that following target recognition and location the scout would call in interdictive fire. However, the scope of this paper will be restricted to the initial and more difficult problem of target detection, recognition, and identification.

Baseline Aerial Vehicle

As a point of departure for our design synthesis we shall start with the concept of extending the capability of the existing light observation helicopter from that of clear day operations into the required conditions of reduced visibility. While one might argue that this is a rather non-systematic approach to a conceptual design problem, one must also recognize the practical impetus of upgrading existing observation helicopters rather than starting from a more idealized base and then requiring development of a totally new airframe.

For purposes of design orientation, a set of specifications for a nominal observation helicopter has been developed by the simple expedient of averaging the respective statistics for both the OH-6A and the OH-58, the US Army's current light observation helicopters. While these averaged performance characteristics are not really representative of either aircraft, they are certainly representative of the class of vehicles of interest. Table 1 lists relevant characteristics.

Baseline Sensor Characteristics

While there are a number of different design options with respect to target surveillance sensors, our interest is specifically restricted to passive electro-optical sensors (E-O) (low light level TV and forward looking infrared). This does not mean that active devices, operating at either radar or optical frequencies, are considered inappropriate for the task but that we simply prefer the passive systems for tactical reasons. Prior to specifying E-O system performance values it is appropriate to consider how the E-O system and its carrier vehicle interact in a fundamental manner. Figure 1 illustrates the basic sensor/vehicle geometry.

While a very simplified overview of the system geometry, Figure 1 does allow us to begin to identify the categories in which design tradeoffs are usually accomplished. Specifically, the E-O equipment designer is predominately concerned with the characteristics of the E-O device i. e. range, elevation

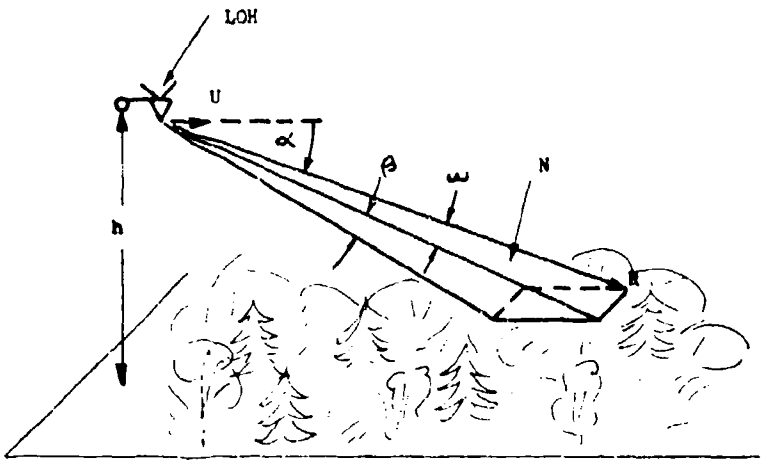

Figure 1. Basic Scout Helicopter Electro-Optical Sensor Geometry

Figures

N - Resolution Elements
U - Airspeed (kts.)
h - Altitude (ft.)
R - Range (ft.)
α - E-O Sensor Depression Angle (deg)
β - Elevation FOV (deg)
ω - Azimuth FOV (deg)

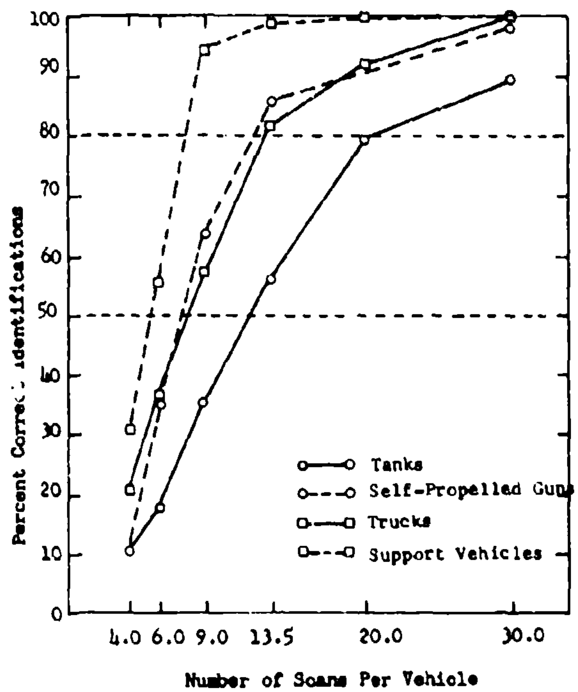

Figure 2. Average Percentage of Correct Identifications for Each Vehicle Class as a Function of the Number of Scans per Vehicle (angles of view combined). (Reference 2)

Cruise Speed	117 kts.
Endurance	2.3 hrs.
Empty Aircraft	2475 lbs.
Crew	400 lbs.
Fuel	425 lbs.
Sensor Payload	450 lbs.
Aircraft Max.	3750 lbs.

Table 1 - Design Point for Night Scout System

<u>Atmosphere</u>

Aerosol Content
Cloud Cover
Illumination Level

<u>Sensor</u>

Bandwidth
Number of Scan Lines
Field of View
Field/Frame Rate
Aspect Ratio
S/N Level
Integration Time

<u>Image Processing</u>

Edge Enhancement
Gamma
Spatial Filtering

<u>Scene</u>

Target Characteristics
Background Characteristics
Terrain Masking
Clutter Level

<u>Display</u>

Luminance
Size
Number of Scan Lines
Contrast
Scene Movement
Dynamic Range
Gamma
S/N Level
Aspect Ratio

Table 2 - Some of the Variables Affecting Information Extraction Performance

and azimuth field of view, and resolution, display size, etc. Correspondingly, the tactical user is predominately concerned with selecting the altitude, airspeed, and sensor depression angle. Hence we have an immediate and direct interaction that in many cases is counterproductive. The specification of E-O device characteristics tends to be driven by technological capability, while the tactical considerations are bounded by such factors as the flight-safety aspects of operating on the front side of the power curve, and operating at a safe night altitude. Hence it is quite possible to have optimal performance (E-O device and flight conditions) of subsystems and yet obtain system performance which is significantly less than optimal. This interaction will be defined more fully in subsequent sections of the paper.

Partitioning of Man/Machine Problem

With this brief look at the interaction of the sensor and the sensor carrier it is now worthwhile to turn our attention to what is probably the key aspect of a successful system design - the interface between the surveillance operator and the surveillance system. As an aid in the further bounding of the problem we shall follow the lead of Biberman et al (Reference 1).

> Two main sets of factors govern the performance of man and his low-light-level viewing aids. The first is well understood and includes the physics of light, optics, solid-state materials, and engineering approaches to the design of photoelectronic devices. The second set is related to the less well-known factors of psychophysics and vision and the interrelation between visual tasks, and quality of the image, the time available, and other subjective matters affecting the observer and his task.

Table 2 identifies some of the variables that can have an effect on the ability of the observer to extract the signal from the noise. Inspection of the number and diversity of the variables in Table 2 provides one with a quick index of the complexity of the problem of specifying an E-O system design. The problem at this stage is to identify the key variables and to initiate a preliminary design based on this smaller and hence more manageable set of design variables. The remaining variables can then be treated as modifiers of the specified system's performance.

Other considerations aside, the single most important characteristic of the E-O system is that a sufficient number of spatial samples of the target be obtained by the sensor. Hence our first task in the preliminary design synthesis is to determine the number of spatial samples required to detect, recognize, and identify targets.

A recent survey of available data on target identification (Reference 2) summarized the results of several earlier studies. Figure 2 shows the number of TV lines (scans) versus percent correct identifications. The conclusion of that study was that on the order of twenty TV lines/vehicle are required for identification. While the absolute use of this number of twenty TV lines for identification is probably not warranted, we can use it as an index of one condition that must be satisfied to obtain target identification.

Concept of Surveillance "Footprint"

Figure 3 defines the sensor "footprint" more explicitly. It is assumed that the sensor down-look angle, α is adjusted so that the maximum range, Rmax, of the E-O device just intercepts the terrain. R intercept is then defined by the maximum look-down angle, ($\alpha + \beta$), and altitude (h). The sensor "footprint" (lines/ground dimension) can be calculated in the following way:

$$(1) \quad \frac{N}{\Delta G} = \frac{N'}{\left[R_{MAX}^2 - h^2 \right]^{1/2} - \dfrac{h}{\tan(\alpha + \beta)}}$$

If the visual feature extraction task (detection, recognition, or identification) is specified in terms of equivalent lines/target dimension then it is convenient to normalize the equation by letting $K = \frac{N}{\Delta D}$ where

K_1 = detection

K_2 = recognition

K_3 = identification

Since α is fixed for a given maximum sensor range, Rmax, and operating altitude (h) the design variable of interest is that of elevation field of view β.

Equation (1) allows one to calculate the vertical field of view as a function of the other parameters specified.

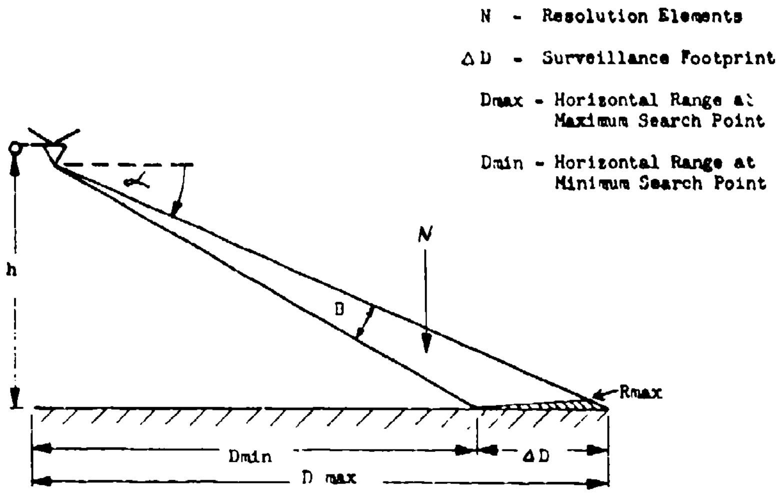

Figure 3. Concept of Surveillance "Footprint"

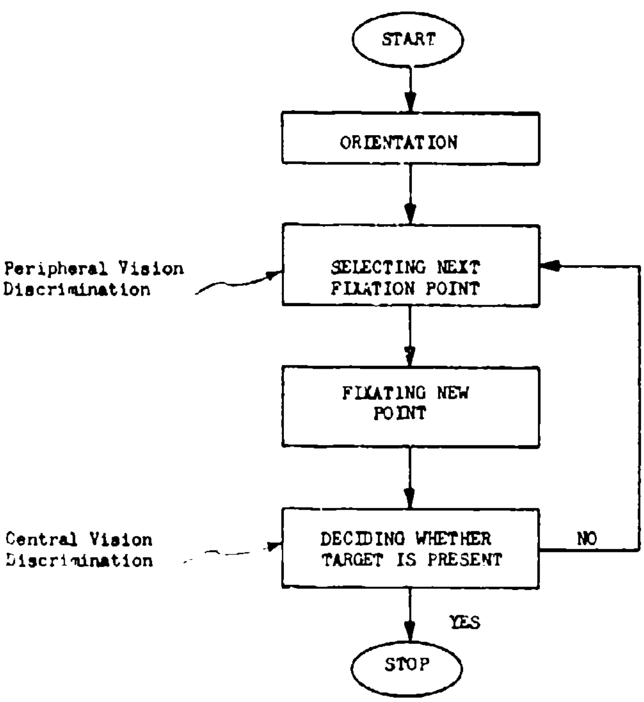

Figure 4. Flow Diagram of the Search Process (From Reference 4)

For representative values we can specify a point of departure for further design iteration.

Assumed Values	Calculated Values
$h = 1500$	$\alpha = 15^\circ$
$R_{max} = 6000'$	
$N = 1000$ TV lines	
$k_3 = 1$ TV line/target ft. (identification)	$\theta = 1^\circ$

For simplicity of discussion we shall assume that vertical FOV equals horizontal FOV. Hence our initial system concept consists of an E-O system with the following characteristics: FOV $1^\circ \times 1^\circ$, resolution 1000 lines, maximum range 6000', flown at an altitude of 1500' with a look-down angle of 15°.

Cockpit Display Considerations

The next step in our design synthesis is that of E-O display specification. We shall adopt a rather conservative estimate of the observer's visual acquity in the helicopter environment as being 20 arc minutes (Reference 3). Assuming a representative eye to panel distance of 30 inches the required size is approximately 9 inches. This calculation is based on the combination of system resolution and minimum resolution requirements.

For $N = 1000$, and the case of target identification (approximately twenty TV lines) then the system can resolve 1000/20 = "50 targets". Then the required display is approximately 50 x 0.18" = (9.0 inches) which is a very practical size for a helicopter mounted CRT display.

Observer Display Search Time

Our preliminary design has now progressed to the point where we can consider it as a baseline E-O concept. It is appropriate to inquire at this stage as to the interaction of tactical operations on the system effectiveness. Given that the image size is such that the observer can readily detect the target if contrast and brightness are at appropriate levels, the next question is that of the time the observer has to search the target.

Reference 4 reports the results of a series of carefully controlled laboratory experiments in target search during which eye motion was tracked by means of a remote camera oculometer system. Based on these experiments the flow diagram shown in Figure 4 of the search process was offered. A significant result of the study was the determination (from the recorded oculometer data) of the relative fixation rate as a function of false target size relative to the actual target size. A cumulative distribution function of fixation time is shown in Figure 5. Search time can be calculated if we can determine the number of objects or points that will be fixated each second and the relative fixation rates for the objects on the display.

In a structured laboratory experiment in which "false target" size can be controlled the relative fixation rate can be measured and hence search time can be computed as a direct consequence of the numbers of different size "targets". In the case of a typically cluttered E-O display, however, we cannot know the distribution so we must resort to the simple concept of assuming that the observer searches the total display in a number of glimpses. Reference 5 develops a rather extensive mathematical model to predict probability of detection of a target on a two-dimension display. A key element of this model is the concept of scanning the display in a number of glances, each glance subtending an angle of four degrees. This study used an estimate of 1/3 of a second for fixation. However, a better value can be obtained from Reference 4 in which scanning time was experimentally measured. Figure 5 presents the results of these measurements. Based on this data we have elected to use a fixation interval of 500 millisec as a reasonable estimate for the target search fixation time for a four degree visual cone.

Now the display specified earlier subtends a visual angle of approximately 18° in both elevation and azimuth. Hence it requires approximately 20 glimpses to cover the display. At 500 milliseconds per glimpse it will take a minimum time of 10 seconds for display search. It should be recognized that this value corresponds to a minimum time for search since it assumes that the S/N on the display is such that a target will be readily detected as a target if that section of the display is searched. In many cases this condition will not be satisfied and hence a number of glimpses will be required.

Reference 1 reports the results of an experiment in which controlled targets (series of rectangles of different sizes) were systematically mixed with band-limited white noise and displayed on an 8 inch monitor 28 inches from the observers eye. "Target sizes" corresponded to typical sizes for real tactical targets on a similar display. Hence extrapolation to the Night Scout helicopter design concept is quite valid. Figure 6 presents the results of the experiment in terms of the cumulative probability of detection versus the display signal-to-noise ratio. From the standpoint of system specification then it is assumed that the display SNR is greater than 5.

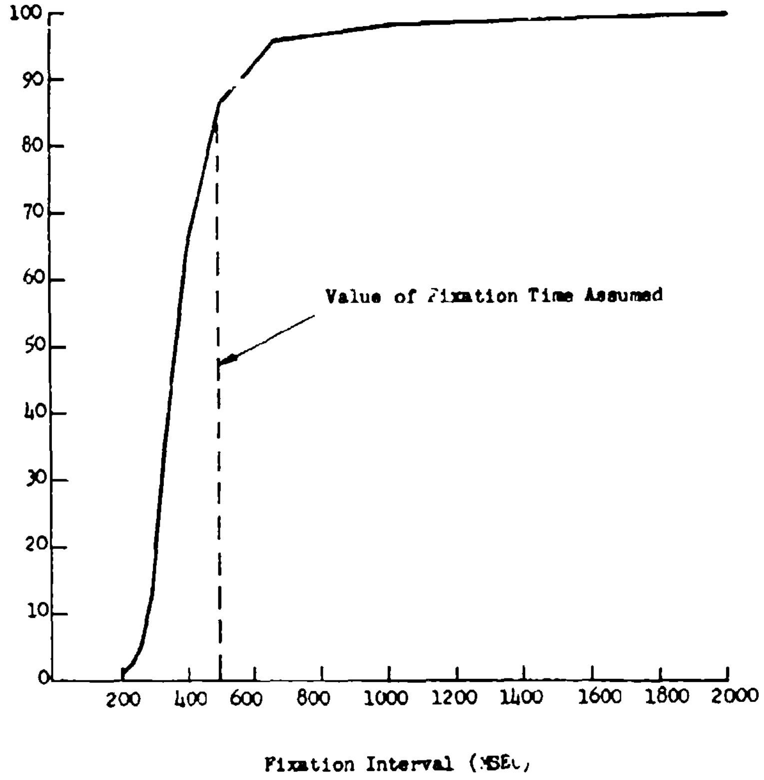

Figure 5. CDF of Fixation Interval (Data from Ref. 6)

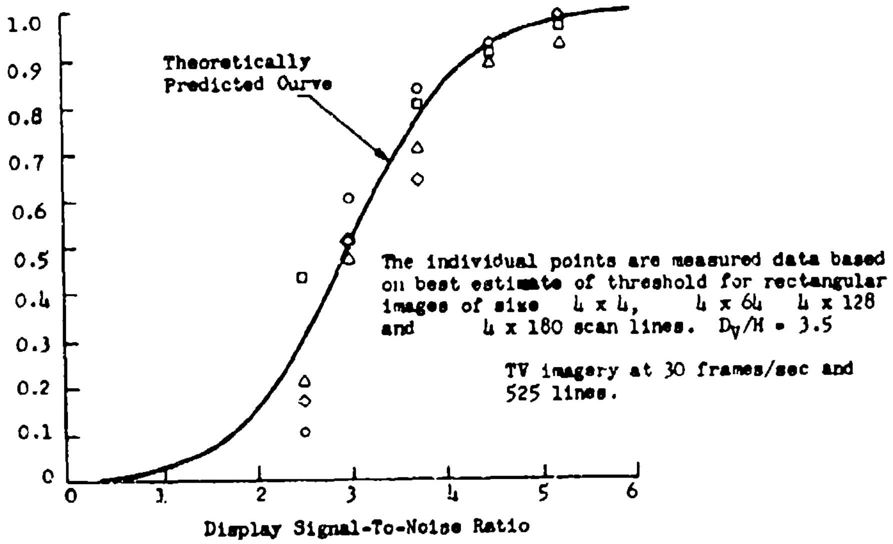

Figure 6. Measured and Predicted Probability of Detection (Data from Reference 1)

Reference 6 established an exponential model for search time as a function of target single glance probability of detection and display area which is more representative of the actual case. However, as we are interested in establishing bounds on performance, we have assumed $P_D = 1/P_G$. That is, the probability of detection is one - given that the area is searched. The generalised model is given in equation 2. $P_{(t)}$ is the probability of detection as a function of scanning time, P_D is the probability of detection for a visual cone of four degrees, t is the time of search, and A is the display area in degrees squared.

$$(2) \quad P_{(t)} = 1 - \left[\exp - \frac{156 P_D}{A} t\right]$$

Effect of Aircraft Motion

To this point we have treated the image on the display as stationary. That of course is not the actual case. The time for the "image" or surveillance "footprint" to be traversed is simply

$$(3) \quad t_s = \frac{\Delta D}{u} = \frac{\left[R_{MAX}^2 - h^2\right]^{1/2} - \frac{h}{\tan(\alpha+\beta)}}{u}$$

for the system parameters outlined earlier. Setting the time available equation equal to the time for display search yields

$$u = \frac{\left[R_{MAX}^2 - h^2\right]^{1/2} - \frac{h}{\tan(\alpha+\beta)}}{n\, t_s}$$

For n = 1 (single glimpse at each element of display) and the system parameters outlined earlier u is approximately 50 kts which is an acceptable cruise speed for a light helicopter. It is important to note that the required speed is dependent on the number of glimpses required which is in turn dependent on both the physical size of the display and the single glimpse probability of detection. Hence a higher probability of detection will require lower airspeeds. This illustrates the E-O versus operational interaction noted earlier.

For the design concept outlined it is evident that some form of image stabilization is required. Image stabilization is concerned with both the elimination or at least the significant reduction of aircraft motion (both angular and translation) on the image. One approach would be to stabilize the turret sensor to insure that the line of sight is stabilized to a point on the ground during the target area search time.

Aircrew Considerations

Reference 7 identifies a number of environmental considerationsfor attack helicopters in a NATO environment. While not exactly a match for the night scout task it does provide insight into related task consideration; one particular area needs to be emphasized - that of dark adaption requirements for the flight crew.

The pilot, who is essentially concerned with either night VFR flight or IFR flight operations, will tend to operate in a dim-illuminated cockpit both to maintain his night vision adaptation as well as to minimize aircraft detection by ground elements.

The observer, on the other hand, is concerned with operating the display at a brightness level that maximizes probability of detection. In general, the brightness levels associated with maximizing the probability of detection are incompatible with the cockpit illumination levels desired/required by the pilot. Hence for our design concept the cockpit arrangement places the observer in the rear of the observation helicopter and hence is capable of being enshrouded to permit high illumination of the display scope without pilot interference. Figure 7 shows the general aircraft arrangement of our scout helicopter.

Summary of Preliminary Design Concept

Our point design night scout helicopter can be summarized as follows:

Field of View	$1^\circ \times 1^\circ$ (for identification) $6^\circ \times 6^\circ$ for detection
Stabilization	Motion and line of sight stabilization
Resolution	1000 line
Display	Approximately 9 x 9 inch panel mounted CRT
Signal/Noise Display	5

Operational Effectivity

Given our scout point design the task is to determine its relative tactical effectivity as an aid in measuring the relative worth of possible design alternatives. One such index is area searched/unit time. For the parameters outlined earlier the proposed scout helicopter will be able to search approximately $30 km^2/hr$. This may be an unacceptably low search rate relative to tactical areas that need to be searched.

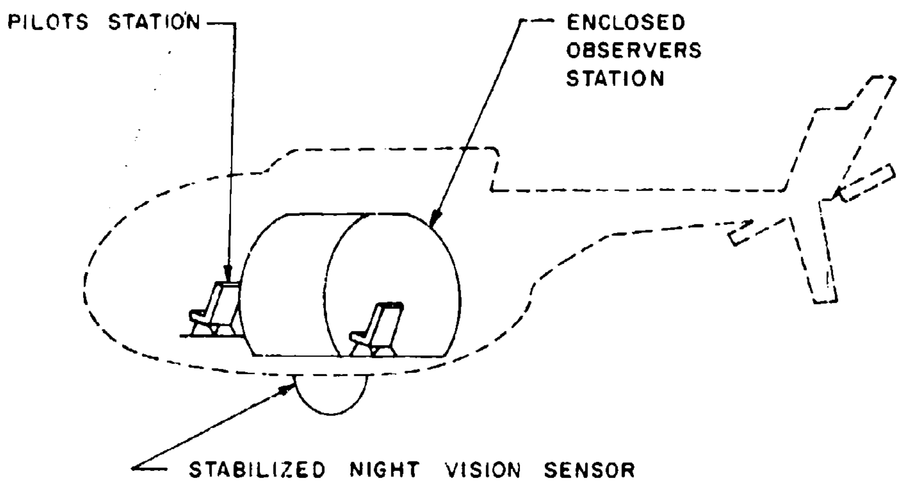

FIG. 7 NIGHT-SCOUT HELICOPTER — BASELINE CONFIGURATION

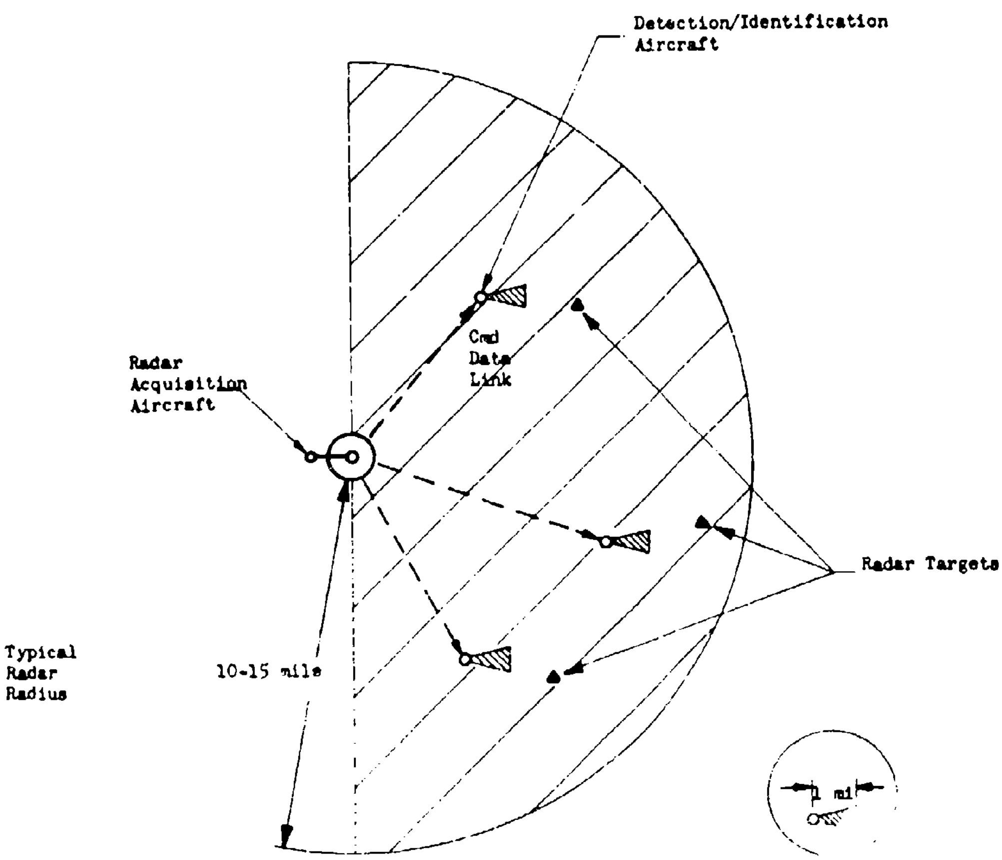

Figure 8. Dual Helicopter Control Concept
Acquisition & Detection/Identification

Design Optimization - Target Identification

In brief, our rather conservative design effort has resulted in a system conceptual design that essentially insures the capability to accomplish that most difficult of battlefield tasks - target identification. However, as a counterpoint to this significant capability is the potentially restricted area coverage identified earlier. The problem then is to devise a viable system concept that will enable us to maximize the capability of this scout system while providing for coverage of significantly larger areas of terrain.

Dual Sensor Concept

One such concept would be to add a long-range area coverage radar system to the Scout Helicopter. Such a system could conceptually provide a pointing or cueing capability to the more precise night vision system for subsequent target detection (in this case target handoff) followed by target identification.

Aircraft Lift Capabilities

Earlier in the paper the nominal capability of the type light observation helicopter was specified. Since we now have a design point for the nominal scout system it is possible to compare the required with the practicable to determine total system feasibility from an aircraft lift standpoint.

A reasonable weight estimate for the night scout system is as follows:

Night Vision Sensor	50 lb.
(NV) Stabilization System	150 lb.
Display	30 lb.
Navigation System (LOS Stab.)	50 lb.
Radar	250 lb.
Baseline Avionics	75 lb.
TOTAL	605 lb.

Comparison with the data in Table 1 indicates that the baseline system exceeds the available lift capability by a significant amount.

Alternative Approach - Dual Scout Concept

In fact, the representative hardware weight estimates for the combined radar-night vision system exceed that of the design point helicopter's lift capability and hence rules out the concept of a single aircraft system. There is however an alternative method for implementing the system concept in an aircraft compatible way. In short, there is no absolute need to make each scout helicopter totally self-sufficient since a more efficient solution is to use one longer range radar system to provide target data to one or more scout helicopters as shown in Figure 8. As indicated in Reference 9, the key to successful airmobile operations is the integration of the total capabilities of the Army rather than the development of single mission aircraft that accomplish all missions on a lone-ship basis.

Dual Scout Implementation

The use of the dual scout approach, while eliminating the problem of attempting to install all of the equipment in a single scout helicopter, does bring with it the additional constraints of a common and accurate navigation system, a data link, as well as a means for coordination of the total "system" as suggested in Figure 8. These additional constraints, however, are well within the state of the art and can be met with appropriate "system" level planning.

Conclusions

A design point study for a night scout helicopter has been completed. The interaction among tactical considerations and E-O system attributes have been identified. Finally, the search effectiveness for a nominal design has been calculated. Based on the limited area search capability forecase for the design point system, a concept for a dual helicopter system has been developed.

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DISCUSSION

Major Perry (UK)

What concrete evidence have you to state that ground vehicles will spot your helicopters before you see them? Secondly, you cannot really believe that the need to fly high is viable in North West Europe? You must stay down with the trees, as shown by the analysis we have of some 300 to 400 flying hours, including hours at night. Our findings are perhaps summed up by the word "Tactics", I suppose, and seem to prove you wrong.

Mr Kenneally (US)

I do have empirical data from Army tests, which I presume could be made available to you. Based on that data is our current design requirement for night scout helicopters. We would not invest all this expense in electronic systems for helicopters if it were not necessary.

Major Perry (UK)

Why not put your display against the real outside world, so the display content matches the real view? Perhaps a full-size real-life kind of Head-Up display is what I mean, although I know you are thinking mainly of TV. It would be a matter of turning brightnesses up and down to give a match.

Mr Kenneally (US)

People have looked at the idea of night vision displays on HUD, such as the 'night window'. The problem even with a zero-content TV screen is one of loss of dark vision, however. Then you need a good deal of space, and have to make some equipment trade to find it. An even bigger problem is the need to stabilise the equipment to look at a point, given the bumpy aircraft ride.

GENERAL DISCUSSION

Dr Huddleston (UK)

Before opening the general discussion, I first want to give Dr Bloomfield time to complete an answer, and then to accept a question I acknowledged from Mme. Heynemann.

Dr Bloomfield (UK)

This is an answer to Mr Overington. We were dealing with a complex visual display, which most acuity studies have not treated, and expected an interaction between viewing distance and display complexity. In fact, there turned out to be none.

Mme. Heynemann (France)

Could I ask Dr Taylor about the application of the Blondel-Rey formula to flash stimuli. With the increasing use of electronic sources, light time is getting briefer and briefer, generally less than a millisecond. Do you think the Blondel-Rey formula will always apply? In particular can the physiological constant 0.2 sec (a threshold concept) still be correct?

Dr Taylor (US)

Single brief pulses in the nanosecond and microsecond range, and indeed, well into the millisecond domain, appear to follow Bloch's Law exactly at threshold. This is true, moreover, regardless of pulse shape (as shown by Long in 1951) and for the case of multiple-flick trains of pulses whose total extent do not exceed critical duration. The threshold for multi-flick pulse trains longer than t_c is now under study, but we do not have sufficient data as yet to enable any conclusions to be drawn. I would guess, however, that the function will again be complex, especially as eye-movements come into play and probabilistic summation occurs. Thus, the Blondel-Rey "constant", a, may or may not have any meaning for electronic flash sources operated in the multi-flick mode.

It's in any case known that the value of a varies, experimentally, over a very wide range, and is quoted only with some faith as being 0.20 or $\bar{0}$.21 sec. It ranges from 1.0 sec to 0.05 sec at least. Thus 0.2 sec is a convenience, and has no theoretical under-pinning, except in the context of an appropriately limited set of conditions. Practical application demands a simple, single value, that's all, and 0.2 sec has been adopted by C.I.E.

Dr Huddleston (UK)

Now to the open discussion. With their permission, Messrs Bailey, Hilgendorf and Kenneally represent, I think, some of the more practical people we have present, if other laboratory workers here will join me in being below the practical salt. All three have spoken about aids to vision; specifically, that flares are not developed up to known current needs, that head-aiming ability is still an exlusively empirical topic, and that low-light TV leaves us too ignorant to agree precisely where we are most ignorant. Could I, then, ask each in turn to say bluntly whether they think elegant laboratory-based modelling is a help or a painful hindrance in evaluating equipment requirements?

Major Hilgendorf (US)

I have no doubts that the laboratory-developed models and techniques are a quite fantastic aid. However, we try to work at three levels; the basic psychophysics, then simulation trials, then flight tests in that sequence.

Doubtless, many of the visual parameters that concern us could be investigated in a light-proof room with the subject on a bite-board. But we have a responsibility for "face-validity" in our research efforts, and must tie in our work to things that the actual practicioners understand. I can bring a tactical commander into my terrain model laboratory and he can look at scenes like others he has actually experienced before. Very few of our tactical commanders are impressed by a bite-board and optical bench. But we know our good simulations are founded on previous basic research of low or zero "face validity".

Colonel Bailey (US)

I think that sums my opinions quite adequately. Some people, however, construe the pragmatic world as being a non-scientific one, and that is not correct at all. We try to take established principles from basic work and apply them to practical problems, but in fact the two are not separate but rather continuous areas of activity.

Mr Kenneally (US)

From a design stand point, there is no doubt that models have a very great deal to offer, if only to give relative numbers to use in selecting options. In the previous discussions, the world seemed to be divided into two camps; those for models and those against. But that's an artificial kind of distinction.

The model has a place as a filter, too, to save money on hardware and flight tests which would be quite ineffectual. The key is to work the model and test effort complementarily, the one built on the other in a supportive fashion. I don't doubt the use of modelling at all.

Colonel Bailey (US)

Did Dr Taylor mean, earlier, that certain models should not be put "on the menu"?

Dr Taylor (US)

My comment was really that one should use the model but not "eat the menu". Models have a useful place in directing work and thinking, but to swallow a model whole, uncritically, is a real danger. The ingredients should be looked at carefully.

Mr Overington (UK)

Can I address a general comment to Dr Taylor, regarding the Blondel-Rey equation. I believe that by starting with the known physical properties of the eye one can show a discontinuity to be expected in the region between 0.25 and 1.0 second. Indeed, the asymptotes of the total function would be the Bloch Law at exposure times of less than 0.01 sec, and a constant value law would apply for values greater than 10 sec. In between, the large variations as amongst various experimenters can be explained in terms of contrast, size and presentation parameters, and would be predictable from these same physical properties. I shall be publishing these conclusions shortly.

Dr Taylor (US)

I have no doubt that several concurrent effects operate in the transition range. Certainly, it looks as if the quantum (square root) case is adhered to for at least a short time over part of the range. Then, as you go to longer durations, you get the business of multiple-look probabilities and also the effects of spontaneous eye movements giving hit probabilities for many cones. We have a mixture of effects, then, and find the Blondel-Rey specification too simplistic. The practical importance, in terms of, say, energy saved, is not really germane to this discussion.

Dr Grether (US)

I'd like to enter another variable, the matter of combat degradation. Models predict laboratory data quite well, and may predict simulation or field test data too, but the combat situation seems to throw in another gross effect. I'm not aware of anyone succeeding at putting any factor or whatever into model predictions to account for combat situation variables.

Dr Huddleston (UK)

Yes, thank you for your question, but I pass it on to our speakers with some trepidation. I'm keenly aware that the issue is a very sensitive one, probably meriting special treatment at a future symposium.

Mr Kenneally (US)

We have a programme running at present to do with night vision from helicopters. May I just relate what one individual told me, that calculations as to what could be seen were fine, but when he got to combat he became a lot better just after being shot at! It may not always be a degradation, but a motivation bonus or something like that.

Major Hilgendorf (US)

Dr Grether knows I've been worrying, and worrying only, around this problem for about 4 years. We've attempted to monitor our subjects with physiological measures both in the laboratory and in flight, using all sorts of measures and appealing to all sorts of theories, but still nothing holds together by way of a finding. One embarassing problem for our theories is that some of our best foward air controllers, those who can really acquire targets, are older, need corrective lenses, are by no means "tiger" types, and are often being heavily shaken around at the time! They report they're very stressed in combat, and return to base with a dry mouth, for instance, and perspire heavily, and perform greatly. I don't know how we're ever going to predict this. Perhaps some part of arousal theory may hold the key.

Dr Huddleston (UK)

The only material I can mention today is that World War II and Korean War data examined by Norman K Walker in the States, of whom I'm sure you're aware. I personally find only part of his data and even less of his conclusions acceptable. Of the few items I accept, the most notable is not really classifiable as combat degradation of human performance. This concerns the attacking of bridges in Southern Europe with partially guidable bombs, where the individuals stayed long enough to estimate where the bomb was going roughly. If it was going left, they kicked it right, if right, they kicked it left, then flew away as quickly as they knew how. I call that shrewd thinking, not a stress effect in the context of the question we're asking.

Dr Grether (US)

Yes, I'm somewhat aware of Mr Walker's work, and evaluate it similarly to yourself.

I think the combat situation is somewhat complicated. There is a stress on the individual but also a general stress on the whole situation or environment, not a personal stress but, for example, a great confusion and a kind of on-going gross misjudgement or mismanagement.

Mr Ericson (US)

I might mention one happening at the Naval Weapons Centre, China Lake. We had combat bombing accuracy data with errors 3 or 4 times as high as Test Range data. Someone arranged practice bombing in the mountains north of the China Lake Range, for squadrons who had not seen the area, coming in on a simulated strike. These data were closely similar to the combat data. It seems to me that Range testing crews gather a great deal of familiarity with the area which is unlike operational use. Perhaps we should spend even more efforts on simulation of the task.

Wing Commander Anderson (UK)

A main problem here is getting the information (about hit accuracy). In World War II the very noticeable thing was the unwillingness of any interrogator to impute anything but extreme courage in the aircrew, and the inability of the aircrew member who had just risked his life to believe he hadn't done the job properly. This is quite a genuine phenomenon.

I conducted some limited experiments myself, and discovered that the target identification was very much tied up with the danger involved. In peacetime and training you get a pat on the back for correct identification and attack. In wartime you get something nasty and hot in some other part of your anatomy! The outlook in wartime is completely different so that there may be a vested interest on the part of aircrew in finding the wrong target, and this very strong effect has to be squarely faced.

REALISTIC CONSIDERATIONS OF TARGET ACQUISITION ON LINES OF COMMUNICATIONS

by

Roy K. Frick
Diane E. Summers
Thomas E. Tyson
Aeronautical Systems Division (XROA)
Wright-Patterson AFB, Ohio 45433

SUMMARY

This paper presents an approach to determining the probability of acquiring targets by a search aircraft which flies along an enemy line of communication (LOC). A line of communication is defined as a route, e.g., a road, waterway, or railroad, and the targets of interest are trucks, boats, or other appropriate carriers. The analysis approach consists of three areas of investigation: (1) analyzing the contour (twists and turns) of a route for purposes of establishing a preferred flight path plus determining the frequency distributions of LOC aspects relative to this flight path, (2) computing the probability of detecting a target, given a set of LOC, target, and flight path conditions, and (3) integrating the results of the first two areas of investigation to produce the probability of target acquisition for the overall set of conditions.

The methodology presented in this paper can be applied to investigate conditions of target acquisition for existing lines of communication in the real world.

LIST OF SYMBOLS

θ ≐ a parameter used in a target detection model which is sensitive to sensor, target, background, and atmospheric conditions among others.

P_D ≐ probability of target detection.

h ≐ height of masking obstacle.

H ≐ altitude of search aircraft.

w ≐ 1/2 width of LOC.

W ≐ horizontal component of distance between LOC and aircraft.

d ≐ horizontal component of distance between masking obstacle and the line of sight to the target.

P_A ≐ probability of target acquisition.

α ≐ crossing angle of LOC.

β ≐ offset distance - LOC to flight path.

STATEMENT OF THE PROBLEM

Target detection by an overflying aircraft depends on many things such as light level, target and background signatures, atmospheric absorption, and time-in-view of the target. Of these, the probability of detection for a given target/background combination is ordinarily extremely sensitive to the time the target is in view. Time-in-view is a function of the sensor ground area coverage, aircraft velocity, location of the target relative to the sensor coverage, and the masking effects of terrain and vegetation. These factors cannot be realistically determined until paths taken by the aircraft and the target have been specifically defined.

If the search aircraft is also an attack aircraft, the general problem of target acquisition involves both the ability to initially detect a target and the ability to convert on the target, that is, to subsequently turn into the target and successfully reach an acceptable weapon release point.

The location of the target is assumed to be equally likely anywhere along the LOC. The aircraft flies a preplanned flight path which has been established after considering the general contour of the route. This flight path determination is treated by the line of communication (LOC) model discussed later in the paper. The search aircraft may not be able to follow all of the twists and turns of the route because of turn limitations of the aircraft. The LOC model considers the flight path to consist of a series of straight line segments, and chooses a flight path which maximizes the total fraction of the LOC which is in the field of view of the search aircraft.

As the aircraft flies along the LOC, the route below will wander back and forth across the ground projection of the flight path. Most of the route will be offset from the flight path, and when it crosses the flight path it will do so at some angle. This difference between the route and the flight path acts to reduce the probability of target detection because of terrain or foliage masking. The degree of masking, and hence, the time in view of the target, is a function of both the offset and crossing angle of the flight path relative to the LOC. The LOC model, in addition to determining the preferred flight path, computes the frequencies of offset distances and crossing angles of the route relative to the flight path of the aircraft.

For a given set of values of offset and crossing angles, a time-in-view can be determined for a given degree of masking. This masking is a function of aircraft altitude, height of the objects (such as hills or trees) along the LOC, and the width of the LOC. These factors, plus the speed of the aircraft, the sensor field of view, and the maneuver (turn) limits of the aircraft, determine the time of exposure of the target. This time of exposure can be translated into terms of probability of detection by a mathematical model, using target and background characteristics as additional inputs.

The problem posed is to integrate the output of the LOC model and the time in view to give an overall probability of detecting a target along a LOC (e.g., road).

THE LINE OF COMMUNICATION MODEL

Nearly any aircraft can follow a relatively straight road, waterway, or railroad in flat country in such a way that its sensors are always looking ahead and down the road, since no turns are necessary. As the route becomes more tortuous, the patrolling systems are required to turn more in order for the target sensors to be pointed ahead and down the route. As more and more turns are required, the effect of patrol speed becomes significant since the faster aircraft have larger turn radii and thus cannot negotiate as many turns as the slower systems. When a turn cannot be negotiated without the route passing out of the sensor field of view, a flight path must be chosen so as to eliminate the turn and cut a swath through the tortuous section of the route as shown in Figure 1.

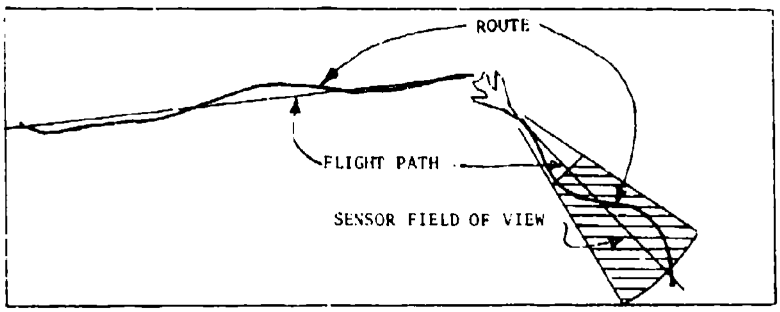

FIGURE 1

AIRCRAFT FLIGHT PATH OVER TORTUOUS SECTION OF ROUTE

The Line of Communications Model includes a flight path determination subprogram which employs optimization techniques to define a feasible path which maximizes the percent of the route passing through the sensor ground area coverage. Inputs to this program include: (1) rectangular coordinates of the LOC to be analyzed, (2) maximum number of aircraft turns permitted, (3) a minimum on-course distance between turns, (4) aircraft speed, altitude and G-limit, (5) sensor field of view dimensions in azimuth and elevation, (6) the sensor depression angle, and (7) the x coordinates for an initial set of aircraft turns.

The first step in determining the flight path is to define the route to be patrolled as a locus of points in a linear coordinate system. An LOC is defined by tracing the paths of specific routes, selected as part of a study scenario, from maps. A linear coordinate system is then superimposed on the trace of the route and the x and y coordinates of the route recorded.

Once the initial trace of the LOC is determined, a "best" flight path will be selected as described below. An initial flight path is chosen and is approximated by a series of straight line segments connected by circular segments, the radius of these circular segments being dictated by aircraft maneuverability limits (a procedure for selecting an initial flight path is given in Appendix A). Hence, a path is completely defined once the x and y coordinates for the aircraft turns have been specified. Given the input x-coordinates for the initial set of aircraft turns, least squares procedures are utilized to determine corresponding y coordinates. This procedure tends to minimize the aircraft offset distance from the LOC. Using the sensor depression angle, aircraft altitude and field of view dimensions, the location of the sensor ground area coverage relative to the aircraft flight path, i.e., the sensor "footprint" is determined by appropriate methods. The percent of the LOC actually passing through this sensor swath is the figure of merit assigned to this initial flight path. An improved flight path, (one with a higher figure of merit) is then sought through a systematic search of the neighborhood of the initial x-coordinates. Repetition of these procedures until specified tolerance limits are reached defines the "best" flight path assumed for this analysis. Reference is made to Figure 2 which is a flow diagram of the basic steps in determining the best flight path.

Once the flight path has been determined, two important quantities associated with each LOC point can be computed. These are: (1) the perpendicular distance from each LOC point to the nearest point of the flight path, referred to as the "offset distance", and (2) the absolute value of the angle formed by the intersection of a line segment joining two adjacent LOC points and the local flight path segment. In subsequent paragraphs this will be referred to as the "crossing angle" for the related LOC point. The frequency distribution of offset - crossing angle combinations for this "best" flight path is an output of the LOC model.

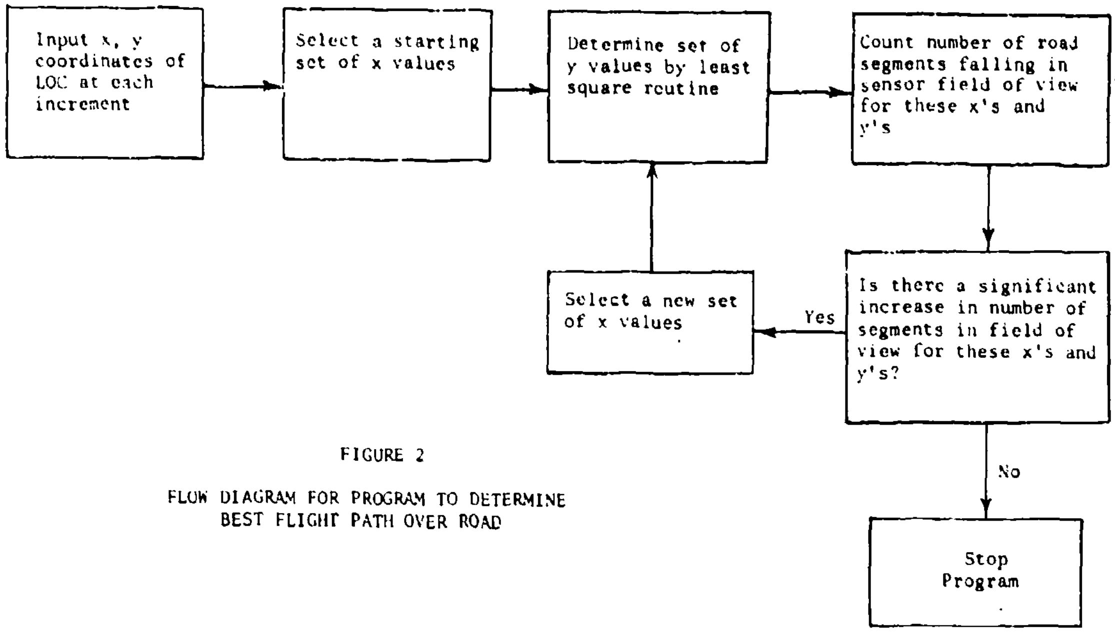

FIGURE 2

FLOW DIAGRAM FOR PROGRAM TO DETERMINE BEST FLIGHT PATH OVER ROAD

THE TARGET DETECTION AND MASKING MODEL

The probability of target detection depends on sensor, target, and background characteristics, plus the time-in-view of the target. Functionally, the probability of detection can be represented as

$$P_D = f(\theta, t) \qquad [1]$$

where t is the time in view and θ can be a parameter which collectively accounts for sensor, target, and background characteristics. This parameter can be sensitive to type of sensor used (e.g., radar, I.R., visual) and can also account for human factors. Often, the probability of target detection is based on an exponential model of the basic form:

$$P_D = 1 - e^{-\theta t} \qquad [2]$$

The parameter θ must be determined to some extent on an empirical basis. A model, such as equation [2], can be derived on a pure empirical basis, or it can be based on an executive routine which accounts for various components of a sensor system, considering physical characteristics such as lines of resolution, sweep, signal-to-noise ratio, etc. One example of such a model of the latter type is given in reference (1).

We will not present the theory behind such a model, or discuss in detail the various methods one could employ in determining the parameter θ. Furthermore, we will not give the probabilistic basis for a model based on equation [2]. Discussion of the theory of target detection is given in reference (2).

For this paper, we will limit our discussion to the other variable of interest, that being the time-in-view. Time-in-view is a matter of geometry. This geometry has three parts pertaining to: (1) sensor ground coverage, (2) the aircraft maneuver limit, and (3) masking. These parts are independent and therefore could be discussed in any order. We will take them in the order in which we have listed them starting with sensor geometry. The sensor "footprint", that is, the pattern on the ground will have varying shapes depending on the type of sensor used. For illustrative purposes, a radar sensor usually is fan-shaped, the sides being segments of radial lines and the leading and trailing edges being concentric arcs whose centers lie at the intersection of these radial lines. This intersection lies directly beneath the aircraft. The fan shape is symmetrical about a centerline which is parallel to the aircraft flight path. The dimensions of the fan are, for the most part, proportional to the altitude.

The maneuver limit is of interest if the search aircraft also serves as an attack aircraft. Once target detection has taken place a sequence of events must then take place prior to the attainment of a weapon release point. Cursors must be set, the aircraft must be turned to a correct heading, there may be a handoff to a terminal sensor system and then final flight corrections must be made to the aircraft heading. Figure 3 depicts the general situation. If minimum required times are known for each operation, these, in addition to the speed, altitude, g-limits of the aircraft, and weapon travel determine the envelope which we term the "maneuver limit." The maneuver limits, assuming constant max g turns and constant speed, is simply two arcs - one on either side of the flight path concentric with the arcs of the right or left turns in the flight path.

The beam footprint and the maneuver limit are straight forward representations of what happens in the real world but masking is not so amenable to geometric representation. The hills and foliage of the real world must be greatly simplified before they can be expressed mathematically. A statistical model featuring Monte Carlo techniques could be used, but a deterministic model using the simplified concepts discussed below is often adequate.

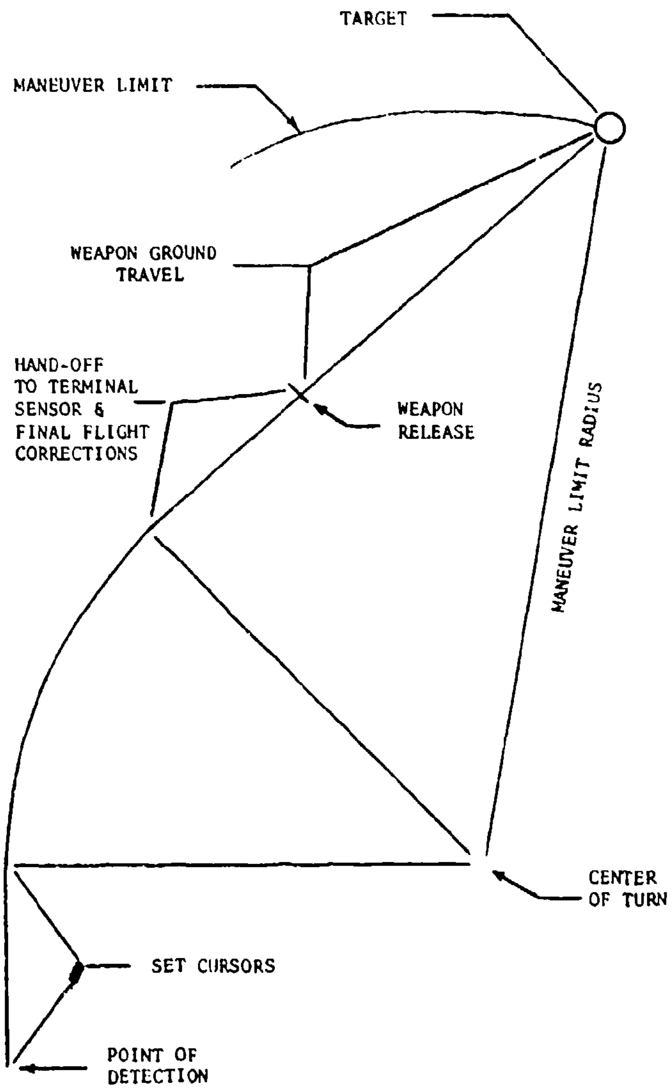

FIGURE 3

MANEUVER LIMIT DETERMINATION

The simplified model has been called the "Wall Model." The earth is flat and the LOC is a channel between parallel walls which are of uniform height. Further, to simplify the geometry it is assumed that the LOC segment upon which the target is located is straight though it may be at any angle to the flight path. As a consequence, the envelope of points at which the target comes into view of the aircraft is two parallel lines that are also parallel to the LOC segment. Between these parallel lines the target is unobstructed - outside of the lines it cannot be seen (Figure 4). This may not be immediately obvious but the proof is simple.

For this proof let the target be a point on the centerline of the LOC (Figure 5):

Let h = height of the masking obstacle.

H = Altitude of the aircraft above the LOC.

w = 1/2 the width of the LOC.

W = horizontal component of the distance between the aircraft and the LOC.

d = horizontal component of the distance between the masking obstacle and the target measured along the line of sight.

D = horizontal component of the line of sight distance between the aircraft and the target.

by similar triangles

$$\frac{W}{w} = \frac{D}{d} = \frac{H}{h}$$

Thus W does not depend upon where the target is on the LOC but only upon w, H, h, and this proves that the masking envelope is two parallel lines.

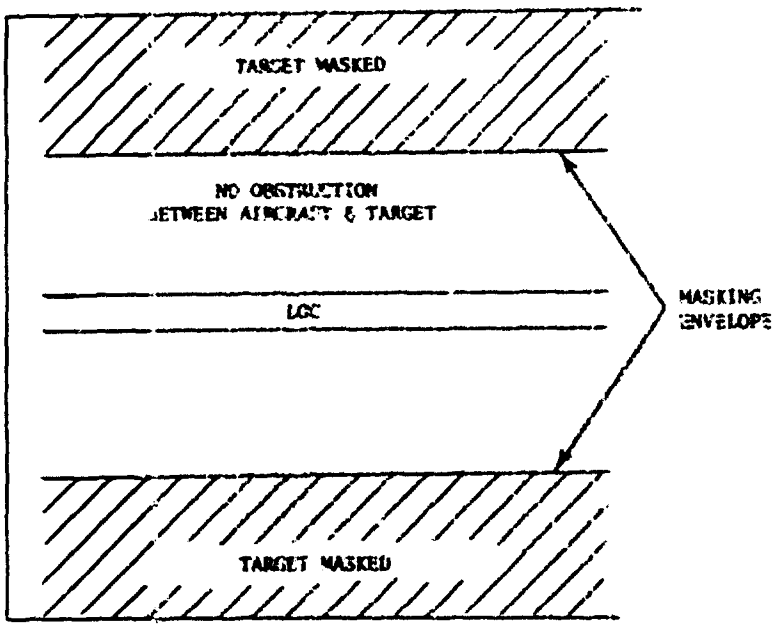

FIGURE 4. MASKING ENVELOPE

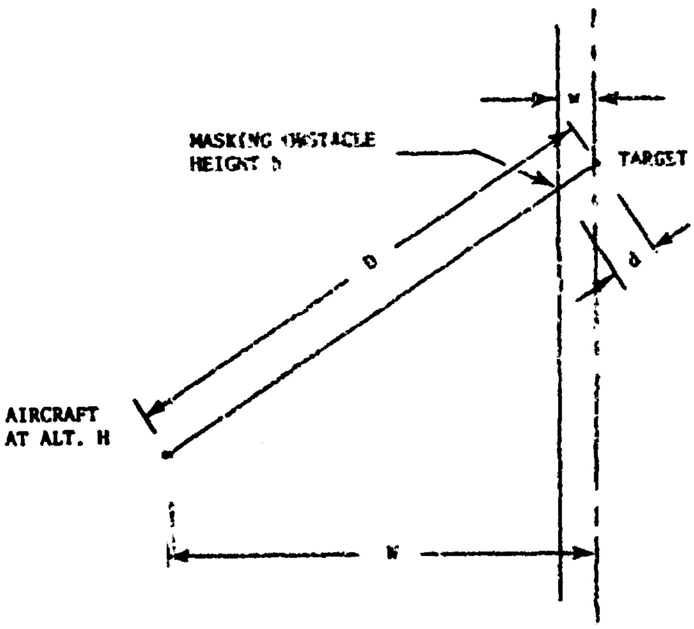

FIGURE 5. MASKING ENVELOPE GEOMETRY

Figure 6 shows the effect on time-in-view. The aircraft approaches a route along a given flight path. When it reaches point A, the intersections of the flight path and the masking envelope, the entire LOC centerline comes into view. A target is seen at this instant at point T_i. As the aircraft continues along the flight path the target moves relative to the aircraft along a line parallel to the flight path until it moves out of radar coverage at point T_o. (Of course, T_i must be within the sensor footprint or the target is not seen until the target has moved along the line $T_i - T_o$ to a point inside the radar beam).

When these geometrical details are put together, the results are typically like those shown in Figure 7. The tick marks on the horizontal axis at the bottom of the Figure represent the offsets for which time-in-view is calculated. A vertical line segment above a tick mark, except for the vertical axis, represents the ground distance over which a target could both be seen and, if seen, attacked. This distance divided by aircraft speed is the time-in-view at that offset. In Figure 7, the masking limit and the maneuver limit have combined to give no view of a target at all on the left of the flight path. At offsets to the right these two factors, plus the offset and the crossing angle, determine the magnitude of the time-in-view of the target.

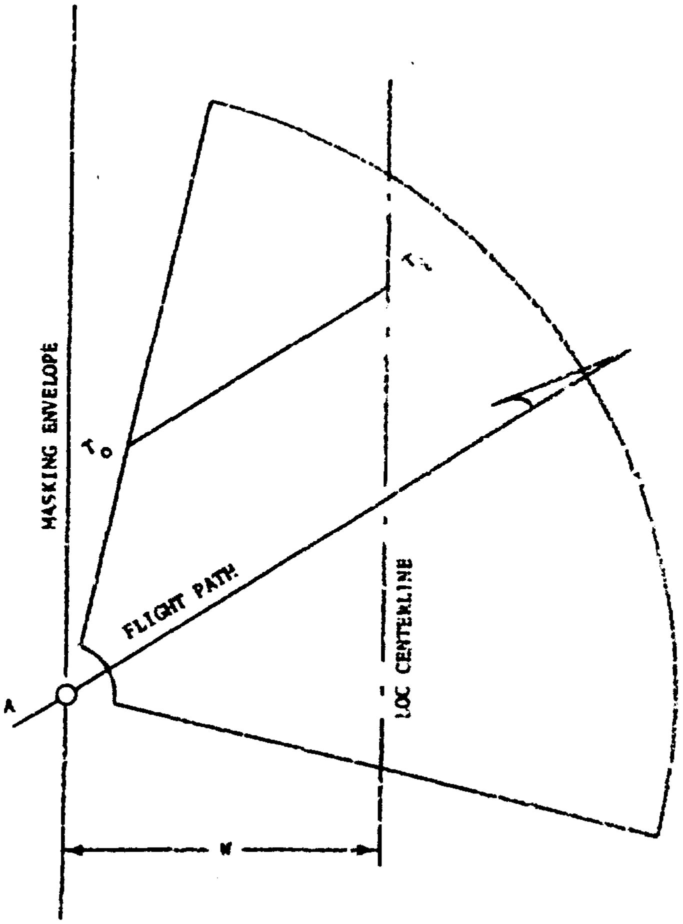

FIGURE 6

TIME-IN-VIEW DETERMINATION

THE INTEGRATED TARGET ACQUISITION MODEL

The overall probability of target acquisition is determined by integrating the output of the LOC model and the target detection and masking model. As shown earlier, the LOC model gives the frequency of occurrences of offset and crossing angle combinations for specific roads and chosen flight paths. A table, such as that given by Table 1 as an example, can be prepared which gives the frequencies of all possible combinations of offsets and crossing angles. Table 1 happens to be data taken from an actual route and a chosen flight path which was used in a study.

Once a table similar to Table 1 has been prepared, a target detection model is used to compute the probabilities of detection for the set of offset and crossing angle combinations for corresponding values of time-in-view. The probabilities of detection and the frequencies from the LOC are combined to give the overall probability of target acquisition.

$$P_A = \sum \sum P(D/\alpha, \beta)\, p(\alpha, \beta)$$

where

P_A = probability of target acquisition

$P(D/\alpha, \beta)$ = probability of detection, given a set of conditions α, the crossing angle, and β, the offset distance.

$p(\alpha, \beta)$ = the probability of occurrence of the conditions α and β.

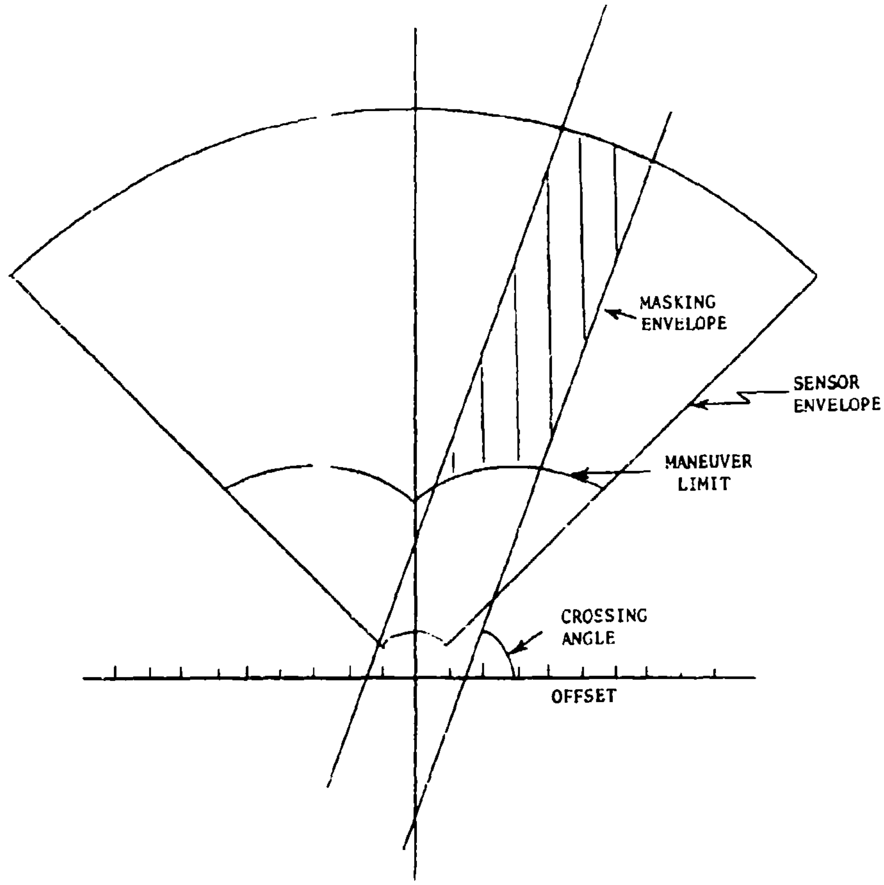

FIGURE 7

COMBINED EFFECTS OF MASKING AND MANEUVER LIMIT

CONCLUDING REMARKS

The capability of a search aircraft to detect targets located on the ground is a function of the time-in-view of the target, in addition to the physical characteristics of the target itself, the background, the sensor, and the atmospheric conditions. This paper has concentrated on the time-in-view consideration, and has specifically shown how the geography and the geometry of the target, relative to the search aircraft, can be analyzed when considering targets located along a line of communication.

Frequently studies of target detection and acquisition assume a specified time-in-view, or treat it parametrically. For many studies, it may be that time-in-view is more critical than the performance of the sensor systems used. If such be the case, it is important to consider the geography and geometry of the situation, as we have done here, to account for the effect of masking and the performance capabilities of the search aircraft.

TABLE 1

TYPICAL OFFSET/CROSSING ANGLE PROBABILITY MATRIX

ANGLE OF INTERSECTION (DEGREES)	OFFSET DISTANCE (MILES) 0	1/8	1/4	3/8	1/2	5/8	3/4	1	1 1/4	TOTALS
0	.042	.096	.011							.149
10	.027	.032	.005							.064
20	.027	.058								.085
30	.015	.011	.005		.011					.043
40	.005		.005							.010
50				.005						.005
60	.005									.005
70										0
80			.005							.005
90		.005								.005
100										0
110		.005								.005
120		.005								.005
130	.011	.011								.022
140	.021	.032	.021	.005			.005			.084
150	.037	.027	.021	.005	.011	.005				.106
160	.154	.117	.027							.298
170	.027	.026	.032	.005	.019					.109
TOTALS	.372	.423	.132	.020	.041	.005	.005			1.000

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2. Morse, P. M., and Kimball, G. E., Methods of Operations Research, Wiley, New York, 1951.

3. Garvin, P. J., Summers, D. E., and Summers, W. G., "Shed Light Effectiveness Model, Volume 5, Target Masking Subroutine," SES 67-21, Deputy for Development Planning, ASD, WPAFB, Ohio, June 1967.

APPENDIX A

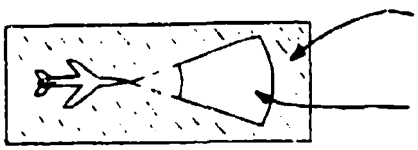
PROCEDURE FOR

SELECTING INITIAL BREAK POINTS IN FLIGHT PATHS

A crude method for establishing the initial break points used in determining the "best" flight path is described here. The break points serve only as starting points from which the optimization program described in section on the LOC Model begins searching for the best break point locations. That program will determine the best flight path for the number of joints determined by this procedure. Thus, while the exact location of break points determined here is not important in determining the flight path, the number of joints is.

The procedure begins with tracing an LOC to be analyzed from US Army 1:50,000 scale maps. One mile on these maps is represented by 1.25 inches. The maps are traced onto paper containing a linear coordinate system in 1/8 mile units.

The ground projection for the sensor field of view to be analyzed is then drawn on a piece of transparent plastic to the same scale as the trace of the road. All areas of the plastic except the field of view projection are then covered with a non-transparent material. This looks as shown in the figure below.



The exact size and shape of the field of view projection depends on the type of sensor used, the search altitude of the aircraft, the direction in which the sensor is pointing, and the angular width and depth of the field of view.

The number and approximate location of break points are then determined by a simulated flight of the field of view projection (which allows only that portion of the road actually covered by the particular sensor to be seen) over the trace of the LOC. The simulated flight consists of moving the transparent field of view across the trace of the LOC at the appropriate speed, turning when necessary to keep the LOC in view. The following ground rules are used in doing this:

a. The field of view must be moved over the LOC in a series of straight line segments connected by curved turns.

b. The turns must approximate the turn radius of the aircraft as closely as possible.

c. The field of view must be moved across the LOC at a rate appropriate with the aircraft speed.

d. When the LOC passes a certain point on the field of view and it is evident that it will soon pass out of the field of view, a turn is made to bring the LOC back into the center of the field.

DISCUSSION

Dr Greening (US)

You gave the impression that the computed probability had a sharp maximum at a value around 160° to the line of communication. Is there some reason for that kind of a cusp in the graph?

Dr Frick (US)

For 160° crossing angles (that is, almost going vertical to the road) offsets were very small, as you say. I don't know why that should be, especially.

This optimization procedure doesn't necessarily give a global optimum. You obtain a flight route, plot all the relevant x, y values as explained in the paper, and define a certain road segment. Then a regression is performed, and describes the break points of that segment. You repeat this for several segments, and collect those points which tend to give the smallest number of offsets possible. Then a computer routine taking account of the sensor 'footprint' counts the number of times the road goes out of view, given that flight route. By fairly arbitrary iteration, a new set of line segments is defined and tested for an increase or not in the number of times out-of-view. You stop this rough and ready iteration when you seem to have a good solution subjectively. The values around 160° could be due to the omission of a set of segments which were not tested but could have been, to advantage.

Mr Clement (Belgium)

In such estimations, based on linear regressions, what kind of regression should be taken, Y on X or X on Y, specifically? Could you justify the choice which has been made?

Dr Frick (US)

Perhaps regression techniques aren't even advisable at all. We used them purely for expediency and because they were intuitively appealing. Perhaps a better (but longer) method would be to find a large set of possible flight paths and compute detection probabilities based, as I showed in the paper, on crossing angles and the frequency of offset distances. Finally you would choose the best one, and it may not be the one favoured by the regression method I described.

THE EFFECTS OF BRIEFING ON TELEVISUAL TARGET ACQUISITION

by

K. R. Parkes
Department of Ergonomics and Cybernetics
University of Technology
Loughborough
Leics, England

SUMMARY

Evidence from a number of studies indicates that the nature of the briefing information available to the observer has a marked effect on target acquisition performance. Low-level forward oblique photographs of the target and surrounding terrain have been found to be a particularly effective form of briefing information, but such photographs may not always be available. In the experiment reported in this paper an evaluation was made of the extent to which, in the absence of suitable oblique photographs, perspective representations of the target and surrounding terrain, derived from maps, facilitated televisual target acquisition performance. The effectiveness of these perspective views, used as briefing material in addition to maps, was compared with that of maps used alone, and maps used together with oblique photographs. The results showed that, whilst not as effective as oblique photographs, the perspective views brought about some improvement in performance as compared with the maps alone.

1. INTRODUCTION

The nature of the briefing information available to the aircrew both prior to and during a high-speed, low-level mission is an important factor determining its success. There is evidence that both visual navigation and target acquisition performance are affected by the quantity and quality of the briefing materials provided. For instance, the proportion of fixpoints identified during high-speed, low-level navigation runs has been shown to depend on both the scale of the map used (1), and its content, in terms of the proportions of different types of features shown (2). The importance of briefing materials is even more critical in relation to target acquisition tasks. Whereas it is usually possible to select as en route fixpoints features that are likely to be conspicuous and readily recognised, the target may be small, partially masked and situated in cluttered terrain. Thus it is vital that adequate information is available to the observer about the appearance of the target, and that of the surrounding terrain.

The basic form of pre-mission briefing for high-speed, low-level target acquisition tasks is a map or chart marked with the planned aircraft track and the target position. Various types of photographic briefing material showing the target area from vertical and/or oblique viewing angles may also be available. In addition to these forms of visual briefing information, verbal descriptions of the target and surrounding terrain, and other intelligence information may be provided. Experimental studies have shown that as the amount of pre-mission briefing about the target is increased from a brief verbal description, to detailed cartographic and photographic coverage of the target and surrounding area, acquisition performance improves (3, 4). For instance, Rusis and Rawlings (3) compared five briefing conditions with the finding that the two conditions which included oblique target photographs resulted in significantly better performance, in terms of both acquisition probability and acquisition range, than the three other conditions in which lower levels of briefing information, not including oblique photographs, were provided. A further result of this study was that the provision of vertical photographs in addition to oblique photographs did not improve performance as compared with oblique photographs alone.

These results indicate that, as would be expected, the more closely the briefing information resembles the actual target and surrounding area as seen by the observer, the more effective it is, and that if this optimum information (i.e. oblique photographs) is available, there is no advantage to be gained from providing additional, less useful information. Oblique photographs provide both information about the appearance of the target during a low-level approach, and information about surrounding terrain features and their spatial relationships to the target. Both these types of information aid the observer in acquiring the target. Information derived from the terrain features in the vicinity of the target reduces the uncertainty of the observer as to the target position, thus reducing the area that must be searched in order to locate the target, and influencing search patterns. Information about the appearance of the target itself aids detection and recognition of the target within the search area. A study carried out by Jahns (5) suggests that briefing requirements, in terms of these two types of information, tend to interact with the complexity of the background in which the target is situated, in that performance for conspicuous isolated targets appeared to be highly sensitive to improvements in target briefing, whilst those embedded in complex backgrounds showed relatively less improvement. In the latter case, the requirement seems to be for detailed information about background features to enable the observer to make maximum use of contextual clues.

The important role played by terrain features in the vicinity of the target in providing clues to target position is also indicated by work carried out by Laporte and Calhoun (6). They analysed the clues reported by subjects as important in leading to target designation, with the finding that for most of the targets studied non-target clues were more important to successful recognition than were target clues. More recently, Mitchell (7) has identified three components of major subjective importance in visual acquisition tasks: (i) whether or not the target has visual prominence against its background; (ii) whether the target is in a helpful built-up environment or a simple environment; and (iii) whether or not there are mapped identification features around the target to aid acquisition. Again these components indicate the importance of the target background and the cues it provides.

The studies outlined above suggest that for maximum effectiveness the briefing material provided should enable the observer to accurately visualise the main terrain features in the vicinity of the target and their spatial relationships to each other, and to the target, as seen obliquely during a low-level approach. This can be achieved by providing the observer with at least one low-level oblique photograph taken from a sufficient range to show the target and the features leading up to it. Ideally, altitude and, particularly, approach direction should correspond closely to those of the actual mission. In view of the difficulty of obtaining such photographs for targets situated in hostile territory, suitable oblique imagery may not be available. In such cases the observer must work out for himself from other briefing information the apparent shapes and sizes of features, and their spatial relationships, when seen obliquely from a particular approach direction, in order to visualise how the target area will look during the approach. Data reported by McGrath and Borden (8) suggests that the ability of aircrew to accurately visualise oblique views from maps is limited. Possible reasons for this difficulty are (i) the inadequacy of the information given on the map, for instance, tones, textures, lighting effects and seasonal changes cannot be represented, although they markedly affect the appearance of the terrain; and (ii) the difficulty of mentally making the appropriate perspective transformations.

Evidence that the second of these factors contributes to the problems of low-level target acquisition comes from a study reported by Hagen, Larue and Ozkaptan (9). They found that specialised training in perspective geometry significantly improved the performance of subjects carrying out a televisual target acquisition task, as compared with subjects who received only standard training. The subjects given the specialised training were able to designate the correct target area with a significantly higher success rate, and in significantly shorter times. A different approach was adopted by the present author (10), who investigated whether, in the absence of oblique photographs, perspective views prepared from maps to show accurately the sparial relationships between the target and surrounding features as seen from the appropriate oblique viewing angle would facilitate target acquisition. Under television viewing conditions, such as those encountered with television-guided missiles, the camera field of view and the depression angle of the optical axis of camera lens are fixed, and thus it is possible to prepare accurate perspective views appropriate to any specified altitude, range and approach direction, which correspond closely in terms of the apparent shapes and sizes of features and the spatial relationships between them, and in terrain masking effects, to the television view relayed back by the TV camera as the missile approaches the target. Whilst more sophisticated techniques could be used to generate these perspective views, for the purposes of this experiment it was convenient to prepare them by hand, transferring features from a plan view grid to the corresponding positions on the appropriate perspective grid to produce a master drawings (11).

Two types of briefing material were prepared from these master drawings, in each case using only the information available on a 1" : 1 mile (1 : 63,360) Ordnance Survey map marked with the approach track and target position. For one type, designated 'drawings', a freehand technique was used and for the other, designated 'diagrams', commercial shading materials together with standardised lines were used. The former allowed a greater degree of realism to be obtained, while the latter allowed more rigorous standardisation. The results of this experiment indicated that both types of oblique representation, used in addition to the map, significantly improved acquisition performance as compared with the condition in which only the map was provided, there being no significant difference between the drawings and diagrams. Thus the provision of map information in an oblique form, corresponding more closely to how the terrain actually appears, would seem to be of some value, although as would be expected, the performance improvement observed was not as great as that occurring when oblique photographs were used as briefing. Some examples of briefing materials used in this experiment are shown in Figure 1.

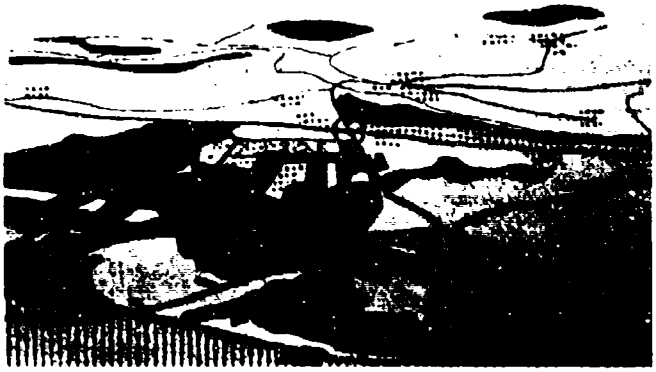
The experiment outlined above was carried out under static simulation conditions, in which still photographs taken at four discrete ranges from the targets were used to simulate the television display. Furthermore, the subjects who took part were students specifically trained to do the experimental task, rather than skilled aircrew. It was, therefore, of interest to determine whether, using a more realistic dynamic simulation technique, and R.A.F. aircrew as subjects, the provision of oblique perspective views as briefing material in addition to maps, would facilitate target acquisition performance and, if so, to what extent as compared with the corresponding oblique photographs. This was the main purpose of the experiment described below.

2. EXPERIMENTAL CONDITIONS

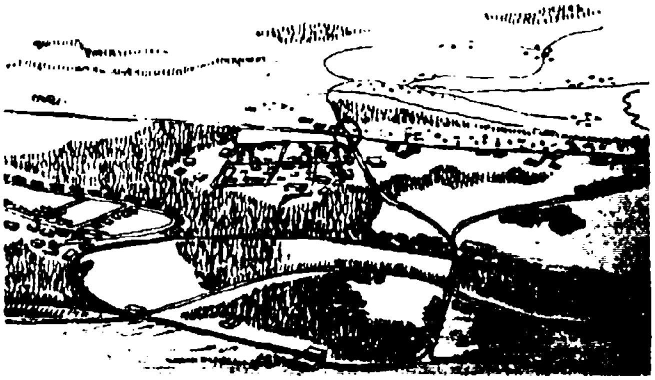
In this experiment the effect on televisual target acquisition performance of oblique perspective views prepared from ½M maps was evaluated, in addition to that of the similar, but more detailed, views prepared from 1" : 1 mile (1 : 63,360) maps, as used previously. Since no significant differences had been found between the effects of the drawings and the diagrams, only diagrams were used in the present experiment. They were designated ½M diagrams and 1" diagrams according to the scale of map used in preparing them. The ranges at which the target was shown in the oblique views, 2 miles (3.2 Km) and 4 miles (6.4 Km) were the same as those used previously. For comparison purposes, conditions in which only the corresponding maps were provided were tested, together with two conditions in which oblique photographs were used. Whilst it would have been desirable to have included vertical photographs in the series of briefing materials tested, this was not possible as no suitable photographs were available.

For route briefing ½M map sections marked with the track, and the target position were used under each condition. Brief verbal descriptions of the targets were also provided under each condition. Briefing materials used under the seven experimental conditions were as follows:

(1) ½M route map
(2) ½M route map + 1" : 1 mile (1 : 63,360) map covering the final approach to the target
(3) ½M route map + ½M diagrams
(4) ½M route map + 1" diagrams
(5) ½M route map + 1" map + 1" diagrams
(6) ½M route map + 'off-set' oblique photographs
(7) ½M route map + 'on-track' oblique photographs



(a) Diagram



(b) Drawing

(c) Photograph

FIGURE 1. Examples of the two types of perspective representation prepared from a 1" : 1 mile map, together with the corresponding oblique photograph. The target, a road junction, is at a range of 2 miles.

The two photographs conditions differed in that in one case the photographs corresponded very closely to the equivalent film frames in the simulation, whereas in the other case they were slightly off-set, as described below. The sixteen targets used to test these briefing conditions included bridges, rail junctions, roundabouts, buildings and similar features. The following experimental conditions were fixed throughout the experiment:

Altitude: 2000 ft. (610 m)
Speed: 430 knots (800 Km/Hr) (average)
Camera field of view: 20° (horizontally) x 15° (vertically)
Camera depression angle: 6½°
Range at lower edge of display: 1½ n.m. (2.8 Km) (approx.)
Display size: 6" x 4½" (15.2 x 11.4 cms.)
Viewing distance: 17" (43.2 cms.), giving real-world viewing angles
Length of routes: 16-32 n.m. (30-60 Km)
Type of terrain: Midlands and Southern England

3. PREPARATION OF BRIEFING MATERIALS

(i) Maps

Standard Ordnance Survey maps were used. The ¼M map sections used for route briefing under each of the experimental conditions covered approximately 6 miles (9.7 Km) of terrain on either side of the marked track, and several miles beyond the target. The 1" : 1 mile (1 : 63,360) map sections used as additional briefing material in two of the conditions showed the final 5 miles (8.1 Km) to the target and 2 miles (3.2 Km) beyond, and were also marked with the track and the target position.

(ii) Diagrams

The oblique diagrams were prepared to correspond with the altitude, camera field of view and depression angle used in the simulation. The specialist responsible for preparing the diagrams was given these data together with map sections marked with the approach track and target position, and a brief verbal description of the target. A transparent grid was placed over the map and the terrain features within the field of view transferred to the appropriate oblique perspective grid, as in the previous work. The set of diagrams prepared from the ¼M scale maps was completed before work on the 1" series was started so as to avoid any of the more detailed information available on the larger scale maps influencing the preparation of the ¼M diagrams. In the preparation of the ¼M diagrams some difficulties were encountered owing to the very small area of map from which the diagrams had to be produced. In particular, very little detail was available, and since line features have to be shown much wider on the map than they are in practice, there was some uncertainty as to their exact position. For each target oblique diagrams showing the target and surrounding terrain as it would appear from the two specified ranges were prepared from both ¼M and 1" : 1 mile (1 : 63,360) maps. A code sheet indicating how different types of features, woodland, built-up areas, railways, motorways, roads, areas of water, etc. were represented in the diagrams was also produced.

(iii) Photographs

The photographs used as briefing material were reprinted from forward oblique photographs taken at the same time as the cine-film used in the simulation was obtained. They showed the target area as seen from ranges of two and four miles with the same field of view as the cine-film. The 'on-track' photographs were printed so that they corresponded closely with equivalent film-frames and in most cases the target was approximately central. The 'off-set' photographs showed a view which was off-set from the equivalent film-frame by a constant amount, the maximum possible using the photographs available. In practice, this was relatively small and the difference between the on-track and off-set photographs was not great.

4. METHOD

(i) Subjects

42 R.A.F. pilots and navigators took part in the main experiment. All had extensive experience of high-speed, low-level flight, although none had experience of televisual navigation and target acquisition tasks. Background information including age, flying hours and scores on Heim's AH5 intelligence test were recorded for each subject. Six subjects were randomly assigned to each of the seven experimental conditions. In addition, six unskilled subjects (students) were tested under the basic briefing condition (¼M map only) for comparison purposes.

(ii) Equipment

The television display was simulated by means of cine-film from the film library produced by the British Aircraft Corporation. These films were rear-projected at a speed of 16 frames/second using a LW Analysing Projector. The display appeared on a small screen set into the subject's console. Viewing distance was fixed by means of a chin-rest. Provision was made for the positioning of briefing materials, appropriately illuminated, and for the necessary response buttons. The subject's console was screened off from the remainder of the experimental area.

(iii) Procedure

Subjects were tested in pairs, but each worked entirely independently. The purpose of the experiment, the nature of the experimental task and the procedure involved were explained in written instructions. Before carrying out the test runs, the subjects were given four runs for training purposes, the first simulation film being seen twice with guidance from the experimenter, if necessary. Whilst it had initially been intended to use eight runs for training purposes, it was found that this was unnecessary, and the final four of these runs were included in the test sequences giving 16 test targets. Prior to each run the subject was allowed as long as he wished to study the briefing materials provided. The time required was typically 5-10 minutes. Having studied the briefing materials he was asked to complete the first part of a questionnaire, indicating on a ranking scale how difficult he expected to find (a) navigating along the route, (b) locating the target area and (c) identifying the target. As part of a separate study (not reported in this paper) concerned with the selection and use of en route fixpoints for navigation purposes, he was also asked to record his chosen fixpoints for the particular route.

During each simulation run the subject was required to navigate visually along the route, to indicate the location of the target area as soon as he was able, and subsequently to positively identify the target itself. Correct responses, omissive and commissive errors were recorded for locating the target area and for identifying the target, together with the corresponding ranges, determined from the frame-count. At the positive identification stage the film was stopped for a few seconds to enable the designation to be checked and the frame count accurately recorded. It re-started automatically, and ran until a fixed range of 10,000 ft. (3.05 Km) from the target was reached. At this point, at which most of the targets were on the verge of disappearing from the lower edge of the display, the experimenter stopped the film and the subject again designated the target. Having completed the run the subject filled in the second part of the questionnaire, which was mainly concerned with the use of fixpoints, but also asked him to record how difficult he had found navigating along the route, locating the target area and identifying the target using the same three-point rating scale as in the first part of the questionnaire.

5. RESULTS

A large amount of data was obtained in this experiment and only an outline of the main results can be presented here. The primary emphasis is on the effects of the briefing conditions tested, particularly on positive identification of the target, since this was the main concern of the experiment but other aspects of performance are also considered.

(i) Target area designation

Analysis of variance carried out on the target area data indicated that the effect of the seven briefing conditions on the probability of correct target area designation was non-significant, but the effect of target differences was highly significant, as shown in Table 1.

TABLE 1

Analysis of variance on target area designations

Source	D.F.	S.S.	M.S.	F	P
Between subjects	41	12.19	0.30		
Briefing conditions (C)	6	2.19	0.37	1.28	N.S.
Residual	35	10.00	0.29		
Within subjects	630	113.31	0.18		
Targets (T)	15	11.38	0.76	4.49	<0.001
T x C	90	13.10	0.15	-	N.S.
Residual	525	88.84	0.17		
TOTAL	671	125.50			

The overall probability of correct target area designation was 0.75, the means for individual targets varying from 0.55 to 0.98. Since the overall mean range of target area designation was 26.000 ft. (8.1 Kms) this variation must have been very largely due to differences in the final approach routes and lead-in features, rather than differences in the targets themselves. Standard analysis of variance techniques could not be used on the range data, as the omissive errors gave rise to missing values. However, it appeared that the provision of additional briefing materials did not increase the ranges at which target areas were designated, and in the case of the diagrams conditions tended to reduce them.

(ii) Positive identification of target

An analysis of variance was carried out on the correct identifications obtained under the seven experimental conditions. As shown in Table 2, the effects of briefing conditions and target differences were significant, as was the interaction between them.

TABLE 2

Analysis of varience on the positive identification data

Source	D.F.	S.S.	M.S.	F	P
Between subjects	41	13.25			
Briefing conditions (C)	6	4.12	0.69	2.63	<0.05
Residual	35	9.13	0.26		
Within subjects	630	144.75	0.23		
Targets (T)	15	32.95	2.20	14.54	<0.001
T x C	90	31.93	0.36	2.34	<0.001
Residual	525	79.87	0.15		
TOTAL	671	158.00			

A similar analysis carried out on the commissive error data showed that briefing conditions did not have a significant effect on commissive errors but target effects, and the targets x conditions interaction, were significant. The overall probabilities of correct identification for each of the briefing conditions are shown in Table 3.

TABLE 3

Probabilities of correct positive identification and commissive errors for the seven briefing conditions

Briefing conditions	Probability of correct identification	Probability of commissive error
(1) ¼M route map only	0.55	0.20
(2) ¼M route map + 1" map section	0.50	0.20
(3) ¼M route map + ¼M diagram	0.61	0.18
(4) ¼M route map + 1" diagram	0.65	0.25
(5) ¼M route map + 1" map + 1" diagram	0.60	0.19
(6) ¼M route map + 'offset' photographs	0.76	0.19
(7) ¼M route map + 'ontrack' photographs	0.68	0.18

On the basis of the a priori hypotheses that oblique views would facilitate performance as compared with the map conditions, that the increase in detail associated with increase in the scale of the map would improve performance, and that oblique photographs would be superior to other forms of briefing, Student's t was used to test the significance of the differences between these conditions. Differences had to exceed 0.17 to reach the 0.01 significance level and 0.12 for the 0.05 level. Comparisons showed that both photographs conditions, (6) and (7), were significantly better than both maps conditions, (1) and (2), condition (6) also being significantly better than condition (5). In addition, the 1" diagrams condition (4) was significantly better than the 1" map condition (2). To obtain a clearer picture of the results the seven conditions were combined to give three briefing types, those in which only maps were used, those in which diagrams were used and those in which photographs were used. The data obtained are shown in Table 4.

TABLE 4

Positive identification for maps, diagrams and photographs briefing types

Briefing types	Probability of positive identification	Probability of commissive error
Maps (1) (2)	0.53	0.20
Diagrams (3) (4) (5)	0.62	0.21
Photographs (6) (7)	0.72	0.19

Comparisons between the correct identification probabilities given in Table 3 showed that differences between maps and diagrams, and the diagrams and photographs, were significant at the 0.05 level, and the difference between maps and photographs at the 0.01 level, again using Student's t test. As can be seen in Table 3, there was very little difference between the levels of commissive errors associated with each of the three types of briefing. The overall effects of map scale were assessed by determining the combined means of conditions (1) and (3), which used briefing information derived only from ¼M maps, and conditions (2) (4) and (5), which involved the additional provision of information from 1" : 1 mile (1 : 63,360) maps. The correct identification probabilities for these two combined conditions were equal (0.58) indicating that the greater amount of detail associated with the larger scale maps and the diagrams prepared from them did not affect performance.

As shown in Table 2, the effect of target differences on positive identification probabilities was highly significant. Mean values for individual targets varied from 0.21 to 0.88. However, of greater interest from the point of view of this study was the significant interaction between targets and briefing conditions. Examination of the data showed that there were eight targets for which individual identification probabilities were particularly low (<0.50) when only map briefing was provided. For this group of targets additional briefing, in the form of either diagrams or photographs tended to bring about a substantial improvement in performance. For the remaining targets performance was relatively good, and was not affected by the provision of diagrams, and only slightly improved by the provision of photographs.

The mean ranges at which correct positive identifications were made were 14,165 feet (4.3 Kms), 14100 feet (4.3 Kms) and 16560 feet (5.0 Kms) for the maps, diagrams and photographs conditions respectively. The cumulative probability curves, illustrated in Figure 2, clearly show the marked improvement in range brought about by the photographs, whereas the cumulative curve for the diagrams condition is only marginally different from that for maps except at short ranges.

(iii) Target identification at 10,000 ft. range

At a fixed range of 10,000 ft. (3.05 Kms), shortly before the targets disappeared from the lower edge of the display, the subjects again designated the target. As for the positive identification data, an analysis of variance was carried out on the correct designations and in this case briefing conditions, targets and the interaction between these factors were all highly significant ($p < 0.001$). The mean probabilities of correct designation and commissive errors associated with each of the three types of briefing are shown in Table 5.

TABLE 5

Correct identification and commissive error probabilities at 10,000 ft. range

Briefing type	Probability of correct identification	Probability of commissive error
Maps (1) (2)	0.78	0.12
Diagrams (3) (4) (5)	0.86	0.08
Photographs (6) (7)	0.91	0.05

It can be seen that differences between the correct identification probabilities, although statistically significant, are relatively small at this short range.

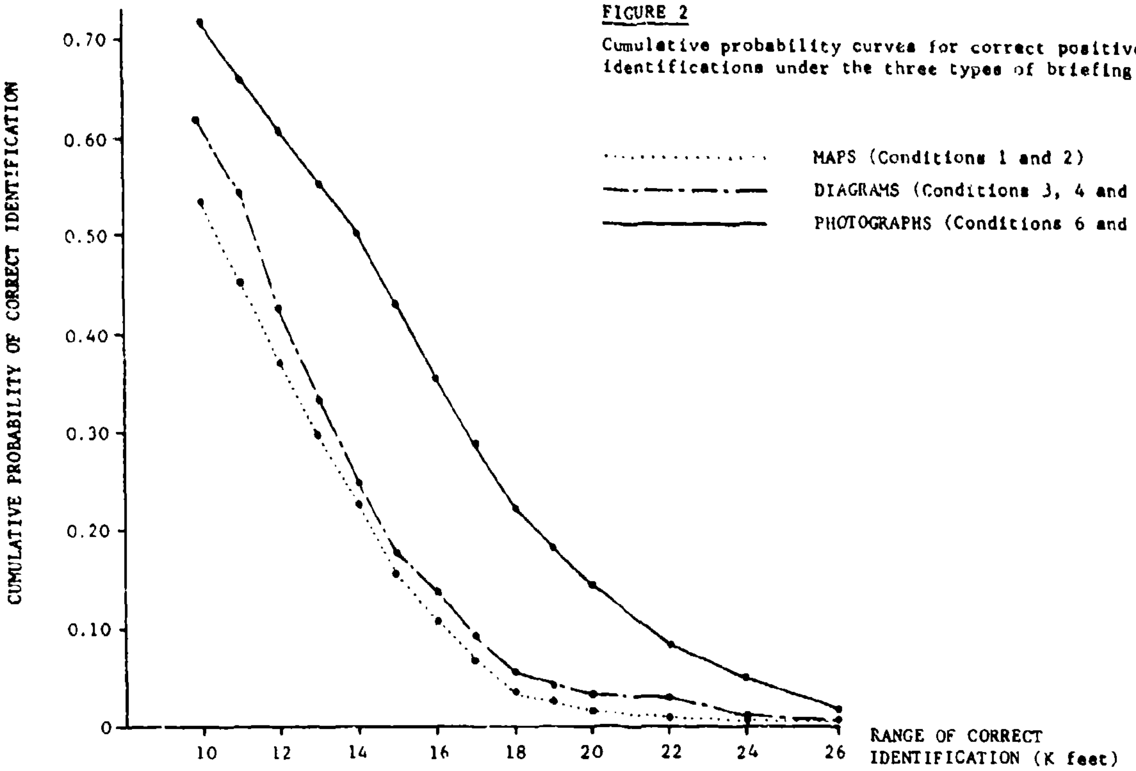


FIGURE 2

Cumulative probability curves for correct positive identifications under the three types of briefing.

(iv) Comparison of skilled and unskilled subjects

The performance of the six skilled subjects assigned to the ¼M map only condition was compared with that of six unskilled subjects (students) tested under the same briefing condition. The results showed that in terms of the probability of correct identification there was very little difference between the two groups, the corresponding values being 0.55 for the skilled group and 0.53 for the unskilled. However, the unskilled subjects tended to make positive identifications at a shorter range, on average approximately 1000 ft. (305 m) closer to the target. The difference between the two groups was much more marked in terms of the probability and range of correct target area designation, in this case the skilled subjects showing substantially higher success rates and longer ranges.

(v) Individual differences

Tests were carried out to determine whether an individual's performance was related to his age, flying hours or scores on Heim's AH5 test but no significant correlations were found.

(vi) Subjective assessments of task difficulty

In general, the subjects' responses to the questionnaire items asking them to rate, on the basis of the briefing information provided, the difficulty of locating the target area, and of identifying the target itself correlated well with their measured performance, and with the further assessments made by the subjects after the simulated run. For instance, the subjective assessments of the difficulty of locating the target area, made with reference to the briefing information, correlated highly with the proportion of correct designations made ($p < 0.005$), and a similar correlation was observed between the expected difficulty of identifying the target and the proportion of correct positive identifications. Thus it appeared that, in general, subjects were able to make valid predictions of the difficulty of target area location and positive identification from the briefing materials provided. However, there was no evidence that the provision of additional briefing materials, diagrams or photographs, increased the accuracy of these predictions, as compared with those made solely on the basis of map information.

6. DISCUSSION

The results of this experiment confirm the findings of previous studies that the use of oblique photographs of the target and surrounding area as briefing material, in addition to standard maps and target descriptions, significantly improves target acquisition performance as compared with that obtained when such photographs are not available. As far as can be judged, the magnitude of the effect in terms of both probability and range of positive identification, was in general agreement with that reported from other studies. However, the main purpose of the present experiment was to determine whether, in the absence of suitable oblique photographs, target acquisition performance could be aided by the provision of oblique views derived from maps. Televisual target acquisition tasks would appear to lend themselves particularly well to this form of aid, since field of view and camera depression angle are fixed, and altitude varies only within relatively narrow limits. Thus oblique views can be generated from maps or other sources such as vertical photographs, to correspond to the television display at specified ranges, providing the direction of the approach track is known. The results obtained in this experiment showed that, in general, the provision of such diagrams improved the overall probability of positive identification, as compared with conditions in which only the corresponding maps were provided. The overall effect was significant, and of a magnitude about half as great as that due to oblique photographs. However, whereas the latter had also brought about a considerable improvement in range of correct identification, the diagrams did not. The overall mean range at which identification occurred under the diagram conditions was effectively the same as that under the map conditions. Examination of the cumulative probability curves showed that the improvement in identification probability occurred almost entirely at ranges of 10,000-12,000 ft. (3.05 Kms to 3.67 Kms). These ranges were the ones at which the 2 mile (3.2 Kms) briefing diagram would correspond most closely to the simulated TV display. There was, however, little sign of a similar effect for the 4 mile (6.4 Kms) briefing diagram, which was outside the maximum identification range for most targets.

The failure of the diagrams to bring about improvement in identification range may have been due, at least in part, to the fact that the briefing ranges chosen were inappropriate for the targets studied in this experiment. The 4 mile briefing diagram was at too short a range to affect target area designation, (which occurred on average at about 5 miles range) and too long to have much effect on positive identification of the target. The 2 mile briefing diagram only affected performance for targets which would otherwise not have been identified, or which were identified only at very short ranges. It is possible that diagrams showing the target and lead-in features from longer ranges, say, 3 miles and 6 miles, would have been more effective in improving performance, particularly range of identification, than those used in this experiment.

Since the diagrams were derived solely from the information on the maps, any effect on performance must have been due to the presentation of this information in an oblique form, facilitating the use of background features as clues to target position. This type of presentation appears to have been valuable in improving identification of the eight targets for which identification probability was very low (<0.50) when only map briefing was provided. It is likely, therefore, that for these targets the use of contextual clues was an important factor leading to location and subsequent identification of the target. For the remaining eight targets performance was relatively good under all conditions, and the provision of diagrams did not aid identification as compared with the corresponding map conditions. Most of these targets were relatively conspicuous, and consequently there would be less need for the observer to rely on background clues, and less value in the use of briefing diagrams, particularly as they provided very little information about the appearance of the target itself. It is of interest to note that there was no evidence that the briefing diagrams led to any increase in commissive errors, as could have occurred if they had proved to be misleading.

The superiority of oblique photographs as briefing material, particularly in improving identification range, was clearly demonstrated in this experiment. This superiority can be ascribed to the detailed information the photographs provide about the appearance of the target itself, about vegetation patterns and masking effects, and the general shades and textures of the terrain, which form a complex background to the target. In the present experiment, the effectiveness of the photographs was accentuated by the fact that they were taken at the same time as the cine-film used in the simulation. Thus they corresponded very closely to the simulated TV display, not only in altitude and direction of approach, but also in lighting conditions and cloud shadows, which had a marked effect on the appearance of the terrain. In addition, the photographs used in the present experiment were of a higher quality than such photographs would normally be under operational conditions. For these reasons the data obtained in this experiment may well have exaggerated the effectiveness of the photographs, in relation to the other forms of briefing tested, as compared with that achievable in practice.

One way in which the effectiveness of the diagrams could be improved to approach more closely that of oblique photographs, would be by including information derived from high-altitude vertical photographs of the target and surrounding area, and other intelligence information. This would allow more detailed representation of the target itself, and of vegetation patterns and masking effects, than can be derived solely from maps. In particular, the limited amount of detail shown on ¼M maps is not usually sufficient to allow realistic oblique views to be prepared, and additional information from other sources would make these representations more effective. In addition, as discussed previously, appropriate briefing ranges must be chosen with reference to the characteristics of the viewing system and the nature of the targets concerned. Finally it should be noted that if, as it appears from this experiment, failure to correctly visualise the appropriate oblique view from a map contributes to the difficulties of target acquisition tasks, then this may have implications not only in relation to briefing information, but also to selection and training problems.

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DISCUSSION

Mr Overington (UK)

Were the improvements due to photographic briefing referable to the fact that these photos were taken at the same time as the cine films used in your simulation? If they were, they would freeze all variability of weather, foliage, view angle and so on.

Miss Parkes (UK)

I take your point. As I noted, stills were taken from the cine film itself. Cloud effects were common, a factor you didn't mention, and I take this to be highly important. Improvements due to photographic briefing were exaggerated in my experiment.

Wing Commander Anderson (UK)

Did you intend to vary angle of approach, insofar as preparation of the diagrams or photographs is concerned?

Miss Parkes (UK)

I would have liked to. It seems to me most unrealistic to test always against oblique diagrams showing the same approach angle, and this has very commonly been done in briefing experiments, presumably for ease of preparation of material. It should be investigated.

THE USE OF KELLY'S REPERTORY GRID TECHNIQUE FOR ASSESSING SUBJECTIVE ESTIMATES OF IMPORTANT PARAMETERS FOR TARGET ACQUISITION

Mrs A.J.Mitchell
British Aircraft Corporation Limited
Guided Weapons Division Bristol Works

SUMMARY

Kelly's Repertory Grid Tecanique was employed to study the area of subjective factors involved in visual acquisition of targets, in the hope of covering the discrepancy between the data obtained from psycho-physical studies and actual field data. Two experiments were conducted using highly trained aircrew which have led to the definition of some subjective parameters, and estimates of their importance. Through analysis, three major overlying components were elicited, each giving a scale along which targets could be scored.

These major components were:-

1. The target has visual prominence against the background - Target is absorbed into the background.

2. The target is in a helpful built-up environment - Target is in an urban environment.

3. There are geographical and map identification features around the target to aid acquisition - Ease of acquisition is not increased by identification features.

The next step now must be to investigate any correlations between these results and physical data and attempt to discover a factor forming a link between the two, to improve any model of prediction of performance.

INTRODUCTION

Concern with the understanding of visual acquisition of targets had led to experimentation on several target and observational parameters involved, such as; target size and shape, contrast, complexity, angle of view, meteorological visibility, and speed and altitude of approach; mainly using psycho-physical techniques. However discrepancy was found between the physically measured data and field data, and thus it was felt that not enough work had been done on the more subjective estimates of the factors involved in visual acquisition, which might decrease the discrepancy.

To this end, experiments were initiated with the intention of studying more closely the perceptual and cognitive processes of the observer during target acquisition, with particular emphasis on the problems involved in seeing targets against a structured background as opposed to a simple background. For this, a procedure was required which would both identify the pilot's thoughts about each target in his own terms; while at the same time, would produce data which could be analysed and assessed in a usable form. These requirements eliminated two methods immediately springing to mind, namely, the uncontrolled free choice method, and the forced choice method which merely gives subjective measures of the experimenter's own thoughts. After consideration, it was suggested that Kelly's Repertory Grid Technique might be an adequate instrument for the proposed investigations.

The Repertory Test was devised in 1955 by G.A. Kelly (1) as an integral part of his Personal Construct Theory, in which he suggested that each person has a set of constructs, a construct system, by which he appraises his position and surroundings, and attempts to anticipate future events. Each of these constructs will apply only to a certain number of situations in an individual's experience; and they probably will not exist in isolation; some may tend to over-lap; and certain ones will be more important or more general than others.

All constructs in Kelly's Theory are assumed to have bipolar dimensions, and the relationship between the two poles to be that of contrast. The pole representing the construct is termed the construct or emergent pole, and the contrasting pole, the contrast or implicit pole.

The Repertory Test was designed to look at the content and structure of these construct systems, and provides a means by which statistical measurements can be made of the relationships between constructs. It was initially aimed at role constructs, and in the original procedure the "Minimum Context Card Form" was used. Although variations on this form of Repertory Test have been suggested, it was considered that the original procedure would be the most useful for this present investigation. (See description in METHOD).

Kelly devised an extension to the basic method, the Grid Form, in which once the construct had been elicited, the subject was asked to classify each element under one or other of the poles. This can be done for each construct, and the whole grid drawn up in tabular form, with the elements along one axis and the constructs along the other. Various modifications of the Grid method have been designed, but the one considered to be most useful for this investigation was the Rating Grid Form in which the subject rated each element for each construct on a scale of 1 to 7. This method allows the subject to allocate as many elements as he wishes to either pole, while at the same time being able to draw greater distinction between the elements.

The entire Repertory Grid is based on a large number of assumptions:-

(a) That the sample of elements is an adequate representation of the total population of relevant elements in the subject's environment.

(b) That the relationship between the two poles of the construct is that of pure contrast. In experiments employing the Repertory Grid technique the subjects are rarely asked to rank or rate the elements for both poles, although if time was available the validity of the results would be enhanced by this.

(c) That the constructs given by the subjects can be applied to situations with which the subjects have not been confronted. Hunt (1951, in Bonarius 1965)(2) demonstrated the validity of this assumption.

(d) That the constructs elicited are pre-existing, and are not newly developed during the test.

(e) That the subject does not alter his view at all between the process of eliciting construct poles, and of using them for sorting the elements. If he does blur the distinction he makes between the poles it may be said that rather than giving a construct and contrast pole, the subject in actual fact is using two construct poles. Thus it is important to re-check the construct and contrast pole meanings with the subject while he is completing the sorting task.

(f) The experimenter must assume that the verbal labels the subject gives to the construct, and the explanation of the meaning of the construct given, is adequate to give the experimenter a practical understanding of how he is organising the elements in the test.

Some constructs do not have verbal labels, and represent non-verbal and pre-verbal bases of discrimination and organisation, (Bannister and Mair 1968)(3). These may occupy important positions in the layout of an individual's orientation towards himself and his environment. Also, sometimes only one pole of a construct will be capable of upholding a verbal label and in such a case the other pole is said to be submerged.

As well as accepting the assumptions behind the Repertory Grid Technique, there are certain practical difficulties involved in its use. Each subject will usually be required for a considerable length of time to complete an exhaustive interview. However, as the subject is intimately involved with the matter of the test, the results are unlikely to be affected by the boredom of the subject.

As has been previously suggested, one of the main difficulties is that of understanding the verbal labels given to the constructs. The experimenter has to be careful not to prompt the subject while he is eliciting constructs, and also to be careful to record the subject's personal interpretation of them, uncontaminated by any view the experimenter himself may hold.

Even when just one grid is completed, a large amount of data is produced. Thus if a number of subjects are used, extensive analysis will be required to draw out all the available information. It has been suggested that it may be worthwhile investigating a single case in depth when an elaborate course of treatment is under progress. (P. Slater 1965)(4).

After consideration of the assumptions and practical problems involved, the validity of the Repertory Grid Technique might be questioned. A test/retest validation cannot be designed for an individual, but possibly it may be applied to a grid designed for general use. The internal consistency of a Repertory Grid can be established through the occurrence of significant relationships between certain of the constructs. Possibly similar grids obtained from the same subjects on different occasions could be compared entry by entry, although slight differences would be expected.

Bannister and Fransella (1967)(5), conducted a study to assess the validity of a Repertory Grid's measure of political construing, and found that, in this context, Repertory Grid techniques appeared to have substantial validity.

Despite the assumptions and difficulties involved, there are several advantages in using the Repertory test. By using this technique one is able to covertly examine the relationship between a subject's construct dimensions, without the subject fully realizing what is being measured. Most subjects tend to imagine that it is their actual judgement of each element within the sorting task which is being measured.

A second advantage is that Repertory Grid testing is essentially a highly flexible technique, and not a single test. Elements, constructs, elicitation procedure, and scoring method can all be varied, and thus there appears to be little practical limit to the range of the type, size and purpose of individual grids, which can be formed. This flexibility means that the technique is potentially useful for numerous types of investigation, for explaining individual's construct systems on many topics, by varying the elements accordingly. Also, the test enables the investigator to record quantitative information on areas of personal conceptualisation, which are difficult to examine by the more conventional methods of questionnaires, standard interviews and projective tests.

One of the major advantages of the Repertory Grid Technique is that it permits the study of the dimensions along which the subject locates individuals, and the rest of the world which confront him, rather than an attempt to classify the subject on the examiner's own personal dimension system.

This study uses the technique to examine factors affecting visual acquisition of targets by pilots flying at high speeds and low altitudes. Thus, essentially, what is of interest are the pilots construct dimensions around the area of detection and recognition of various types of targets, in order to view the targets through the pilots eyes and use the information thus gained in the way the pilot would utilize it, rather than as the experimenter thinks the pilot would see the target and use the information.

As it is hoped that the subjective results obtained will be used in conjunction with objective measurements, quantitative data on the subjective estimates is required, with the eventual aim of classifying the targets in these terms. Due to the Repertory Grids versatility, then, it is possible, by selecting the relevant elements, administration procedure and scoring method to make the technique applicable to the present problem.

The study was conducted in two parts. The first experiment was designed as a preliminary investigation to elicit the main constructs used in this area; and the second experiment, to verify the results obtained, and to investigate the effect of using two different interviewers; and of "giving" the subjects constructs which have previously been elicited, to rate the elements on. As the entire procedure of eliciting constructs and rating them, was very lengthy, it was hoped that this could be shortened, particularly in further experiments where it might be just part of the investigation, either by using more than one interviewer, or by the subjects rating "given" constructs. Hence the reason for the latter part of the second experiment. It should be noted, that although this procedure of "giving" constructs could be termed "prompting", the prompting was done, not with the experimenters thoughts, but with the constructs generated by other aircrew subjects.

To sum up the introduction, the experimental aim of the investigation is: to establish the way in which aircrew construe targets.

EXPERIMENT 1.

METHOD:

Nineteen highly trained aircrew were used as subjects. Fifteen elements were used, taking the form of photographs of targets, varying in taking range from 5K ft. to 20K ft. Ordnance Survey Maps (scale = 1" to 1 mile) of the relevant area with the actual target ringed, were displayed with the photographs.

Each subject was interviewed individually, each interview being initiated by a brief explanation, during which it was emphasised that the experimenter was interested in the visual acquisition of the targets, and thus, factors such as the quality of the photography, etc., were not really of importance to the main aim. Such an instruction was felt to be justified in this particular case, as aircrew are used to identifying targets from photographs, and can generalise from photographs to actual conditions. The set of photographs and their maps were then presented, one at a time, and the subject was told what the target was, and asked to locate it on the photograph using the maps as a guide, thus to a small extent, simulating an acquisition task.

The minimum Context Card form for eliciting constructs was employed. That is, the subject was shown a triad of the target photographs and asked to give one important way in which two were similar, and differed from the third, with respect to the visual acquisition of the targets shown. The construct elicited was recorded, and the subject asked to specify the contrasting pole, if this had not already been stated.

A rating form of scoring method was used, employing a seven-point scale. The subject was asked to rate all the elements, on the seven-point scale, for that construct; first rating the elements not included in the triad, and finally the elements in the triad; where the elements exactly illustrating the construct pole were rated one, and those at the contrast pole, were rated seven. If the subject felt unable to rate any elements for a certain construct, he was asked to give it a rating of 0.

If a subject gave a construct, and then on being asked to rate the elements on it, felt unable to rate the majority of them, either because the construct applied only to the particular triad of elements it was elicited on, or because the construct was not scaler, the construct was noted down and the subject encouraged to suggest a different construct.

Once the ratings on one construct were completed, three more targets were selected, on the basis of their having similar ratings on the previous construct; and were presented to the subject, who was again asked to suggest a way in which two were similar and differed from the third.

This procedure was repeated a number of times to elicit further constructs, until the subject did not appear to be able to generate any more original constructs.

If, during the Repertory test the subject did not introduce the construct of the target standing in a simple background as opposed to a structured background, then this was given to the subject at the end of the interview. Care was taken both to specify both poles of the given construct, and to ensure as far as possible the subject's interpretation of the label given to the construct was similar to that of the experimenter's.

Throughout the interview, care was taken not to prompt the subject in anyway, and notes were taken of any remarks the subject made either in explaining his constructs, or of any more general remarks on target acquisition.

RESULTS:

The data from each subject was recorded in tabular form, with the elements along one axis, and the constructs elicited along the other. (For an example see table A).

Twenty apparently different constructs were elicited:-

SUBJECT: 4
DATE: 12/2/71.

FLYING HOURS: 1200
PRESENT DUTIES: NAVIGATOR
AIRCRAFT: BUCCANEER

GLOUCESTER 10.K	FAREHAM	FORT NELSON	LITTLEHAMPTON	NEWPORT PAGNELL	SALISBURY	WEYHILL	GOSPORT 15K.	SHOREHAM	GOSPORT	WOOKEY HOLE	HAYLING	M50/RIVER SEVERN	CORFE	YEOVIL
1	1	7	4	2	3	2	4	1	2	7	2	(7)	(3)	(1)
7	6	7	7	7	7	7	7	7	7	6	7	(7)	(1)	(2)
2	7	(3)	(6)	7	7	7	7	(1)	2	7	2	1	1	2
2	1	2	1	(2)	(7)	(2)	2	1	3	7	1	1	1	1
1	(2)	7	1	1	2	1	1	1	2	3	(3)	3	(7)	7
1	(1)	0	1	1	(3)	3	1	1	(6)	2	3	3	2	2
1	(1)	3	3	(5)	7	3	2	(1)	2	3	1	1	1	1
1	5	(1)	(4)	5	7	(4)	2	2	3	3	3	2	2	1
5	2	3	3	2	7	3	5	3	7	7	1	6	1	2

• ( ) MEMBER OF TRIAD

CONSTRUCTS

(1) Good lead-in features - No lead - in features.
1 7

(2) Helpful Contours. - No helpful contours.
1 7

(3) Good vertical displacements - No vertical displacements
1 7

(4) No confusion around target - Confusion around the target
1 7

(5) Good I.P.s. - No I.Ps
1 7

(6) Range and bearing from known feature
Good 1 Bad 7

(7) Aspect of the target
Good 1 Bad 7

(8) Contrast
Good 1 Bad 7

(9) Simple background - Complex background
1 7

TABLE 'A'

Construct Pole		Contrast Pole
Simple Background	-	Complex Background
Vertical Displacement	-	None
Lead-In Features	-	None
Good target/background contrast	-	Poor target/background contrast
Large target	-	Small target
I.P.s (Identification Points) near the target	-	None
Unique target	-	Not unique
Uncamouflaged target	-	Well camouflaged
Target is near a built-up complex	-	Not near a built-up complex
Water as lead-in feature	-	None
Target is unobscured on approach	-	Obscured
Familiar target	-	Target is not familiar
Target is not confusible with other features	-	Confusible
Area target	-	Pin point target
The target is a line feature	-	Not
The target is immediately recognisable	-	Not
Helpful geographical location of target	-	Not helpful
Shape of target contrasts with surrounding	-	Poor shape contrast
Good range and bearing from known feature	-	Poor
Good target aspect	-	Poor target aspect
Photograph is true to map	-	Not
Movement on or around target	-	None
Easy back-stop	-	None
Target easily seen whatever the weather	-	Will not be seen easily in bad weather
Local knowledge	-	None
Easily destructable target	-	Not

Other constructs given that were not rated

The targets are bridges	-	Not
No cloud shadow over target	-	Cloud shadow
Water near the target	-	None
The target is on a coastline	-	Not

A Principal Components Analysis was carried out on the raw data grids, using a program provided by the M.R.C. service for analysing Repertory Grids.

The nineteen subjects generated 161 constructs (although many were similar across subjects), and the Analysis was used to reduce these constructs to a set of overlying components. One way of defining a principal component is as a scale which can be derived from the constructs for measuring the elements. It is also possible to relate a component directly to the elements and define it in terms of an element vector from which construct loading can be derived. (Slater 1967)(6).

Fourteen components were brought out, the first three appearing to be major ones and a further three having certain prominence. Dr. Slater suggests that although many components may be needed to complete an exhaustive analysis, it is unusual to find much variation left in a grid after three components have been extracted. In this case, the first component accounted for thirty six percent of the total variation within the grid; the first three components for approximately sixty percent; and the first six for eighty percent. Thus, these six components were studied more closely.

The loadings of the constructs and elements on each of the six components were given by the program. In an attempt to find verbal labels for these components, the constructs and elements with either high positive or high negative loadings were identified and plotted on a single axis. (For an example see Table B).

The constructs at one end identify one pole of the component, and those at the opposite end, the contrasting pole. By comparing across the element and construct axes the main constructs describing each target can be seen.

The program also showed the Polar Co-ordinates, i.e. "latitudes" and "longitudes", for each of the constructs and elements, which enabled their distribution in three-dimensional space to be illustrated, by mapping them on spheres. By doing this, a picture of the clustering of the constructs was given, and the

LOADINGS ON COMPONENTS (1)

HEAVILY LOADED CONSTRUCTS			ELEMENTS	
Urban Environment Complex Background Not Isolated No Lead-In | Not Unique Poor Contrast		Target is in the Middle of Activity Urban Environment Well Camouflaged Small Target Poor Shape Contrast Poor Contrast		Salisbury Bus Station
	0.8		4.0	
Complex Background		Poor Contrast Complex Background		
	0.6		3.0	
		Near a Built-Up Complex		
	0.4		2.0	
Near a Built-Up Complex		Funnel Features Load-In Features		Stratford Theatre
	0.2		1.0	Henstridge Control Tower
I.P's Near the Target Flat Terrain		Man-Made Features		Weyhill Radio Masts Merrifield Control Tower Gosport Oil Tanks Gloucester Cathedral
	0		0	
Natural Features		Rolling Terrain No I.P.s.		Bridgewater Bridge Rampisham W.T. Station Ford Rail Junction
	-0.2		-1.0	
No Built-Up Complex		No Lead-In No Funnel Features		M50/River Severn Yeovil Causeway over Reservoir Longleat House Shoreham Road Bridge Naval Vessels
	-0.4		-2.0	
		No Built-Up Complex		
	-0.6		-3.0	
Good Contrast		Simple Background Lead-In Features		
	-0.8		-4.0	
Good Shape Contrast Isolated Target Unique Target Not Camouflaged Target in Open Country		Simple Background Large Target Good Contrast Rural Environment Simple Background Rural Environment		

TABLE 'B'

relationship between constructs and elements, shown, i.e. Constructs which lay nearest together, correlated most closely. (For examples, see Tables C and D).

CONCLUSIONS

Although an extensiveamount of information was obtained through the analysis, difficulty was found in converting statistical figures into psychological prose, as there was still a degree of subjectiveness in selecting verbal labels for the components. However, this was tentatively attempted by a panel of three, bearing in mind the intention to check them in a second investigation.

By examining the constructs with high positive and high negative loadings, and the respective elements, on component 1, it was decided that the constructs underlying the components were mainly concerned with the target in its immediate background, and whether it stands out, or it absorbed into the background. This was validated by looking at the targets with high positive loadings on this component, and also by the distribution of constructs around the major axis, of the sphere. The following five components were examined in a similar manner, and it was suggested that the verbal labels for the first three components be:-

1. The target has visual prominence against the background/Target is absorbed in the background.

2. Helpful built-up environment/Rural environment and target simplicity.

3. Geographical and map identification features around the target to aid acquisition/Ease of acquisition of target is not increased by I.P's etc. as target features alone are sufficient for acquisition.

Difficulty was found in allocating labels to the next three components, although it is thought that they may be concerned with actual target features.

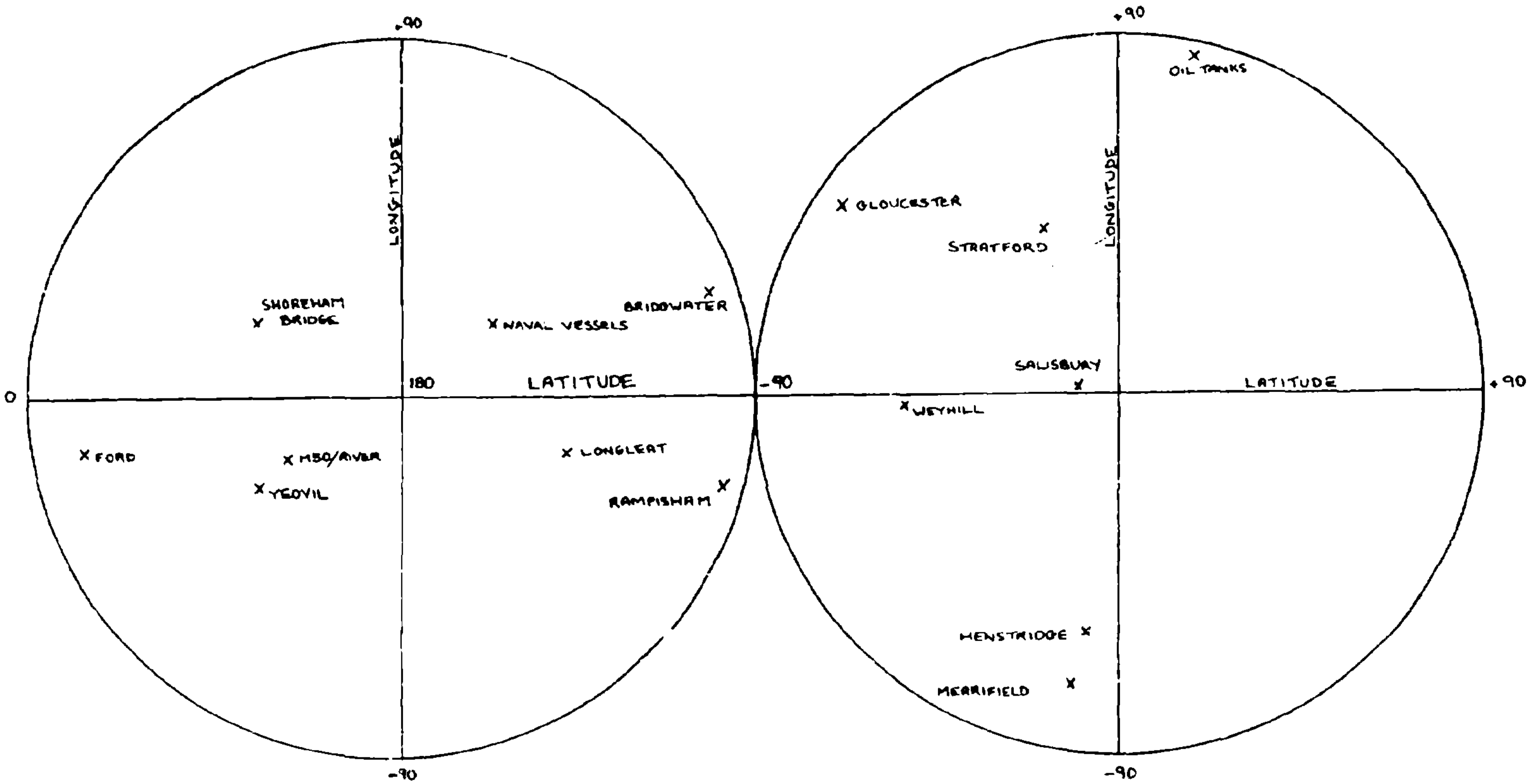

TABLE C

DISPERSION OF ELEMENTS - DIRECTIONS OF TARGET VECTORS.

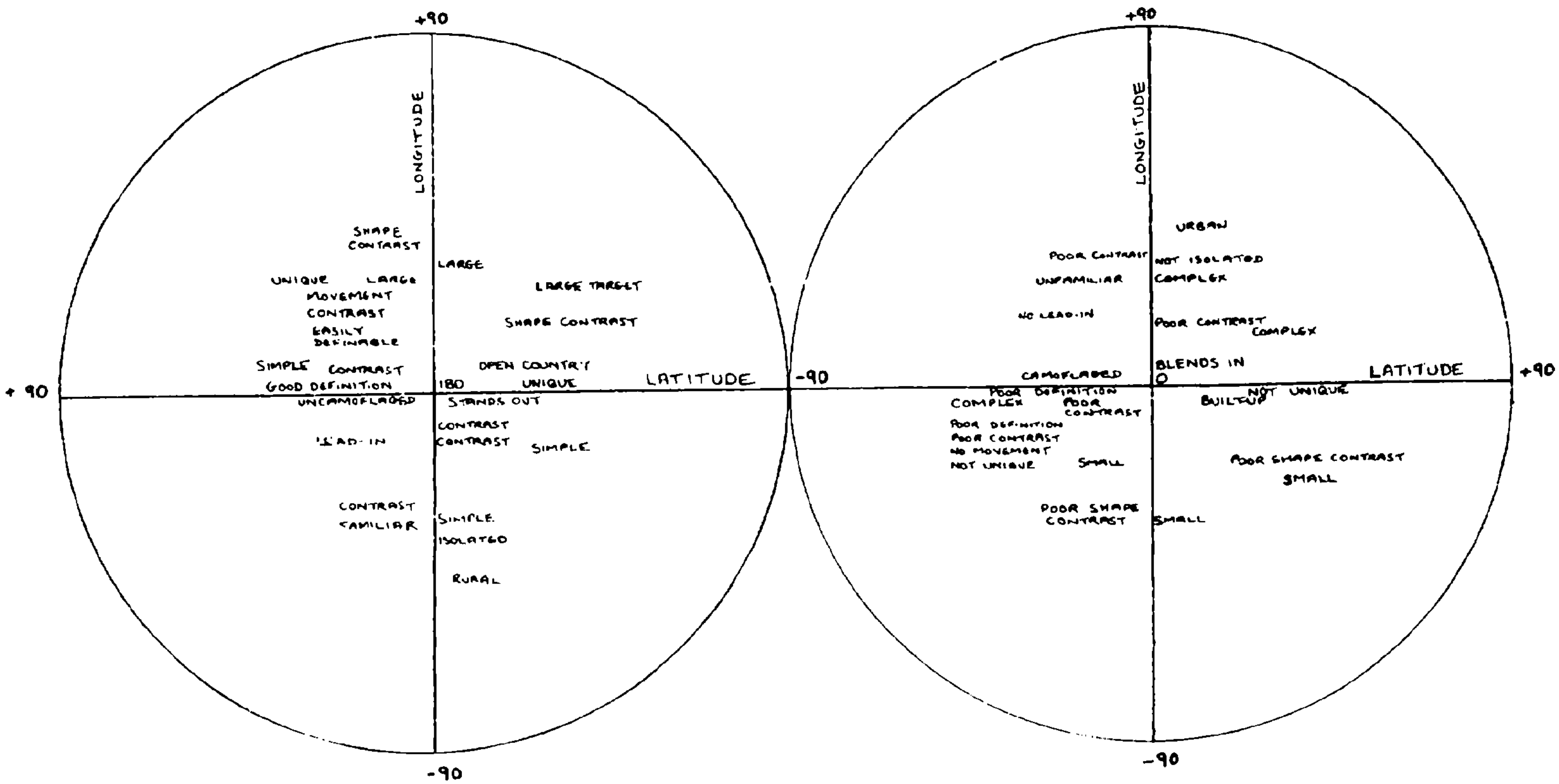

TABLE D

DISTRIBUTION OF CONSTRUCTS HEAVILY LOADED ON COMPONENT ONE.

EXPERIMENT 2

METHOD.

Two groups of sixteen subjects were used, all of whom were trained aircrew.

Fifteen different photographs of targets, all taken at a range of 5K ft. were selected using knowledge gained from the previous experiment to ensure a varied but representative selection of elements. Ordnance survey maps of the relevant areas, were again presented with the photographs.

Essentially the same procedure was used as in the preliminary study, except for the following modifications:

(a) Two groups of subjects were used. The subjects in the first group were interviewed in exactly the same manner as those in the previous experiment. However, the subjects in the second group were not required to elicit their own constructs, but were "given" fourteen constructs derived during the previous study, and from the first group of subjects in the study; on which to rate the elements. The "given" constructs were:-

1.	Simple background	-	Complex background.
2.	Good vertical displacement	-	Poor vertical displacement.
3.	Good line lead-in features	-	None.
4.	Good colour contrast	-	Poor.
5.	Large target	-	Small target.
6.	Identification points near target	-	None.
7.	Unique target	-	Not unique.
8.	Uncamouflaged target	-	Well camouflaged.
9.	Target unobscured on approach	-	Obscured.
10.	Familiar target	-	Not familiar
11.	Unconfusible target	-	Target could easily be confused with nearby features.
12.	Helpful geographical location	-	Not helpful.
13.	Target near a helpful built-up area	-	Not.
14.	Good shape contrast	-	Poor.

Both poles of each contruct were supplied, and care taken over the subject's interpretation of each. The order of presentation of constructs was randomised for each subject.

(b) Two interviewers were used, each taking eight subjects from both groups.

All subjects were shown the same set of photographs and maps.

RESULTS

The data was tabulated as in Experiment 1.

Both interviewers elicited similar sets of major constructs from their subjects, and thus it was possible to examine the effect of using two different interviewers, on the subject rating of the elements. A Kendall Coefficient of Concordance test was carried out on both groups of subjects:- for Interviewer 'A', for Interviewer 'B', and for both combined; on six main constructs. This indicated that there was no significant difference between the ratings by the subjects under Interviewer 'A' and those under Interviewer 'B', and also, that in all cases the subjects appeared to be using a similar scale of reference for rating targets on similar constructs.

Again, a Principal Components Analysis was carried out on the raw data grids, taking the two groups separately. For the first group, fourteen components were brought out, the first six being studied more closely, as in the previous study. The grids derived from the second group, by "giving" the subjects constructs, were treated slightly differently, in that they were aligned by construct and element, and combined to form a Consensus Grid. High correlation (the lowest being 0.65) was shown between individual grids and the consensus grid.

OVERALL DISCUSSION OF RESULTS FROM BOTH EXPERIMENTS

The constructs generated during both experiments were very similar, and the few constructs elicited in one study and not in the other were either very general, e.g. Target is immediately recognisable/not; target is predominant/not; or were elicited by only a few subjects.

Subjects tended to generate the first few constructs readily, and then think more carefully over further ones. Also, if the triads presented early on in the interview did not allow for the elicitation of constructs which the subject personally felt most important, then the subject would either introduce these into general conversation at the first opportunity, or would elicit them when presented with a further triad of elements, whether they were representative of it or not. A number of apparently important constructs appeared regularly across the subjects, the order of their appearance depending on the targets used in the elicitation triads, as the importance of any construct varied from target to target.

The nucleus of regularly generated constructs consisted of:- contrast of target against the background; size of the target; vertical extent of the target; lead-in and identification features; the shape of the target contrasting with surrounding shapes; and the complexity of the background and the predominance of the target. The size and vertical extent of a target were always judged in relation to its background. If the target was a large building in the centre of a complex of large buildings, then it would not itself appear large, whereas if the same target was surrounded by smaller buildings or fields, then it would seem much larger. In a similar manner, the immediate background will also affect the apparent vertical extent of the target.

The best types of lead-in features were considered to be railways, rivers, and motorways, and the best identification points, woods and water features; although it was stressed that if there were too many rivers and woods etc., then they would merely increase confusion rather than being of any help.

In some of the photographs, the targets were large, contrasted sharply with the background, and took a prominent position on the photograph, and thus could easily be acquired without the use of any lead-in or identification feature, although these could be present, in this type of case subjects found difficulty in rating the photograph for useful lead-in or identification features as they were not actually required. However, under real conditions, a pilot would use lead-in features and track checks a long time before he could actually see the target and thus the subjects referred to the Ordnance Survey maps for earlier evidence of lead-in features, in order to rate the targets for these constructs.

As a first step in the analysis of the results, the Kendall Coefficient of Concordance test was carried out on the raw data grids, and the results indicated that on the whole, the subjects used a similar scale of reference for rating the elements. This was even true in the second experiment, regardless of which interviewer was testing. Although interviewer 'A' was more restricted by subjects' length of availability, and thus did not obtain as many constructs as interviewer 'B', both interviewers obtained similar major constructs; and thus it would seem that there was little difference between the results gained by them. However, the interviewers held a series of pre-test discussions on the Repertory Grid technique, and planned as far as possible how to conduct the interviews, using the strategy of saying as little as possible during the experimental sessions to avoid prompting subjects, while at the same time encouraging them to elicit new constructs and helping with any problems arising in the rating of the elements. Thus, before it can be assumed that any number of interviewers can be used, this aspect of the technique should be examined further, as probably interviewers should be trained in the technique together, in order to gain similar results.

From the Principal Components Analysis, loadings of constructs and elements on each component could be examined in order to suggest verbal labels for the components.

Constructs from the consensus grid at the positive end of component (1), were of the type:- "Target is near a helpful built-up complex"; "Target is well camouflaged"; "Target is obscured"; there is poor target/background contrast, and "the target background is complex". These were also shown by the analysis of the grids using "elicited" constructs from both experiments. All sets of results showed similar constructs at the negative end of the component, e.g. "target is unique", "target is isolated"; "target is not camouflaged"; "the target background is simple"; and "there is good target/background contrast". Hence the major component appeared to be an overlying factor concerning the visual prominence of the target as opposed to it bein absorbed into the background.

Underlying component (2), from both groups of experiment 2, are the constructs; - "good vertical extent"; "large target"; "built-up complex"; and "no lead-in features"; at one component pole; and the constructs: - "small targets"; "good lead-in and identification features"; and "poor vertical extent" at the opposite pole. These correspond to the constructs underlying component (3), of the first study. It was decided that the component overlying these constructs could be described by, "whether the terrain surrounding the target has useful identification and run-in features, or whether the target is so large and unique in the area that the eye will immediately be drawn to it and thus identification points will not be needed".

Both sets of grids in the second study gave the following constructs at the positive end of component 3:- "target is near a helpful built-up complex;" "the target background is complex"; "target has poor vertical extent" and, "good lead-in and identification features"; and at the opposite pole:- "simple target background"; "no built-up complex"; "unique target" and "lack of other features to confuse the target with". These constructs correspond to the constructs under component 2 in the first study. Thus the overlying component could be labelled, "The environment is a helpful, built-up area./ The target environment is simple".

Components 4, 5 and 6 do not appear to take any obvious form for any of the groups of grids examined, and thus it is considered that as far as these studies show, the first three components cover the most important factors, according to subjective estimates, for influencing the visual acquisition of targets. However, one cannot say that the less obvious components are completely devoid of interest as they may involve considerations that only a small number of subjects had noted and felt important.

Although a few difficulties in using the Repertory Grid technique were encountered, namely, that of interpreting accurately the meanings implied by the subjects to their constructs; and the considerable length of time needed to complete an exhaustive interview with each subject; these were not unsurmountable, i.e. detailed notes were taken of subjects' descriptions of their constructs; and longer periods of time could be made available. Thus, overall the technique was considered to be a highly sophisticated instrument, capable of providing adequate information about the way in which aircrew construe targets.

To sum up the information gained in these two studies, it was shown; that the aircrew subjects tended to use similar constructs, and to use the same scale of reference for rating the elements on the constructs; that the targets are seen in relation to their background and not in isolation; that there was little difference in the data collected by the two interviewers; and that the grids containing elements rated on "given" constructs gave the same principal components as those with "elicited" constructs, although the weighting given to the first component, by the subjects rating "given" constructs was much heavier, than that given by other subjects. The three major components derived, overlying constructs used for the acquisition of targets were:-

(1) The target has visual prominence against its background./ The target is absorbed into the background.

(2) There are geographical and map identification features around the target to aid acquisition./ Ease of target acquisition is not increased by identification featres.

(3) The target is in a helpful built-up environment. /Target is against a simple background.

The first of these appears to be dominant.

The next step is a comparison of grid results with physical data, in order to gain a more complete model for prediction of performance. Attempts are already being made in this direction, using psycho-physical techniques for recording detection and recognition thresholds, followed by a Repertory test, using the same targets.

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SOME PSYCHOMETRICS IN RELATION TO TARGET ACQUISITION

by

Sandra J. Seale

BRITISH AIRCRAFT CORPORATION LIMITED
GUIDED WEAPONS DIVISION : BRISTOL WORKS
TARGET ACQUISITION RESEARCH GROUP

SUMMARY

The variance associated with acquisition performance arises from 'between subject' differences and 'within subjects' differences. Psychological tests have been used in the past in an attempt to assess the factors contributing to this variance, but the results have been inconclusive. A recent more intensive study was conducted, using a pattern discrimination test, the Witkin Embedded Figures Test. Previous experimental work using this test indicated that the test would be suitable for the target acquisition situation in that it would estimate analytical ability, which was hypothesised as being a factor contributing to the variation in acquisition performance.

Although no overall significance was found between EFT scores and measures of acquisition performance under various briefing conditions, the study highlighted the difficulties involved in using psychometric tests in the context of target acquisition. The paper examines these difficulties and illustrates the contribution to the methodology in this area to which they have led.

1. INTRODUCTION

Studies of target acquisition have concentrated mainly on the effects of environmental and target parameters on operator performance. Among the aims of this research is the ability to predict operator performance under a given set of conditions. In its simplest terms, it is hoped that this information will be of use in the design of weapon systems. The results of many simulation studies indicate that the controlled variation of physical factors such as target size and contrast etc. does not give consistent results in terms of operator performance. Similarly, there is a discrepancy between flight results and simulation results which cannot be completely explained by consideration of the various differences in physical parameters. It has become increasingly obvious that some means of assessing differences due to the operator should be employed in order to explain the inconsistent nature of acquisition results. If one considers the performance of individual subjects, the problem becomes twofold - not only does the same task produce different results for different subjects, but the same operator may give significantly different results for the same target on consecutive trials. Results from acquisition studies have a variance drawn therefore, from 'within subjects' as well as 'between subjects'.

These 'individual differences' are considered to be the main source of variation in experimental findings, and it is surprising therefore that comparatively little effort has been spent in trying to establish the factors contributing to this variation. Psychological opinion suggests that the main source of possible variation may arise due to individual differences in intelligence, personality, psycho-motor ability and, linked closely with all these three, perceptual skills. There are several standard psychological tests which may be employed to assess variation in these factors. The question arises as to the use of psychological tests - are they any better at predicting operator performance than simulations? The answer is far from simple. As already discussed, the main problem appears to be interpreting acquisition results in view of the variation which occurs. The first step in evaluating the results is to understand the factors contributing to the variation. Psychological tests would appear to be the only method there is at present of assessing these factors. Whether one can actually predict with confidence on the basis of the tests is another matter. Certainly there are tests which are claimed to predict tendencies towards certain specific behaviour patterns, and in clinical psychology they are used extensively. Extreme scores on personality tests may be used as predictors in the acquisition/tracking situation, but in general, these tests should be used and interpreted with caution. The main use of tests would appear to be in the explanation of significant individual differences in performance, definition of the population sample on standardized dimensions for valid comparisons with previous work and selection of comparable population samples.

The main problem appears to be choosing the appropriate psychological test. A test is usually chosen on the basis of three criteria. Firstly, a definition of actual use to which the test will be put, e.g. selection or standardisation. Secondly the appropriateness of the test for the task with which the results are to be compared. Finally, there should normally be some hypothesis about the nature of the individual differences being investigated. This does not, of course, preclude the use of tests on an intuitive basis. In addition, the test should satisfy the basic standard test requirements such as reliability and validity.

Psychometric tests have been used by BAC in the past in conjunction with acquisition and tracking tasks. However, where tests have been used, they have generally been an afterthought to the main study, and often the choice of tests has not been based on any of the three major criteria mentioned above. As a result no extensive evaluation of factors contributing to the variation in results or of the tests used has been completed. The tendency has been to use a standard intelligence or personality test and the tests used include Eysencks Personality Inventory, Ravens Progressive Matrices (Advanced and Standard), the Catell 16 PF and the Heims AH5. Very few significant correlations between the tests and acquisition tasks have been found, and the main findings are summarised in Table 1.

Recently, a more intensive study using a specialized test, the Witkins Embedded Figures Test (EFT) was conducted by BAC, and it is proposed to devote this paper to consideration of this particular study since it highlighted the difficulties inherent in choosing an appropriate psychological test.

TABLE 1.

CASES WHERE PSYCHOLOGICAL TESTS HAVE BEEN APPLIED TO BAC AIR TO GROUND TARGET ACQUISITION EXPERIMENTS.

BAC HUMAN FACTORS STUDY NOTE	PSYCHOLOGICAL TEST USED	RESULTS
SERIES 4, No. 9	E.P.I. RAVENS STANDARD PROGRESSIVE MATRICES	RAVENS FOUND TOO INSENSITIVE
SERIES 4, No.17	E.P.I. CATELL 16PF RAVENS ADVANCED PROGRESSIVE MATRICES	NO. SIG. CORRELATIONS BETWEEN ANY TESTS AND ACQUISITION RANGE
SERIES 4, No.19	E.P.I. CATELL 16PF HEIMS AH5	EXTREME SCORES ON FACTORS E & G IN 16PF CORRELATED WITH 'POOR' PERFORMANCE. NO OTHER SIG. CORRELATIONS
SERIES 4, No.22	HEIMS AH5 CATELL 16PF	DETAILED ANALYSIS NOT PERFORMED
SERIES 4, No.29	HEIMS AH5 CATELL 16PF	NO SIG. CORRELATION FOUND BETWEEN NON-DETECTION PERFORMANCE AND TESTS
SERIES 7, No. 3	RAVENS ADVANCED PROGRESSIVE MATRICES E.P.I.	NO SIG. RELATIONSHIP FOUND
SERIES 7, No. 5	CATELL 16PF E.P.I.	SIGNIFICANT CORRELATION BETWEEN LIE SCORES AND DETECTION PERFORMANCE ON BOTH TESTS FOR THE SMALL SQUARE PATTERN
SERIES 7, No.10	WITKINS EMBEDDED FIGURE TEST	NO SIGNIFICANT RELATIONSHIP BETWEEN EFT SCORES AND ACQUISITION PERFORMANCE OR SEARCH TIMES

2. RATIONALE OF THE STUDY

The E.F.T. is essentially a pattern discrimination task based on Witkin's work on perceptual style, and would seem directly applicable to the target acquisition situation.

A brief outline of Witkin's work is included, since full appreciation of the test depends on having some understanding of the work which led up to the development of the test. Witkin (Ref.1) performed a series of experiments to examine the manner in which individuals perceived the orientation of a rod within differently orientated surrounding frames. He found that individuals, at one extreme, perceived the rod as being upright regardless of the orientation of the surrounding frame, whilst at the other extreme individuals found it impossible to align the rod with the vertical due to the orientation of the surrounding frame. In a later study using the perception of the upright when body position and room were tilted, Witkin found similar results: in both situations some individuals were able to overcome the influence of the surrounding field (i.e. the tilted room) whilst others were strongly influenced by it. Later Witkin (Ref.2) adapted test material developed by Gottschaldt (1926) in order to obtain some measure of 'perceptual style' apart from that involved in the perception of the upright. This test is known as the Embedded Figures Test; in this the subject's task is to locate a previously seen simple figure which is contained, and partially obscured by colour and configuration, within a complex figure. The measure of perceptual style is the total time taken by the subject on the items in the test.

Subject's responses to this test are described along a continuum of 'perceptual style' ranging from those who are Field Independent (proficient at separating the figure from its context) to those who are Field Dependent (find difficulty in separating the figure from its context). Witkin found high correlations between subjects' performance on the space orientation tests and the Embedded Figure Tests. This led to the postulation of a generalised analytical trait in perception which was related to certain personality factors.

Two recent studies have tried to relate the perceptual style of individuals to more specialised practical aspects of perception. Barrett and Thornton, (Reference 3) found perceptual style significantly related to the ability of subjects to perceive a human-like dummy which appeared in the path of a car-driving simulation. Thornton, Barrett and Davies (1963) found significant correlations between perceptual style, indicated by the Embedded Figures Test and the ability to correctly identify targets in aerial photographs.

In view of these results, it was hypothesised that target acquisition performance, where subjects 'extract' a target from a background, would be correlated with the individual's perceptual style as measured by the Embedded Figures Test. Further if the results of Barrett and Thornton were confirmed for dynamic target acquisition, the test could possibly be used in two major areas. First in experimental design, where subjects could be matched on the basis of their test responses. Second in the area of selection for specialised roles such as photo-interpretation and fighter reconnaissance.

The main aim of the study was to test, for a sample of aircrew, the relationship between target acquisition performance in a dynamic simulation, as measured by various scores, and scores from the Embedded Figures Test. A subsidiary aim was to establish whether there is a relationship between flying experience (in terms of hours flown) and E.F.T. scores - the hypothesis being that pilots who have greater experience in resolving conflict between visual cues (derived from instruments) and vestibular cues (due to aircraft motion) should be more field independent.

3. EXPERIMENTAL PROCEDURE AND RESULTS

The test was administered to a total of forty-eight pilots, whose ages ranged from 21-41 years (Mean 25.3 years) Flying experience also varied from 440 hours to 5,000 hours. The scoring technique was somewhat different to that of Witkin, Witkin used a maximum time of 5 minutes whereas in this study a maximum time of two minutes was imposed to make the test shorter. In addition the watch was stopped during any demonstration of the figure by a subject; in the event of an error, timing was resumed. Witkin on the other hand included time taken to trace the figure whether the subject's response was correct or incorrect.

The following measures of target acquisition were taken from an air-to-ground cine simulation running concurrently, investigating the relative contributions of target cue and target area information to acquisition performance.

(i) Acquisition Range - the range at which a subject sees a target when approaching it at normal speed with briefing material.

(ii) Potential Range - the range at which a target becomes potentially visible. Where a subject can distinguish a target when approaching it at a slower speed and knowing exactly where it is [illegible]ed.

(iii) Search Time - the difference between acquire search and acquire target, that is, elapsed time measured in frames.

Four task conditions were given to the subjects, during the simulation, each representing a different level of briefing. The first task was termed 'route learning' and in this condition the subject was shown the film three times detecting and 'talking through' with the experimenter pre-selected reference points to provide active involvement in the task. After the route learning runs the subject was given another map of the same route, this time with the target marked on it and was required to acquire this target. For the second condition, target briefing photographs of the target and its immediate surroundings were given, before and during the first run detection. These photographs were taken at ranges of approximately 5,000, 10,000 and 15,000 feet in order to give the subject an indication of perspective effect due to altitude and approach angle. The next condition consisted of a slow forward run through the film during which the subject acquired the target. This was immediately followed by a fast forward run, again acqui[illegible] the target. During the first half of this condition the subject 'learns' the target within its background and transfers this knowledge to the second high speed run. The final condition was a control condition, which was a normal approach to the target with basic briefing materials of $\frac{1}{4}$: 1 mile map with both target and track marked.

For Acquisition Range, a composite rank performance score was compiled, this being the sum total of each subject's first run performance over all targets. The potential range for each of the four targets was examined separately. Correlations were performed between the composite acquisition performance and E.F.T. time scores and Potential Range for each of the four films and E.F.T. time scores. In addition correlations between E.F.T. scores and Age and Flying Hours were performed. No significant correlations (at the 5% level) were found between any of these measures.

However, since the E.F.T. is essentially a search task, it was felt that comparisons with the elapsed time between "acquire search area" and "acquire target" would be more appropriate. Also, the method of pooling the data used for acquisition performance may well mask the effects due to performance on individual films and briefing conditions. For each film and experimental briefing condition correlations between subjects' EFT scores and their target search time in the cine simulation were performed. These correlations are shown in the table below:-

TABLE 2.

		CONDITION. A	B	C_1	C_2	D	
FILMS	1	-0.11	0.17	-0.44	-0.77^{xx}	-0.41	A = Route Learning
	2	-0.45	-0.62^{x}	0.17	0.01	0.02	B = Photobriefing
	3	-0.16	-0.15	-0.35	-0.35	-0.09	C_1, C_2 = Target Learning
	4	-0.57	0.48	-0.29	-0.09	+	D = Control Condition

xx Significant p 0.01
x Significant p 0.05
\+ Insufficient Data

Again, the overall lack of significance was notable but here there is a trend towards negative correlations. At present there is no explanation to account for these negative correlations.

Inspection of the data revealed that in many instances the potential range measurement was less than the search area range measure. If we assume that the potential range measure is the first point at which the individual would be able to see the target, then it follows that the difference between acquisition range and potential range is a better measure of 'useful' search time. However, if the subject has not acquired the search area before his potential range, the useful search time is then estimated from the difference between the "acquire search" measurement and the "acquire target" measurement. Correlations were performed with EFT scores and this ammended search time measure, for each film/condition combination. None of those correlations were found to be significant. However, the previous trend to negative correlations was less pronounced.

TABLE 3.

	CONDITION.				
	A	B	C_1	C_2	D
FILM 1	–0.04	–0.74	–0.30	–0.20	–0.12
2	0.00	+0.05	+0.40	–0.45	+0.05
3	–0.14	–0.04	+0.28	+0.13	–0.28
4	–0.75	–0.30	–0.50	+0.15	+0.40

4. FURTHER CONSIDERATION OF THE RESULTS

The total lack of any useful correlations between the various acquisition measures and EFT scores was surprising. The experimental evidence from the studies quoted earlier, combined with the nature of the EFT task, i.e. extracting information from a complex background,suggested that the test would be useful. In order to establish reasons for the lack of correlation the data was examined in more detail.

Previous B.A.C. experience of target detection tasks is that detection ranges are approximately log normally distributed. Also, search times as investigated by J. Bloomfield at Nottington (Reference 4) follow an exponential distribution of the Rayleigh Form.

It was decided that the distribution of E.F.T. scores (both Witkin's original data and B.A.C. data) should be examined in normal, Rayleigh and log form. When examined in normal form,(see Fig.1),it was clear that both data sets were non-linear, and could not be considered as normally distributed.

In Figure 2, both sets of data are presented to test the possibility that EFT scores are Rayleigh distributed. There is a possibility that the B.A.C. data is Rayleigh distributed, whilst this is clearly not the case for the Witkin data. This would imply different distributions in the Witkin and BAC data. However, over the same range of scores, Witkin's data is also approximated by a straight line. In view of this it is preferred to regard the BAC data as part only of the larger Witkin distribution. This would also provide an answer to the problem of why no correlations were found between EFT scores and acquisition performance in this study. All the BAC data falls in the upper 50% of Witkin's data, and in relation to Witkin's concept of the field independent – field dependent continuum, this would suggest that all the subjects used in this study cluster at the field independent end. Although the test may adequately discriminate between field independent and field dependent operators drawn at random from the population, it appears that it is too insensitive to discriminate within a group of highly field independent subjects.

In Figure 3, the data is presented to test the possibility that log EFT scores are normally distributed. Both BAC and Witkin data are reasonably fitted by straight lines, and this distribution is strongly supported.

Finally, the data is presented in Figure 4, to test the possibility that log EFT scores are Rayleigh distributed. It is clear that neither BAC or Witkin data is so distributed.

5. DISCUSSION AND CONCLUSIONS

The investigation of the distribution of EFT scores stimulated a reappraisal of the test. The nature of the EFT as seen by Witkin, involves an ability to deal with the field analytically, and this is embodied in the term 'perceptual style'. The aim of this particular study was to test the relationship between target acquisition performance and EFT scores, the hypothesis being that high analytical ability is a factor contributing to good acquisition performance and it follows that the variation in performance may be partly due to this factor. The choice of the Embedded Figures Test as a means of estimating analytical ability was strongly supported by the experimental evidence of Barrett and Thornton, and by the fact that the task was similar to the target acquisition situation, in that in both cases the subject is required to extract information from a complex background.

Correlations between composite acquisition performance, potential range and search time measures with EFT scores failed to show any significant relationship. Similarly, measures of experience (age and flying hours) did not correlate with EFT scores. Some possible reasons for this lack of correlation will be discussed below. Further consideration of the target acquisition task and the EFT task suggests that there may be differences between the two which make the tasks incompatible, and that those differences weaken the apparent face validity suggested by the distribution of scores. One main difference is that the target acquisition task in the cine simulation may only contain a small proportion of the EFT task: in the cine simulation, the target acquisition task included a map-reading exercise. The acquisition of the target depended on the geographic orientation of the subject, using identification points on the track along which the aircraft flew and with the exception of one condition, where photographs were given in the briefing, the subject had no knowledge of the target other than a verbal briefing. It is suggested that the photobriefing condition is more similar to the EFT task in that it is partly a pattern recognition task where the subject recognises the pattern of the target and its immediate surroundings from the briefing photographs. Similarly, a point of difference is the manner in which the target is embedded in its background. In the Witkin test, the simple 'target' figure is 'overlaid' by the background whereas in the target acquisition task, the target is a sub-element of the overall pattern. In the target acquisition situation the target background provides meaningful 'cues' for detection and recognition of the target, whilst in the Embedded Figures the background is designed to obscure and confuse the observer by detracting from the target figure, in a situation where both target and background are meaningless. Again the photobriefing condition in the cine simulation is similar to the EFT task. It was found in the briefing experiment that performance on the photobriefing condition was worse than for the other three levels of briefing. This is explained by the nature of the photographs given in the briefing. Very little target background information was available to provide the meaningful 'cues' for detection, and the information provided was too specific in that the subject waited until he could positively identify the target.

Also, the target acquisition task used a black-and-white ciné simulation whereas the EFT task involves finding a simple figure in a coloured complex figure. Apart from the different colour treatments the tasks differ in that the target acquisition task was essentially dynamic (target growing in size and definition) and the E.F.T. task static. Although each of the task differences considered independently may have little significant effect on the overall result, the combined effects may well have contributed to the overall lack of significance.

The most important single factor is the insensitivity of the test, and evidence for this comes again from the distribution of test scores. The comparison of Witkin and BAC data supports the hypothesis that the BAC subjects, being aircrew, were highly selected for 'field independence', and that the measures used were too insensitive to discriminate within the group. Whether the 'field independence' is innate and unlearned or whether it is the result of training is debatable. It is certainly true that pilots are taught to rely on visual cues and ignore vestibular cues during flight, and the results of the study indicate that they can successfully resolve conflict between the two. On the other hand, investigation of flying experience and EFT scores indicates that flying experience does not influence EFT scores. Again this may be attributed to the insensitivity of the test, but it should be remembered that the range of flying hours was from 440 - 5,000. Another factor worthy of mention is the high rate of guessing which occurred. This is due to the fact that only eight simple target figures were used in the test, and the presentation of the figures was such that only seven were presented frequently. The remaining figure was presented once towards the end of the test. The subjects successfully anticipated which simple figure would occur during the initial inspection of the complex figure, and this may have influenced the overall results.

This particular study was of importance in that because no correlations were found between the test and the acquisition task, the precise nature of the test was examined more closely.

Despite the fact that the test was appropriate on the basis of the three criteria discussed earlier, the lack of correlation was almost significant in itself. The trend towards negative correlations with search time was notable. It is interesting to speculate whether, at this extreme end of the continuum, the subjects performance on the acquisition task is not estimated by the EFT test due to some other factor, such as motivation, or arousal level. All the subjects who took part in the test were aware that their responses were being timed, and were motivated to do well on the test. It may be possible that, at this end of the continuum, any fine discrimination made by the test could be masked by the stronger factor of motivation.

The main finding of this study, i.e. test insensitivity, would also explain why tests used in the past have been unsuccessful in estimating factors contributing to individual variation in results. As previously mentioned, the tests used have generally been a standard intelligence or personality test. In those studies where aircrew or Army personnel have ' n subjects, it is very probable that the subjects are already highly selected by virtue of the nature of their occupations. Army and Airforce selection centres use psychological tests as an aid to their selection procedure. It is easy to imagine some sort of threshold effect operating such that above a certain level, differences in, for example, IQ scores will not be reflected in acquisition tasks. Similarly with personality testing the extreme scores are already eliminated from the population sample. These considerations have serious implications for future psychological testing. Not only must the choice of tests be based on the nature of the individual differences we wish to investigate and the appropriateness of the test, but, it appears that full appreciation of the test components and the population sample is required. Within the context of target acquisition this can be achieved by the development of a comprehensive theoretical framework. This would involve the detailed consideration of both physiological and psychological variables and their interaction, and the evaluation of standard tests to assess their applicability and sensitivity.

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FIGURE 1 Distribution of Witkin and BAC Scores presented against a normal distribution.

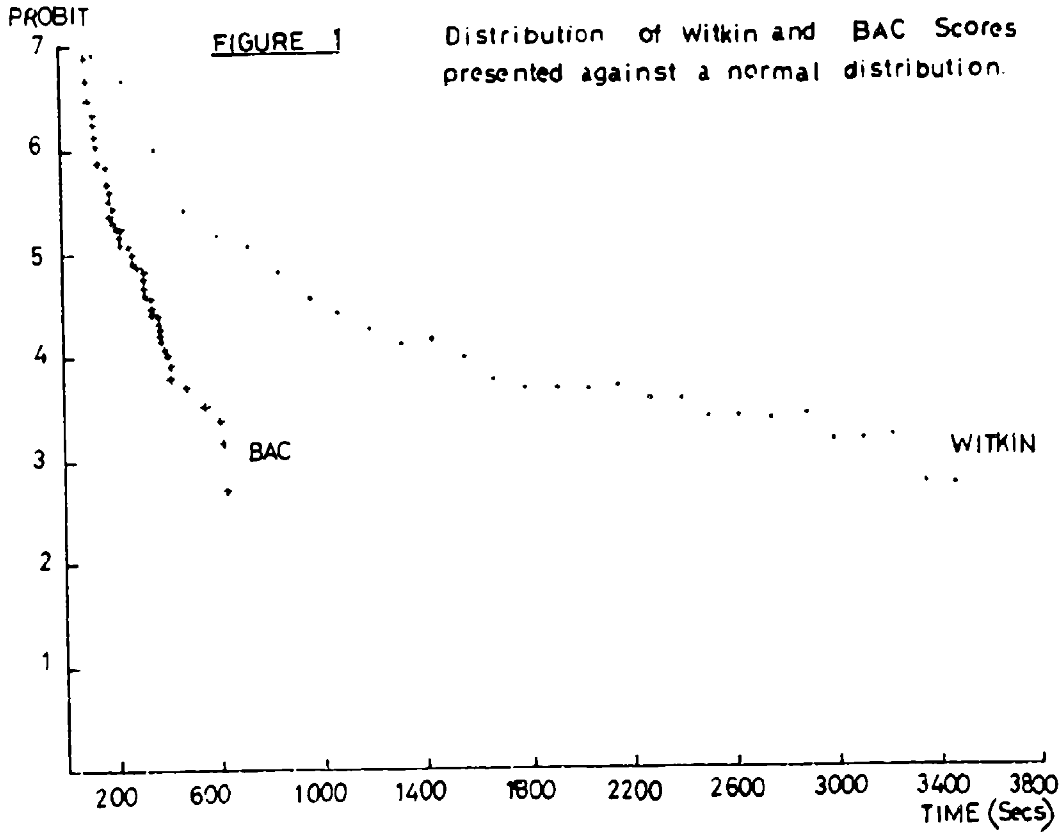
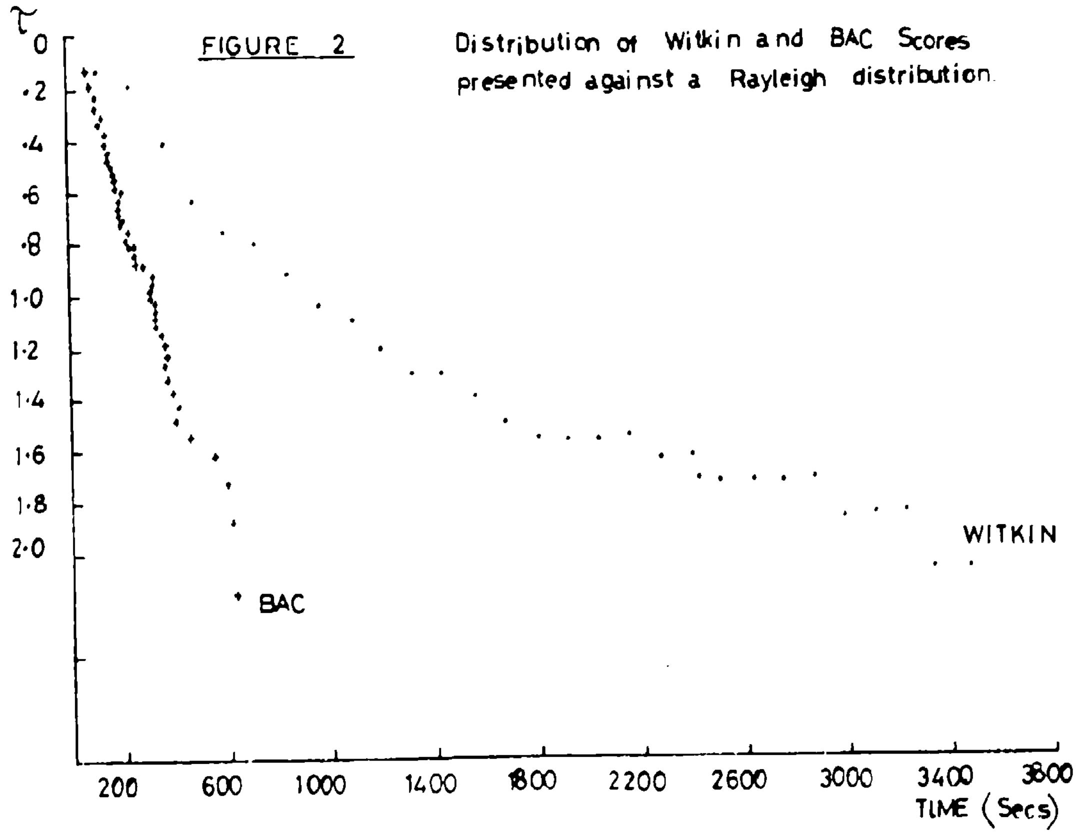


FIGURE 2 Distribution of Witkin and BAC Scores presented against a Rayleigh distribution.



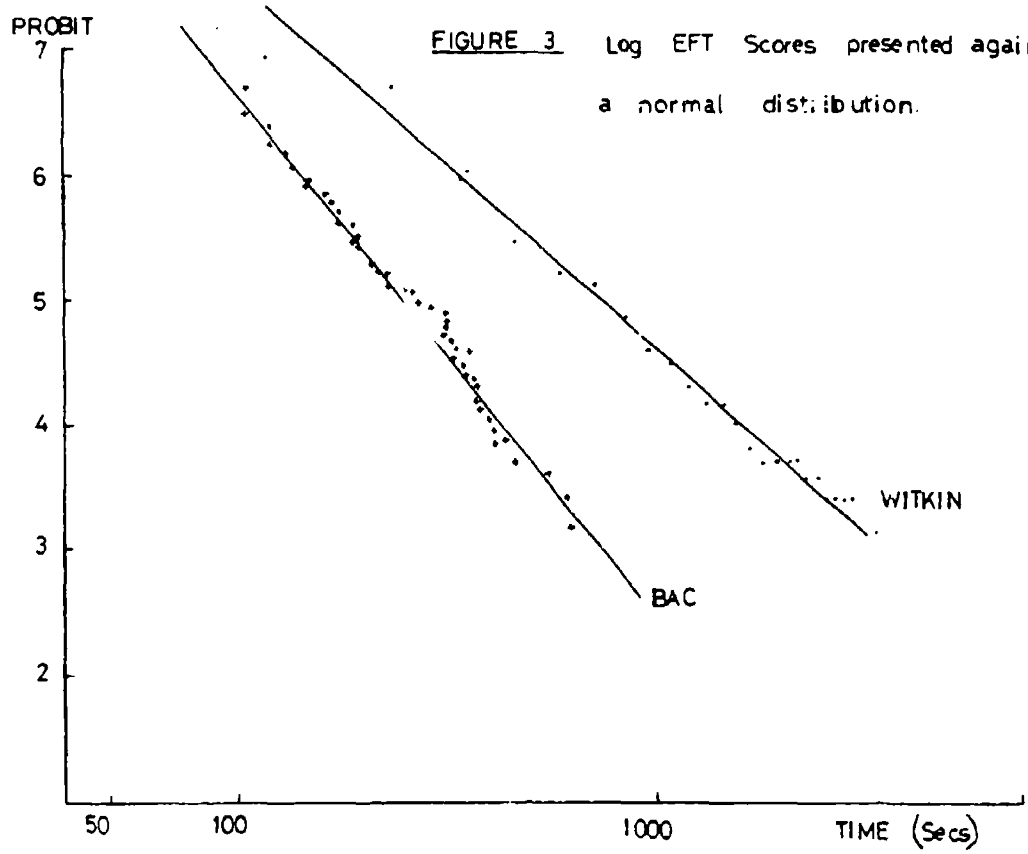


FIGURE 3 Log EFT Scores presented against a normal distribution.

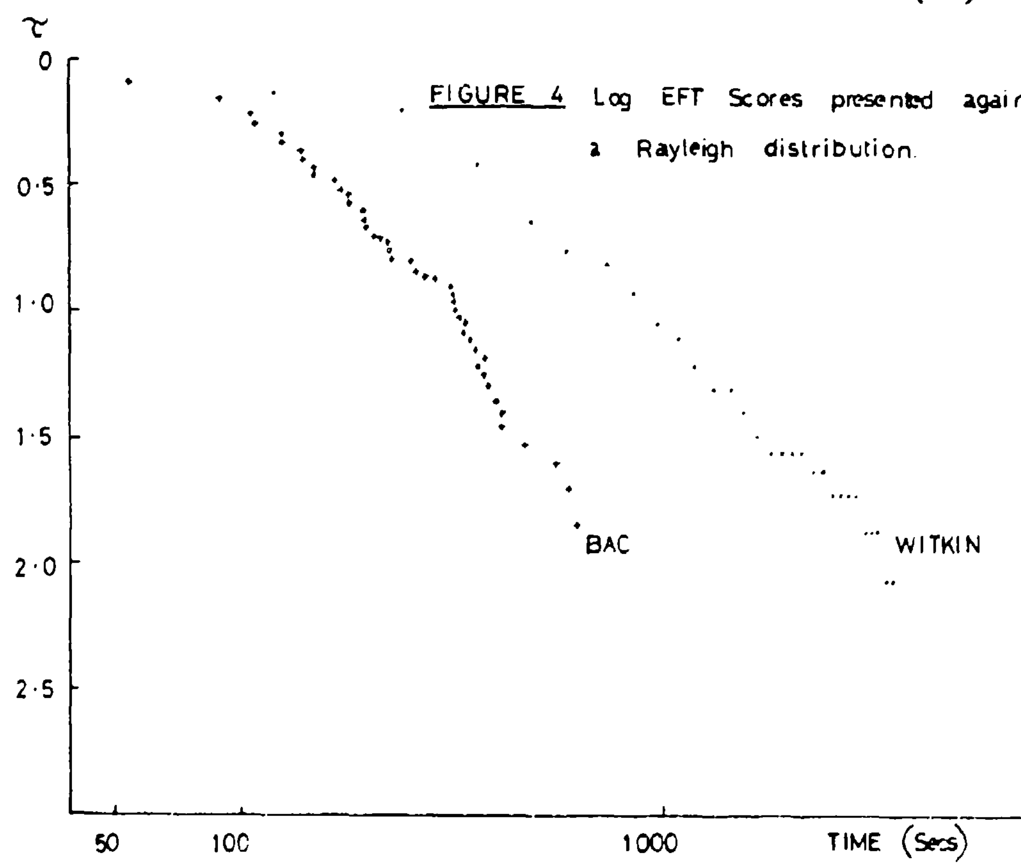


FIGURE 4 Log EFT Scores presented against a Rayleigh distribution.

GENERAL DISCUSSION

Dr Huddleston (UK)

Apart from Dr Frick's analytical description, the foregoing papers have in part tried to mention the vexing topic of inter-observer differences. Could we usefully concentrate our final open discussion on that issue? It seems to me inescapable that a prediction from group mean data alone is unlikely to match operational performance with its likely emphasis on surprise, first-pass effectiveness, and so forth.

Mr Clement (Belgium)

I would like to make a comment on the correlation between target acquisition performance by an operator and his later rating in an aircrew school or flying career. There is a test (from Holland) where the subject is asked to spot groups of 4 points within a row of other groups comprising 3 or 5 points. This is a matter of recognition. We ran this test, among others, with 400 to 500 pilot applicants, and compared scores with pilot course success or failure. There is a correlation; but it disappears completely in a discriminant analysis taking account of other tests in other fields. I would say target perception was a general psychological property, which can be tested by quite dissimilar means, but detecting it as an ability in early applicants does not predict later career.

Mr Silverthorn (UK)

We're not normally able to follow up the career developments of our test subjects. By purest chance I heard of one case, where an Army candidate in training failed both the Witkin Embedded Figures Test and the air gunner course he was on. An Army-Air Force difference in our test results could be due to RAF pilot candidates being compared with Army pilot, air gunner and other trades, and so our data do not allow valid comparisons.

Mr Ericson (US)

Would you comment on the skills required in preparing the briefing diagrams in the context of making that technique available operationally rather than only on an experimental basis?

Miss Parkes (UK)

We looked at 2 techniques, a freehand one and a diagrammatic one. The freehand technique requires a certain minimum level of artistic skill, and as such it's really probably not so appropriate. The diagrammatic technique requires really no artistic skill at all, but a minimum technical skill in plotting coordinates from a plan view grid to a perspective grid. This latter would lend itself well to automatic methods of plotting. In our experiments we have found no difference in briefing effectiveness between these two methods.

Mr Corkindale (UK)

We've heard a fair amount of data described in what I would term conventional threshold form. We haven't heard a great deal of data presented in signal detection form. The point I want to make, following on an earlier reference, is that aircrew subjects do not like to look foolish in public, a thing which they often see themselves doing in the test situation. Very often one notices differences between subjects not in a narrow psychological-cognitive sense but in their willingness to give an answer when they are free to continue to inspect the situation.

Very often in simulator trials, long before the subject gives an answer, he is inspecting one small part of the test field very closely because that's where he believes the target is. But he won't say so. He wants a greater or lesser amount of confirmation. Perhaps this confidence factor distinguishes subjects more than visual characteristics or general psychological attributes do. After all, subjects are generally screened as to vision, and often, aircrew in particular, as to general psychological characteristics. Aircrew are in these two respects a fairly homogenous population. Is there work looking with this sort of signal detection approach in rather more detail than I've mentioned?

Mr Silverthorn (UK)

This kind of research is very much limited by finance, and I know of no studies on any current programme of work. While I agree with your comments, it would be difficult to add a suitable investigation into an existing one without noticing. The likely payoff seems to me to be justifiable financially, though.

Mr Corkindale (UK)

I know it's very convenient to handle a simple figure, say a 50% or 90% threshold, but I have the impression most researchers no longer believe in simple numerical thresholds of that kind. Is it, however, a history of convenience too that keeps threshold data in mathematical models? When I've tried to persuade mathematicians to take an interest in signal detection calculations, their objections have not been theoretical but straightforwardly practical ones.

Mr Overington (UK)

One objective of my modelling has always been to fit threshold data on to signal detection theory. There is a current convention, however, to make operational use of the outputs of a model which give threshold and frequency-of-seeing numbers. But I believe that subject confidence, viewed at the neural level, might well be a signal-to-noise ratio effect, where different observers wait for different ratios or achieve similar results at different rates before coming to a decision.

Miss Parkes (UK)

We have attempted to measure observers' confidence levels after they have made a positive identification. Unfortunately for our efforts, experienced aircrew weren't prepared to make decisions at anything less than "100% confident". This confirms Dr Greening's original comment on the topic. Unskilled subjects, on the other hand, would make decisions at lower confidence levels. For these latter we have, on occasion, found good correlations between confidence level and actual performance.

Dr Huddleston (UK)

I believe Professor Howarth at Nottingham University has had some success in changing student observer criteria by carefully worded instructions accompanied by some verbal bullying. Aircrew with experience, however, generally know better than the experimenter whether a real target is present or not, and their criteria should be much more resistive to this kind of simple verbal assault.

Mr Overington (UK)

Surely if the literal 100% confidence criterion were applied by aircrew you would find an exactly rectangular frequency-of-seeing curve? Some variation at least between 99% and 100% must be present.

Miss Parkes (UK)

We didn't allow our pilots a complete continuum from 0% to 100% confident. They had the choice of 100%, 90%, and, I think, 75% and 50%; certainly only two values below the 90% confidence level.

Dr Frick (US)

I really represent a user of acquisition models rather than a developer, and I tried in my paper to show how a model could be applied, taking into account other issues such as aircraft performance. Talking to other users, and thinking about my own work, I am struck by the number of variables and assumptions in models, which make it most difficult to know just what model form to use. For one thing, the random variable in these models changes from one piece of work to another. Sometimes this variable is slant range, sometimes time-in-view, and there are many others. A system analyst's problem is often one of translating a model from one form to some other which fits the problem at hand.

Dr Huddleston (UK)

If I had to summarize, I would have to plead that our deliberations at this symposium had not covered all the target acquisition topic, and assert that no easy summary was in any case achievable.

I remain impressed by the relative precision with which the important physical parameters can be defined and measured, that is the light path from target to eye, and the relative tenuousness and unapproachability of matters biological, that is the information chain from eye via brain to motor act. While agreeing that the physical problem is complex and very demanding of sustained effort, the biological one has in my view to be set apart as not yet completely amenable to sufficiently elegant methods.

Individual operator differences stand squarely at the top of my personal scale for experimental nausea, irritability and confusion. They seem, of all facets present, to introduce most noise into any predictive model and to be least usefully disscussible in public. Ignorance of the operator in general and in particular is most likely to cheat the exact application of a given acquisition model. Physics generally fails our practical needs because of bad measurement; biology leaves us with little intelligent to say.

Empirical modelling is attempted and proves useful precisely because specific underlying factors defeat our understanding before measurement can even be attempted. Psychophysical data are embarrassingly specific to the context of their measurement. To give one isolated example, one's conclusions on an observer's colour vision depend heavily on which test pigments or test lights are utilised, and the value of normal colour vision is in any case unproven for the target acquisition task. Physical data coalesce nicely into encouraging ideas such as the existence of the solar system, into which concept hundreds of thousands of measurements collapse neatly. Newton's early formulations perhaps rid the world of any need to observe the fall of every apple, but in biological matters we can still be intellectually defeated by a single everyday event. This is certainly descriptive of our current understanding of air-to-ground target acquisition by human vision.