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VISUAL DETECTION AND RECOGNITION
OF CAMOUFLAGED PERSONNEL (U)

By: MURRAY GREYSON and J. ROLAND PAYNE

May 1971

U.S. ARMY MOBILITY EQUIPMENT RESEARCH
AND DEVELOPMENT CENTER
FORT BELVOIR, VIRGINIA

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OF CAMOUFLAGED PERSONNEL (U)**

(10) By: MURRAY GREYSON J. ROLAND PAYNE

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SUMMARY

Research was performed to (1) identify the essential elements and pertinent parameters for a visual model for surveillance of camouflaged personnel in various terrains, weathers, and combat environments, and (2) develop the mathematics and logic of the visual model. The research included a search and study of the available pertinent literature and discussions with many of the recognized experts in vision research and countersurveillance.

A model was developed to account for the effects of luminance and color contrasts in the detection process. It accounts for intrinsic luminance and color contrasts at the target and the effects of the atmosphere and range between the observer and the object.

The state of knowledge concerning the effects of movement and form discrimination was found to be fairly primitive despite the extensive research that has been performed. It was not possible to develop a sufficiently detailed analytical model for the effects of either of these important parameters.

Since it is considered necessary to include a human's judgment in modeling the process of recognizing military objects, empirical data derived from human observers' performance of form recognition, in conjunction with a classification system for backgrounds, are required for developing a realistic empirical model of form discrimination.

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FOREWORD

The research reported in this memorandum has been performed under Contract DACA76-69-^c0-0003 for the United States Army Mobility Equipment Research and Development Center (USAMERDC). Project support has been provided by Mr. John Hopkins, USAMERDC, Authorized Representative of the Contracting Officer, and Mr. Kemper Flint, USAMERDC.

This interim report documents the research performed on Phase I of the task to develop models that can be used in determining requirements for and measuring the effectiveness of camouflage systems for personnel. As the work continues on Phases II and III, the results discussed in this interim report may be modified for presentation in the final report.

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I INTRODUCTION

The goal of the research has been to develop an objective measurement method for determining requirements for and measuring the effectiveness of camouflage systems for personnel.

The method of approach for attaining the goal has been to (1) conduct a search of the applicable literature, (2) visit personnel and agencies that are recognized for their work in areas significant to passive countersurveillance, (3) determine the most important essential elements and pertinent parameters to be considered, (4) examine available models for useful submodels and logic, (5) identify measures of effectiveness, (6) develop and exercise models describing the detection-concealment process for personnel in various environments, and (7) design a field experiment to test the output of the above models in satisfying the study objective.

The research required in this method of approach has been divided into three phases:

Phase I: Visual Systems

- Perform the literature search and make the background visits
- Determine the essential elements and pertinent parameters for the visual model for surveillance of camouflaged personnel in various terrains, weathers, and combat environments
- Develop the logic and mathematics for the visual models

Phase II: Nonvisual Systems

- Determine the essential elements and pertinent parameters for nonvisual systems such as optical, infrared, and radar
- Develop the logic and mathematics for the nonvisual models.

Phase III: Model Integration and Field Experiment Design

- Program the visual and nonvisual system models
- Incorporate the visual and nonvisual system models into the SRI Countersurveillance-Reconnaissance Effectiveness Evaluation (SCREEN) model^{1,2*}
- Exercise the computer models
- Develop the preliminary design for a field experiment to test results of the model study

This document reports the research conducted during Phase I of the study effort.

*The references are listed at the end of the main body of the report.

II INVESTIGATIONS

A. Literature Search

The library resources of SRI, Stanford University, Defense Documentation Center, RECON Central, Medlars, and the Reconnaissance Data Base at Rome Air Development Center were searched. Special collections of documents related to countersurveillance and surveillance, target acquisition and night observation (STANO), located at the U.S. Army Natick Laboratories, Project MASSTER, and the Combat Developments Command Institute of Systems Analyses, were referenced as well as the personal libraries of some of the experts consulted during background visits. The publications obtained from these sources supplemented the literature study that had been conducted for the earlier tasks of this contract involved with (1) the identification of measures of effectiveness for countersurveillance for tactical units and their equipment, (2) a method of classification of targets for countersurveillance purposes, and (3) the development of SCREEN.

Reports studied had varied orientations, including mathematics, physics, chemistry, electronic and electrical engineering, psychology, physiology, ophthalmology, military sciences, military operations, history, surveillance technology, and countersurveillance methodology. They included textbooks, journal reports, technical reports, professional magazine articles, battle action reports, notes, and field and training manuals. They were written as early as 1802 and as late as 1970.

Although the literature search was extensive, most of the time allocated to studying the collected documents was dedicated to the relatively few documents that were of particular importance in the development of a visual model for studying the effects of camouflage for personnel. The fact that the majority of the documents appear to be of marginal value for our research can be better appreciated after reading the discussion in the next section of the multiplicity of parameters and the rather primitive state of the understanding of the interrelations among them.

B. Background Visits

Discussions were held with the persons listed below and with co-workers at their organizations. Discussing with these experts the work that has been done by them and their organizations provided an opportunity to obtain (1) their latest ideas on the aspects of countersurveillance for personnel that are of most interest to each of them, and (2) their perspectives on the important parameters and how they are related.

<u>Person Visited</u>	<u>Organization</u>
Dr. Leon Williams	Honeywell, Inc.
Mr. Ray Schaefer	Honeywell, Inc.
Dr. H. Richard Blackwell	Ohio State University, Institute for Research in Vision
Dr. Wilson Tanner	University of Michigan, Institute of Science and Technology
Mr. Richard LeGeault	University of Michigan, Institute of Science and Technology
Mr. Frank Rizzo	Natick Laboratories
Dr. Walter Lawson	Night Vision Laboratory, Fort Belvoir
Mr. John Hopkins	U.S. Army Mobility Equipment Research and Development Center
Mr. Arthur Stein	Cornell Aeronautical Laboratories
Dr. McAdams	Kodak Research Laboratories
Dr. Robert Boynton	University of Rochester, Institute for Vision Research
Mr. Art Woods	Project MASSTER, Fort Hood
Mr. Ray Attarian	Combat Developments Command Institute for Systems Analyses
MGen. William Fulton	STANSM/ACSFOR
Dr. Siebert Duntley	Scripps Institute of Oceanography, Visibility Laboratory

The Symposium on Tactical Reconnaissance jointly sponsored by the Office of Director of Defense Research and Engineering, DOD, and Electronics Industries Association on 13-15 April 1971 was also attended.

C. Essential Elements and Pertinent Parameters

The devising of a method of stating quantitative requirements for measuring the effectiveness of camouflage for personnel requires not only

a logical, quantitative understanding of how the sensor systems work but also of the way that various camouflage techniques might degrade the value of the conclusions that are in part derived from information obtained from the sensor systems. The essential elements to be considered should therefore include the basic passive countersurveillance methodology, the characteristics and signatures of the personnel using the camouflage, the background and environment containing the personnel, the atmosphere between the personnel and the sensor system, the sensor, the data processing, and the intelligence synthesis processes.

These various essential elements are most properly studied from differing viewpoints. The expertise of the military specialist is needed to identify the deployment parameters of the personnel and sensors in the environment and military situation of interest, the countersurveillance specialist to identify the parameters of known camouflage methods and techniques, the physicist to identify the parameters for describing the energy flow from source to camouflaged personnel to sensor, the physicist and engineer or physiologist to identify signal processing parameters within the sensor system, the engineer and/or psychologist to identify parameters for display and data extraction, the psychologist and intelligence specialist to identify features of the intelligence synthesis process, and the operations/systems analyst to identify a logical structure for integrating the parameters identified by the preceding specialists.

Discussions with and reports by specialists of the above types that have been concerned with the visual process have led to the identification of a myriad of parameters pertinent to the present model development task. These discussions and reports also indicated the areas where research has had some success in relating various parameters, qualitatively and quantitatively, and the areas where only qualitative or vague connections between parameters have been identified, even after a considerable amount of research effort. The state of knowledge is particularly primitive on such questions as how humans recognize complex forms (such as other humans) in complex backgrounds (such as in military situations), and how intelligence is synthesized from extracted data.

Broadly stated, the purpose of camouflage is to hide, blend, disguise, or deceive. Depending on the particular purpose a particular camouflage technique is designed to achieve, emphasis is put on trying to defeat the enemy sensor and intelligence systems at a number of different places. If the basic purpose is to hide or blend, then primary emphasis is likely to be aimed at denying detection and/or recognition

by the sensor system, with secondary emphasis on confusing the data extraction and intelligence synthesis processes. However, if the basic purpose of the camouflage is to disguise or deceive, then primary emphasis is placed on causing the data extraction and intelligence synthesis processes to produce erroneous or untimely output. The current knowledge of these processes suggests that for the foreseeable future, experienced men should be used to account for the output of these processes in models incorporating them.^{3,4}

It was therefore decided that this operations analysis research would probably be most beneficial if it were restricted and directed primarily to the task of modeling the physics and psychophysics involved in the visual detection and recognition of personnel camouflaged for the purpose of hiding and/or blending. With this restricted scope, the primary measures of effectiveness are functions of the probabilities of detection and recognition of personnel. Thus the most pertinent parameters are those that significantly affect the visual detection and recognition processes.

The study was consequently directed toward modeling the effects on the detection and recognition processes of (1) luminous and color contrasts between the camouflaged person and his background, (2) movement, and (3) shape and form. A discussion of these categories of parameters, and the relationships among them, is contained in Section III.

A quantitative model developed to describe the way luminance and color contrasts contribute to the detection process is presented in the appendix.

Only qualitative discussions of the effects of movement, shape and form are possible at this time.^{5,6} The inability to produce meaningful quantitative models in these areas is primarily due to the primitive state of understanding of how people perceive motion; and to the fact that most of the extensive research on shape and form has concerned itself with simple geometric shapes on noncomplex backgrounds, which is not readily extrapolated to complex forms in three dimensional complex backgrounds.

III PERTINENT PARAMETERS FOR VISUAL DISCRIMINATION OF CAMOUFLAGED PERSONNEL

To visually detect and recognize an object (e.g., a camouflaged soldier) an observer's eye must receive a signal from the object and/or cue objects that is sufficiently strong to be noticeable by the observer, and sufficiently different from the signals from the surround of the object that the observer can distinguish the object sufficiently well to classify it. The perception of the signal and the realization that the signal is from a potentially interesting object (i.e., detection) depends directly on a sufficiently strong signal-to-noise ratio at the retina of the observer's eye, and the state of awareness of the observer.

A. Major Pertinent Parameters--for Detection

The human eye is a remarkably sensitive sensor.* However, certain conditions have to exist before a signal from an object can be detected as a potentially interesting signal (interesting in terms of discerning camouflaged personnel). For objects that do not contain a light source there must be a source of illumination incident on the object, some kind of contrast between the object and its surround, and line-of-sight between the object and observer.

Given these conditions a description of the detection and recognition processes depends on a number of pertinent parameters, many of which have large permissible ranges.

1. Illumination

The source of illumination influences the detection process primarily as a function of the brilliance or intensity of the illumination. Bright sources such as direct sunlight enable the eye to perceive

* In 1942, Hecht, Schlaer, and Pirenne performed an experiment basic to much of the psychological work concerned with vision and perception. The results of the experiment show that under optimum conditions a normal human observer will report a flash 60 percent of the time when only about 9 or 10 quanta from the flash are absorbed by the visual pigment in the retina. For comparison, a typical lighted flashlight bulb radiates about 2×10^{15} quanta per millisecond.

color, cause shadows, contribute to good resolution, and permit the use of filters if desired. If the light source is diffuse (e.g., daylight on cloudy days, starlight) then shadows do not occur. As the light level is decreased a point is reached after which color cannot be discerned, and foveal vision becomes of minor value so that the resolution capability is reduced. Artificial illumination can be used in low ambient light conditions, but the penalty is often noise from backscattered light.

2. Contrast

Contrast is a result of the object (or a part of the object) and its surround having different luminous flux in the direction of the observer, or different colors, or both.

a. Luminance

Differences in luminous flux are contributed to by differences in reflectances of the materials in the object and background, the textures, the orientations to the illuminant and observer, and shadows. The reflectance of a material is a function of wavelength, the composition of the material, its texture, and the angles of incident illuminant and observer with the material. For certain angles and textures, a specular reflection of the illumination source (e.g., sun) may occur in the direction of the observer. This specular reflection, or shine, can make objects easily detectable, even if the area of the object is below the resolution limit of the eye for nonspecular reflectance of the illuminant. Shine is a function of the distance from which the material is viewed. For example, burlap is a nearly perfect diffuse reflector when viewed at short ranges; however, at long ranges it can appear to be bright when viewed from certain directions.

b. Color

Differences in color are primarily attributable to different reflectance versus wavelength characteristics for the object and its surround. However, the apparent colors and textures vary as a function of the distance and resolution detail obtained at the time of observation. Materials that appear multicolored when viewed in detail may appear as a single color when viewed under poor resolution conditions and the apparent color may change as the distance is varied (see the Appendix).

3. Line-of-Sight

If there is no opaque material on the straight line between the object and observer, then line-of-sight is said to exist. However, the atmosphere may contain smoke, fog, and/or rain, and there may be vegetation along the path. Thus the amount of light signal leaving the object toward the observer may combine with light from these intervening sources so that the signal is hard or impossible to detect. This degradation also causes a loss in effective resolution.

4. Movement

If illumination, contrast, and line-of-sight conditions are such that a signal from the object exists at the observer, then movement is likely to enhance the probability of detection. However, it is not understood what causes this phenomenon,* despite the research that a number of psychologists have conducted over a long period of time.⁸⁻¹³ Their research has demonstrated that the contribution of motion to the detection process is a function of (1) direction of motion--the chance of detection being best when movement is lateral, and worst when radial to the observer, (2) speed, (3) extent of movement, (4) region of retina that the image is on, and (5) the state of eye adaptation. Motion appears to be perceived either by noting that (1) different adjacent receptors in the retina are receiving the image as time passes, or (2) the object is occupying different positions as time passes. Whatever the mechanism is, the human observer is very sensitive to the perception of motion.

5. Search Process

From the viewpoint of countersurveillance, it is desirable to know the observer's search procedures, his familiarity with his area of responsibility, his expectations of finding enemy elements, and his alertness. Knowledge of the observers' coverage of the area as a function of time would enable a countersurveillance plan to be worked out that would expose the personnel for the shortest expected time, and perhaps when the observer is fatigued or not particularly expecting to detect his enemy. Although it is known that observers tend to search

* In the preface to his book, "Visual Perception," T.N. Cornsweet writes, "I have excluded many topics ... and others because I do not know enough about them to explain them plausibly (for example, the perception of motion)."

first those areas they consider most likely to be occupied by the enemy, it is not known how they select the next place to look, nor how they become aware of more detail as time progresses. An observer's knowledge of the size of the things for which he is searching limits him to the speed with which he can search an area. For example, an airborne observer must search a smaller swath width from the aircraft track when searching for personnel than when searching for armored vehicles or buildings.

6. Clues

An observer rarely searches for his enemy with his eyes only and without some knowledge of his enemy. His ears or nose may alert him to look in specific directions, especially at night. Other intelligence sources may have alerted him to expect enemy personnel at a particular place at a particular time. Or he may observe animals or detect spoor that indicate personnel have recently been or may even still be at the place he is observing.

B. Additional Major Pertinent Parameters--for Recognition

Recognition is a classification process that basically requires the observer to relate the things he is observing to things he has learned in the past. This may be a direct matching such as matching an outline of a helmet and shoulders to his recollection of what a soldier looks like in the open, or it may be a complex combination of matching and deductive reasoning. All the parameters discussed above for detection, except the search process, remain pertinent for the recognition process. Additionally, to classify a detected anomaly of potential interest parameters such as the following can be of major importance: size, resolution, form, clutter, and context as well as the knowledge, training, and motivation of the observer, and any time constraints under which he may be operating.

1. Size

The size of a detected anomaly enables the observer to rule out quickly those anomalies that are much too large or small. The size is also a major factor in computing the maximum distance at which an object can be recognized.

2. Resolution

The resolution capability of an observer looking at a detected object is a function of his visual acuity, the light level, the size of the object, the contrast, and the intervening atmosphere. Counter-surveillance can possibly affect several of these parameters to reduce the effective resolution capability of the observer. For recognition, the object must effectively subtend four to six or more resolvable elements at the sensor.¹⁵

3. Form

In 1957, Dr. H. R. Blackwell, at the symposium on "Form Discrimination as Related to Military Problems," sponsored by the Armed Forces--NRC Committee on Vision, stated "...we don't know enough to solve a single military problem in the field of form discrimination." Discussions with him, Dr. Duntley, and Dr. Harris this year, and study of K. S. Fu's book⁵ indicate the concerted opinion that it probably will still be a long time before sufficient progress is made to model the functions a human observer performs when he recognizes the features of an object of interest imbedded in a cluttered background. Most of the progress made in the fields of form discrimination and feature extraction has been on the basis of relatively simple two-dimensional geometric objects on simple backgrounds, with or without clutter.

However, form and features are at the heart of the recognition problem and work continues in this area in diverse ways. Image interpreters develop keys that are designed to help them recognize and classify features of forms that may be partially hidden in complex surroundings. A great deal of effort is being expended by the computer industry to produce reliable optical character readers (OCRs) that can tolerate more degrees of freedom than the early OCRs allowed. Research groups are working to improve automations that can "see" and distinguish simple three-dimensional geometric shapes. And others are working directly on the problem of machine recognition of military objects in real backgrounds. However, the state of the art must still be considered inadequate for the purposes of delineating the process of recognizing military objects in relatively simple backgrounds from different perspectives, scales, light conditions, and so on, and is certainly inadequate for recognizing camouflaged military objects. Thus it is not expected that models which take form into account can be built until more data are developed on targets and the environment in which they are found. A recommendation on a direction to pursue in this area is found

in Section IV-D. Until more work is accomplished, it probably will be necessary to incorporate the judgment of a human into those parts of models of the visual process that account for the effect of form.

4. Clutter

Clutter is important to the countersurveillance planner because he can use and control it relative to the form of the personnel he is trying to protect. He can reduce the probabilities of detection and recognition by increasing the clutter so that, in effect, the signal to noise ratio is reduced. Clutter can be used instead of direct concealment as a means of making the personnel harder for the observer to detect and recognize. In practice, detection (this term implies potential interest) and recognition occur almost simultaneously when an observer is viewing a cluttered field of view. The amount of time it takes to detect a form or pattern in a cluttered field of view varies with the amount of clutter, the size of the elements causing clutter relative to the size of the objects being sought, and the geometric distribution of the clutter elements. This time can probably be shortened for a particular observer by training and experience.

5. Context

The trained observer uses his training and prior knowledge of the enemy scene and environment to aid in searching for the enemy and for clues that may lead to the enemy. The clues he may observe and cues that he may receive from other sensors direct his search to areas that he is willing to spend more time examining in detail than other areas within his field of view. Prior estimates (correct or false) of the enemy's strength and intentions can cause varying amounts of motivation and alertness in the observer.

6. Knowledge and Training

Action reports indicate that soldiers who were raised in the country are significantly better observers in the jungle and countryside than are the soldiers who grew up in the city. However, it appears that this basic difference can be compensated for by thorough training on target signatures, clues, and search techniques. A thorough understanding of the possible countersurveillance techniques the enemy may use will be of help to the observer, especially against disguise and deception. Similarly, a camouflaged person's knowledge of the enemy's sensor systems and training to defeat them aids in maintaining good camouflage discipline.

7. Motivation

Very little of an observer's time is actually spent detecting and recognizing enemy soldiers. Fatigue and boredom are certainly factors to be considered in an observer's performance. Experiments have been done to evaluate the effects of artificial rewards and punishments on the performance of observers, but no quantitative data are available to indicate the effect of motivation deriving from battlefield pressures and the rewards and punishments of life and death. Motivation varies with time on duty, with the observer's assessment of the likelihood of finding anything, and the potential consequences if he does or does not. Thus, if a sufficient light signal for detection and recognition arrives at the observer from the camouflaged soldier, the probability of the observer detecting the soldier is dependent on the observer's motivation and consequent alertness. Although this is a major area of uncertainty, very little data exist to indicate the distribution of the probability of detection as a function of motivation or alertness.

8. Time

An airborne observer usually constrains the area that he searches because of the time that any one area is within his line-of-sight. The width of the area he can cover depends upon the size of the objects for which he is searching, the amount of clutter, the aircraft speed, and the cockpit geometry. Because of time constraints he may elect to search a given wider area less thoroughly, relying on cues and knowledge of the enemy to make such a decision quickly. For example, he may spend most of his time searching areas that are immediately adjacent to suspected enemy lines of communication, while only cursorily looking at the large areas a short distance away and within his line-of-sight.

The ground observer in an observation post is likely to have sufficient time to search his area of responsibility in the detail he feels is adequate to detect soldiers. However, his search process is likely to vary with time, as is his efficiency. Observers on patrol and moving will often have to sacrifice searching in sufficient detail to find enemy soldiers within their line-of-sight. Thus the efficiency of their search process is likely to be reduced when they are moving through a cluttered area. On the other hand, movement and time allow the patrol to view detected anomalies from different aspects to aid in the recognition process.

On clear days the shadows change with time. The resulting change in the form of the shadows gives the aerial observers optimal times for flight to take advantage of the shadow for both detection and recognition. The changing shadow patterns must also be considered seriously by the soldier employing countersurveillance discipline to take advantage of shadows of natural objects and to minimize the value of his own shadow to any observer.

IV MODELING EFFORTS

A. General

The desire has been to develop a model of the visual process that would correctly relate the parameters described in Section III to permit the calculation of the probabilities of detection and recognition of camouflaged personnel in military situations. It has become increasingly evident that an adequate cause and effect model cannot be developed at this time since the theory explaining the relationships among many of the parameters is not well developed, nor is likely to be in the near future. Although much of the theory for the physics of light as used in this application is understood, and applicable data have been generated and collated, little theory or useful data exist for modeling the effects of the psychologically oriented parameters. This deficiency is particularly grave because the degree of success of camouflage techniques for personnel is critically dependent on the human observer's ability to recognize forms or patterns related to camouflaged personnel and to synthesize the pieces of data he perceives into intelligence.

Much of the germane research done by psychologists has been aimed at describing and quantifying the variability of specific parameters from observer to observer and even with the same observer at different times. For example, experiments have been performed to determine the probability distributions on such parameters as:

- (1) The minimum light intensity threshold of the eye⁶
- (2) The minimum luminance contrast required to recognize simple shapes on homogeneous backgrounds¹⁶
- (3) The minimum differences in color that can be detected¹⁷
- (4) The minimum detectable motion of a light source.⁸

Most of the experiments have necessarily been tightly constrained to try to evaluate the variability of the parameter of interest as a function of another parameter or two. Thus the experiments are sterile insofar as each attacks only one aspect of the many faceted problem of a soldier in the field trying to detect and recognize a camouflaged enemy soldier.

The data and theory that have resulted from previous research and modeling efforts indicate that luminance contrast, color contrast, movement, and form are basic elements in the visual process of detecting

and identifying a camouflaged soldier. An attempt was made to develop models for the effects of each of these basic elements and their associated pertinent parameters, with the intent of then integrating the resulting models into a single model that would be useful in studying the visual detection, recognition, and concealment processes for personnel in various environments.

B. Luminance and Color Contrasts

A model for the determination of the effects of luminance and color contrasts on target detection was developed and is presented as the appendix of this report so that it can be used as an independent document. The appendix presents theory on color contrasts and luminance contrasts separately and then combines them to yield a model of their combined effects on target detection. The appendix constitutes the main analytical contribution of this research effort to the community's tools and understanding of the visual process.

C. Movement

The attempts to account realistically for the effects of movement were frustrating and unsuccessful from the point of view of being able to develop a model that combines the factors important to the perception of motion in a deterministic or probabilistic manner. Neither were sufficient data identified to permit the development of an empirical model. The basic reason for not being successful in this effort is probably the relatively primitive state of knowledge of the perception of motion, as pointed out earlier. A contributing reason is that the detection of movement of an object with respect to its background is dependent on a luminance or color contrast existing, so that basic experiments are somewhat harder to design.

D. Form Discrimination

Similarly, the primitive state of knowledge about shape, form, or pattern discrimination precludes the development of a sophisticated sub-model for that part of the visual process. Since form discrimination is the key to the recognition of camouflaged personnel, it is important that an adequate model be developed. As also indicated earlier, a great deal of research is being conducted in this basic area for a variety of applications. However, not enough data have yet been developed about military target forms in relation to the environment in which such targets are found.

It does not appear feasible to develop a cause and effect model of form discrimination in the near future. To develop an empirical model for this process, whether or not a human is involved in exercising the model, an empirical data base to use in classifying targets and target backgrounds is needed. A method for classifying military targets is presented in an earlier report of this project,¹⁸ but a method of classifying backgrounds--or more properly, surrounds of the targets--is needed.

Although the exact nature and number of the background parameters that affect the visual perception process are not well known, it would appear that a complete set of such parameters, at a minimum, would include qualitative and quantitative indices for the following factors:

- Nature of the elements within a background
- Size distributions of elements within a background
- Extent of the background that is viewed by the observer
- Relative mix of elements within the background
- Degree of order or disorder of elements, both with respect to individual form and grouping
- Color and luminance contrasts within the observer's field of view
- Illumination level

Unfortunately, the present state of knowledge does not permit such detailed indexing to be performed. The result is that the basic research efforts to classify backgrounds should be designed around the subjective abilities in background classification of individuals experienced and knowledgeable in visual observation.

To develop the basic research data, a group of such individuals would be required to select a set of representative visual backgrounds that are of military interest. The visual backgrounds might be presented in the form of large photographic prints. The group would then be asked on an individual basis to separate the photographs into a finite number of sets of similar scenes and to state the characteristics of the scenes that governed the selections. In this phase of the experiment, care would have to be exerted to ensure that different views of the same scene were included.

On the basis of an analysis of the group classifications, a preliminary set of characteristics would then be chosen. In this step, attempts would be made to relate the characteristics defined by the group to the factors listed previously and to other factors unknown at

present. When enough characteristics have been defined, sufficient data will exist for the conduct of the subsequent experiment of placing one or more targets within such backgrounds and determining the ability of visual observers to recognize such targets. The second experiment would be designed to discover the significance and interactions among the parameters.

Until such experiments fill the present void of data on the characterization of target backgrounds, little can be done to construct analytical visual models that incorporate the effect of shape, form, or pattern.

V CONCLUSIONS AND RECOMMENDATIONS

There is inadequate theory and data to formulate analytic models for assessing quantitatively the contributions of movement and form on the process of visual detection and recognition of camouflaged personnel.

Provisions for enhancing the probability of detection to account for some of the effects of target motion can be incorporated when the model developed for color and luminance effects is incorporated into SCREEN. However, the magnitude of the enhancement will have to be determined on the basis of empirical data that do not yet exist.

It will probably be necessary (and to some extent desirable) to use human judgment in models that account for form discrimination in sufficient detail to recognize camouflaged personnel.

It will also be necessary to use men to perform the intelligence synthesis function and hence to a large extent the evaluation of deception techniques.

The model developed to account for the effects of color and luminance contrasts is of potential use in application areas such as the analysis of

- (1) Uniform colors
- (2) Camouflage colors and patterns
- (3) The value of visual filter systems
- (4) The effect of visual screening systems
- (5) The use of colored signal systems

To provide the possibility of modeling the effects of movement and form discrimination data should be developed on the basis of a classification system, with empirical data on representative elements in each category of the classification system. In particular, data should be generated and used in developing a classification system for backgrounds in environments likely to be encountered in military conflicts. Both Dr. Blackwell of Ohio State University and Dr. Duntley of Scripps Institute of Oceanography are working on methods of quantifying an observer's performance of a visual task. Once a classification system is developed, their methods could perhaps be used to obtain the empirical inputs needed for a model of form discrimination. Note that in both of their approaches a human is used to perform the visual task and recognition judgments.

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Appendix

A MODEL FOR THE DETERMINATION OF THE EFFECTS
OF COLOR AND LUMINANCE ON TARGET DETECTION

Appendix

A MODEL FOR THE DETERMINATION OF THE EFFECTS OF COLOR AND LUMINANCE ON TARGET DETECTION

1. Introduction

The ability of a visual observer to detect objects at a distance depends on a number of factors, included among which are luminance and color contrast. For many years, technologists active in the area of visual surveillance and surveillance-system countermeasures have tended to avoid the quantitative physical and psychological (psychophysical) aspects of distant color discrimination, justifying their actions by the statement that color differences tend to disappear rapidly as the ranges between an observer and sets of objects increase. Despite this lack of attention to the more fundamental aspects of color discrimination color research of an empirical nature continues within agencies and organizations concerned with photography and camouflage. This research probably could be materially assisted by basic information on the impact of color on the detection process. Moreover, there is reason to believe that, out to a few kilometers--ranges that encompass almost the total capability of a visual observer in typical tactical environments--color differences can have significant effects on the detection process.

In October 1970, SRI was requested by the U.S. Army Mobility Equipment Research and Development Command (USAMERDC), as part of the research activity under Contract No. DACA-76-69-C-0003, to develop a detailed model for the visual discrimination of camouflaged personnel. In partial response to that request, designated as Task 6 of the contract, a detailed visual model incorporating both color and luminance contrast factors has been developed.

This Appendix describes the work that was performed and the models that were developed. Section 2 summarizes the historical background of luminance and color discrimination, and discusses the derivations of color mixture equations. Quantitative relationships for the atmospheric degradation of luminance and color contrast are developed in Section 3. Section 4 summarizes the results of some sample computations done with the models in Sections 2 and 3. The Appendix is concluded with two annexes: Annex A contains color coordinate and spectral reflectance

data for selected objects; and Annex B describes methods for the determination of atmospheric extinction coefficients.

2. The Characterization of Color and Luminance

a. General

In 1802, Young postulated that human color vision might be explained by the existence of individual retinal receptors composed of a number of fibers, each of which was sensitive to a specific color. To illustrate his hypothesis, he discussed a receptor consisting of three fibers, each of which was sensitive to one of the primary colors. Fifty years later, Helmholtz pointed out that it was unnecessary to postulate three types of fibers, provided that a single fiber could transmit three different color messages to the brain. Five years later, in 1857, J. C. Maxwell provided an experimental foundation for the trichromatic nature of human color vision by demonstrating that a monochromatic light could be simulated to a human observer by a combination of two other monochromatic lights and a white light. These measurements were extremely significant in that they provided a set of quantitative facts that ultimately permitted the development of quantitative color scales.

Since Maxwell, much has been learned in the field of human color vision. The physics and photochemistry of the eye and its component parts have been more or less clearly elucidated, and theories describing the visual mechanisms of the retina and the basic nature of human psychological responses to color have been classified. Most important, however, methods for the quantitative characterization of color in terms of a "standard" human observer have been developed. The existence of these color "metrics," as complex and as imperfect as they are, has permitted much to be done in standardizing color and light sources, and in determining the effects of environmental factors on human color vision.

Below are described some of the relationships that are significant in the determination of color and luminance differences among objects. The methods used follow the treatments of Graham, Judd and Wyszecki, and LeGrand.

* References for this Appendix are shown at its end.

b. The Basic Relationship

1) Monochromatic Radiation

Let L_1 , L_2 , and L_3 be the luminance of a selected set of monochromatic light sources S_1 , S_2 , and S_3 , and let L_w be the luminance of a white light source, S_w . By adjustment of luminance levels, it can be shown that with respect to a human observer, the color obtained by the illumination of a perfectly diffusing reflector by two of the monochromatic lights can be matched, both in color and luminance, by the other monochromatic source and the white light. Mathematically, the relationship can be written

$$L_1 + L_2 \equiv L_3 + L_w, \quad (1)$$

where the symbol $\equiv$ implies both color and luminance match.* The wavelength of the source, S_3 , is called the dominant wavelength of the color mixture $S_1 + S_2$.

The terms in Eq. (1) can be treated as algebraic quantities, and a generalized expression for monochromatic color mixtures can be written as:

$$L_p + L_q + L_r \equiv L_w. \quad (2)$$

A negative luminance value for a monochromatic source, which has no physical meaning, implies that the source so represented is the one that must be mixed with the white light to obtain the desired color mixture match.

* It should be noted that a luminance match can exist without a color match, i.e., $L_1 + L_2 = L_3 + L_4$, and vice versa.

Let a set of light sources be selected so that

$$L'_p + L'_q + L_r \equiv L_w \quad (3)$$

Since the choice of wavelengths is somewhat arbitrary, the white reference source, in theory, can be matched by another set of lights,

$$L''_p + L''_q + L_\lambda \equiv L_w \quad (4)$$

Subtraction of Eq. (4) from Eq. (3) and rearranging yields the general law of color mixtures,

$$L_p + L_q + L_r \equiv L_\lambda \quad (5)$$

where

$$L_p \equiv L'_p - L''_p \quad (6)$$

and

$$L_q \equiv L'_q - L''_q \quad (7)$$

The law states that with respect to a human observer, any monochromatic light source can be considered to be the sum of three other monochromatic light sources.

2) Multichromatic Radiation

Let a set of three monochromatic sources illuminate a screen. By Eq. (5), we have,

$$\left. \begin{aligned} L_1 &= L_p + L_q + L_r \\ L_2 &= L_s + L_t + L_u \\ L_3 &= L_v + L_w + L_x \end{aligned} \right\} \quad (8)$$

Summing each column, there obtains

$$L_1 + L_2 + L_3 = (L_p + L_s + L_v) + (L_q + L_t + L_w) + (L_r + L_u + L_x) \quad (9)$$

But by Eq. (5) it is true that

$$\left. \begin{aligned} L_p + L_s + L_v &\equiv L_a \\ L_q + L_t + L_w &\equiv L_b \\ L_r + L_u + L_x &\equiv L_c \end{aligned} \right\}, \quad (10)$$

and thus,

$$L_1 + L_2 + L_3 \equiv L_a + L_b + L_c \quad (11)$$

Equation (11) can be generalized and for any set of n monochromatic lights it can be shown that

$$L_n \equiv \sum_{i=1}^n L_i \equiv L_\alpha + L_\beta + L_\gamma, \quad (12)$$

where L_n represents the color and luminance of the mixture of the n lights,ⁿ and S_α , S_β , and S_γ are some selected set of monochromatic sources.

3) The Primary Sources

In the development of Eq. (5) it was stated that S_r could be replaced by S_s and a match could be obtained by a suitable adjustment of the luminance^λ levels of the other two sources, S_p and S_q . This statement is true only if none of the individual sources, S_p , S_q , or S_r can be matched by a combination of the other two. Thus, the selection of the reference light system is arbitrary, subject to the constraint listed, and any light source can be matched by a proper selection of the luminance levels of the three monochromatic reference sources. The reference sources so selected are referred to as "primaries."

4) Changes in Primaries

Equation (12) can be represented as a vector equation of the following form:

$$\underline{x} = x_1 \underline{i}_1 + x_2 \underline{i}_2 + x_3 \underline{i}_3 = \sum_{k=1}^3 x_k \underline{i}_k, * \quad (13)$$

where $\underline{x}$ represents the luminance and color of the source, $\underline{i}_k$ is a unit luminance along the k^{th} primary color axis, and $x_k \underline{i}_k$ is the luminance level of the k^{th} primary. Define a new set of primaries for which the unit luminance along each of the new color axes is:

$$\left. \begin{aligned} \underline{i}'_1 &= q_{11} \underline{i}_1 + q_{12} \underline{i}_2 + q_{13} \underline{i}_3 \\ \underline{i}'_2 &= q_{21} \underline{i}_1 + q_{22} \underline{i}_2 + q_{23} \underline{i}_3 \\ \underline{i}'_3 &= q_{31} \underline{i}_1 + q_{32} \underline{i}_2 + q_{33} \underline{i}_3 \end{aligned} \right\},$$

or

$$\underline{i}'_k = \sum_{r=1}^3 q_{kr} \underline{i}_r, \quad (k = 1, 2, 3), \quad (14)$$

in terms of the old color axes. In the new primary system, the color vector $\underline{x}$ becomes

$$\begin{aligned} \underline{x} &= x'_1 \underline{i}'_1 + x'_2 \underline{i}'_2 + x'_3 \underline{i}'_3 \\ \underline{x} &= \sum_{k=1}^3 x'_k \underline{i}'_k \end{aligned} \quad (15)$$

* Since the discussion that follows deals primarily with both color and luminance, the symbol $\equiv$ has been dropped for simplicity in favor of the equal sign. Where only luminance is indicated, specific statements will be made in the text.

Substituting Eq. (14) into (15), there obtains

$$\underline{x} = \sum_{k=1}^3 \sum_{r=1}^3 x'_k q_{kr} \underline{1}_r \quad (16)$$

$$\underline{x} = \sum_{r=1}^3 \left(\sum_{k=1}^3 x'_k q_{kr} \right) \underline{1}_r, \quad (17)$$

so that

$$x_r = \sum_{k=1}^3 q_{kr} x'_k. \quad (18)$$

Thus, the relationship between the coefficient in each primary system may be determined from the vector equation

$$\underline{x} = Q^T \underline{x}' \quad (19)$$

$$Q^T = \begin{vmatrix} q_{11} & q_{21} & q_{31} \\ q_{12} & q_{22} & q_{32} \\ q_{13} & q_{23} & q_{33} \end{vmatrix} \quad (20)$$

and Q is the coefficient matrix of Eq. (14)

$$Q = \begin{vmatrix} q_{11} & q_{12} & q_{13} \\ q_{21} & q_{22} & q_{23} \\ q_{31} & q_{32} & q_{33} \end{vmatrix} \quad (21)$$

Since the unit vectors of the new primaries are linearly independent (i.e., one primary is not a mixture of the other two, an

inverse matrix, $(Q^T)^{-1}$, exists and

$$\underline{x}' = (Q^T)^{-1} \underline{x} \quad (22)$$

By these arguments, it can be seen that the specification of color and luminance of a color mix can be made in terms of sets of three linearly independent monochromatic primaries, all of which can be related to one another.

It can also be shown by a sequential application of Eq. (13) that the primaries need not be monochromatic. In such instances, as in the monochromatic case, a negative primary luminance coefficient identifies the source that is mixed with the white source. However, in the multichromatic case, the negative luminance value can also imply a requirement for filtering.

c. Tristimulus Value and Chromaticity Coordinates

1) Tristimulus Value

Let P_i be the radiant flux* from a source, S_i . Accordingly, the luminous flux, F_i , is given by

$$F_i = K_m V_i P_i, \quad (23)$$

where

$V_i = K_i / K_m$ = relative luminous efficiency of S_i ,

K_i = luminous efficiency of S_i , and

K_m = maximum luminous efficiency (680 lumens/watt).

In colorimetry, it is often convenient to use units of different magnitudes for different primaries. Thus, let a tristimulus value be defined as:

$$C_i = \frac{P_i}{e_i} \quad (24)$$

* See Annex A for unit definitions (in Tables A-13 to A-15).

where e_1 is the unit of radiant flux for the source. Substituting back into Eq. (23), the tristimulus value becomes:

$$C_1 = \frac{F_1}{l_1} \quad (25)$$

where l_1 is the luminous unit of the source and is equal to

$$l_1 = K_m V_1 e_1 \quad (26)$$

2) Relation between Tristimulus Value and Luminous Flux

The luminous flux, F_s , of any source, S , can be expressed as the sum of the luminous fluxes of the primary components that match the luminance and color of the source, i.e.,

$$F_s = F_1 + F_2 + F_3 \quad (27)$$

and

$$C_s = C_1 + C_2 + C_3 \quad ,$$

where F_1 , F_2 , and F_3 are the luminous fluxes and C_1 , C_2 , and C_3 are the tristimulus values of the primaries. It follows that

$$F_s = l_1 C_1 + l_2 C_2 + l_3 C_3 \quad (28)$$

It should be noted that these relationships are developed in terms of a human observer. Thus, a color and luminance match does not imply an equality of $e_1 C_1 + e_2 C_2 + e_3 C_3$ with the radiant flux of the source.

3) Chromaticity Coordinates

In many problems, only the color variables are of interest and only relative values of the tristimulus values are required. To treat such problems, the term chromaticity coordinate has been defined as:

$$c_1 = \frac{C_1}{C_1 + C_2 + C_3} = \frac{C_1}{C_s} \quad (29)$$

where

$$c_1 + c_2 + c_3 = 1 \quad , \quad (30)$$

and

$$l_s = \frac{F_s}{C_s} = l_1 c_1 + l_2 c_2 + l_3 c_3 \quad . \quad (31)$$

The term l_s is called the trichromatic unit of the source, S, and is a function only of the color of the source.

It follows from the definition of the chromaticity coordinate that a two-dimensional grid system, with two of the coordinates comprising the axes, could provide a geometrical representation for a color system. Figure 1 illustrates a chromaticity diagram developed by Wright in 1929, based on a monochromatic red-green-blue primary system in which the units of the red and blue primaries are chosen so that equal tristimulus values of each with a small negative blue component produce visual stimulation equivalent to yellow radiation of wavelength 582 mμ, and equal tristimulus values of the blue and green primaries with appreciable negative red components produce visual stimulation equivalent to 494 mμ. The curve on the figure, called the spectrum locus encompasses all of the visible wavelengths. The equienergy source depicted is a source that emits equal energies at all wavelengths.

As can be seen from the diagram, Wright's system required that certain colors below 530 mμ and above 650 mμ be defined in terms of negative chromaticity coordinates, a situation that was unsatisfactory to the workers at that time. There is also some difficulty in defining the source colors and primaries in an unambiguous manner.

4) The Distribution Coefficients

To make color comparisons, it is sometimes necessary to compute tristimulus values from source energy distribution curves. Consider a source, S, and the radiation from that source in a finite waveband $\Delta\lambda_j$. The radiant flux from the source in the waveband is $E_{\lambda_j} \Delta\lambda_j$. Since the tristimulus values are additive, this energy flux corresponds to a tristimulus value of ΔC_{λ_j} for the waveband. By definition, the chromaticity coordinates of the waveband are

$$c_{1\lambda_j} = \frac{\Delta C_{1\lambda_j}}{\Delta C_{\lambda_j}} \quad (32)$$

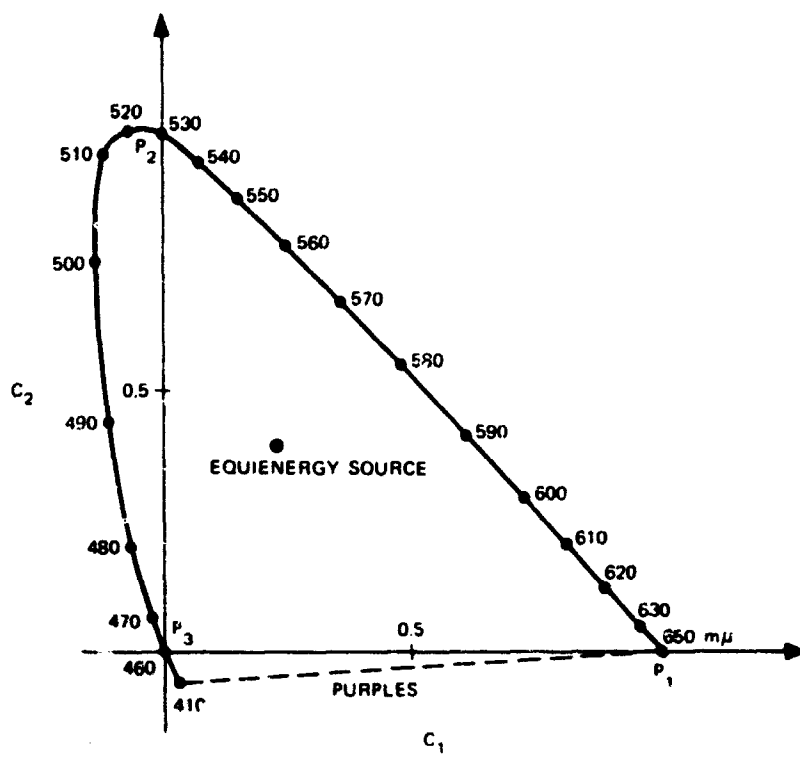


FIGURE 1 WRIGHT'S CHROMATICITY DIAGRAM

Similarly, for the total emission from the source, we have

$$C_i = \sum_j \Delta C_{i\lambda_j} = \sum_j c_{i\Delta\lambda_j} \Delta C_{\lambda_j} \quad (33)$$

where the summation is done over all wavelengths in the source, the luminous flux corresponding to the radiant flux is

$$\Delta F_{\lambda_j} = K_m V_{\lambda_j} E_{\lambda_j} \Delta\lambda_j \quad (34)$$

and if ℓ_λ is the luminous unit for wavelength λ , then

$$\Delta C_{\lambda_j} = \frac{\Delta F_{\lambda_j}}{\ell_{\lambda_j}} = \frac{K_m V_{\lambda_j} E_{\lambda_j} \Delta\lambda_j}{\ell_{\lambda_j}} \quad (35)$$

which by Eq. (33) yields

$$C_i = K_m \sum_j \left(\frac{C_{i\lambda_j} V_{\lambda_j} E_{\lambda_j} \Delta\lambda_j}{\ell_{\lambda_j}} \right) \quad (36)$$

Define a distribution coefficient

$$\bar{c}_{i\Delta\lambda_j} = \frac{C_{i\lambda_j} V_{\lambda_j}}{\ell_{\lambda_j}} \quad (37)$$

Substituting Eq. (37) into (36) yields

$$C_i = K_m \sum_j \bar{c}_{i\Delta\lambda_j} E_{\lambda_j} \Delta\lambda_j \quad (38)$$

a relationship that permits the relatively simple computation of tristimulus values and chromaticity coordinates from tables of source distribution coefficients and radiant energy distributions. From Eqs. (38) and (31), it can be seen that

$$v_{\lambda_j} = \sum_{i=1}^3 l_i \bar{c}_{i\lambda_j} \quad (39)$$

and

$$l_{\lambda_j} = \sum_{i=1}^3 l_i c_{i\lambda_j} \quad (40)$$

d. The XYZ System

In 1931, the CIE* proposed that the XYZ primary system be adopted as an international reference system. The system is based on the use of a set of hypothetical primaries with the following characteristics:

- (1) The points representing the primaries X and Z were assumed to have no luminance characteristics, permitting the total luminous flux of the color to be represented by the value of the Y primary, the luminous unit of which was chosen arbitrarily to be unity.
- (2) The sides XZ and YZ of the triangle formed by the primaries are tangent to the spectrum locus, thus ensuring positive values for all chromaticity coordinates.
- (3) An equienergy source is equidistant from both the XZ and YZ axes.

From the characteristics of the primaries, i.e.,

$$\begin{aligned} l_x &= l_z = 0 \\ l_y &= 1 \end{aligned} \quad (41)$$

* Commission Internationale de l'Eclairage.

and Eq. (37), distribution coefficients in the XYZ system become

$$\bar{x}_{\lambda_j} = \frac{V_{\lambda_j} x_{\lambda_j}}{y_{\lambda_j}}, \quad \bar{y}_{\lambda_j} = V_{\lambda_j}, \quad \bar{z}_{\lambda_j} = \frac{V_{\lambda_j} z_{\lambda_j}}{y_{\lambda_j}}. \quad (42)$$

Curves of the distribution coefficients for the visible wavelengths in the XYZ system are shown in Figure 2, and the spectrum locus for the visible wavelengths is shown in Figure 3. Numerical values for the distribution coefficients of the visible wavelengths of selected sources are given in Annex A.

e. The Determination of Tristimulus and Coordinate Values in the XYZ System

In the XYZ system, the tristimulus values of any source, S , are:

$$\left. \begin{aligned} X_S &= K_m \int \bar{x}_{\lambda_j} E_{\lambda_j} \Delta\lambda_j \\ Y_S &= K_m \int \bar{y}_{\lambda_j} E_{\lambda_j} \Delta\lambda_j \\ Z_S &= K_m \int \bar{z}_{\lambda_j} E_{\lambda_j} \Delta\lambda_j \end{aligned} \right\} \quad (43)$$

where Y_S is equal to the luminance of the source. Thus, the tristimulus values and chromaticity coordinates can be compared directly from absolute radiant energy data. However, in most instances, published radiant energy data are relative. Thus, it is necessary to convert Eq. (43) into a form that will handle relative energy distribution values to computer chromaticity coordinates.

All radiant energy distribution tables are of a form such that

$$\frac{E_{\lambda_j} \Delta\lambda_j}{R_T} = \frac{W_{\lambda_j} \Delta\lambda_j}{W_{\lambda_j} \Delta\lambda_j} \quad (44)$$

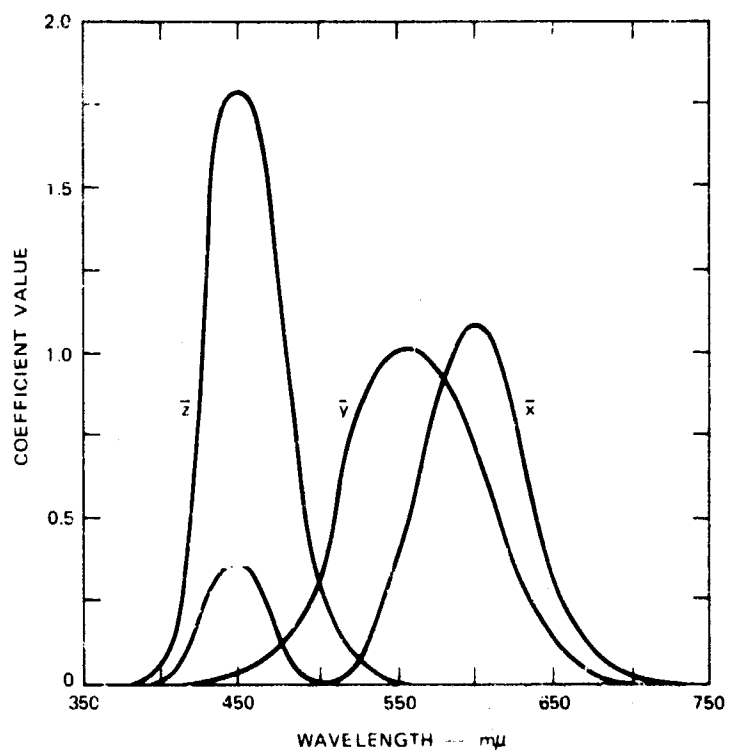


FIGURE 2 DISTRIBUTION COEFFICIENTS, XYZ PRIMARIES

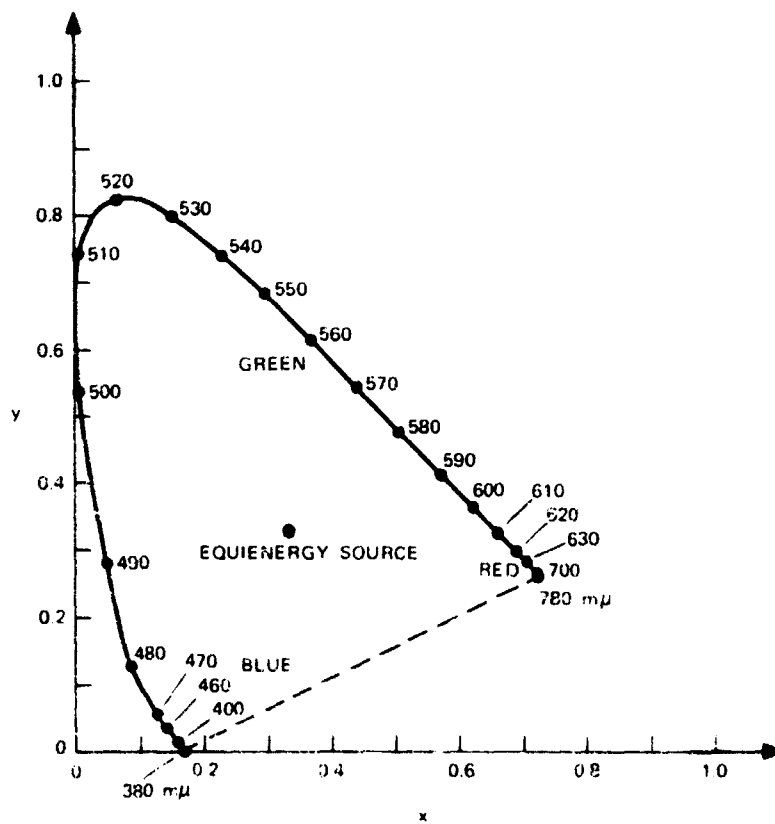


FIGURE 3 XYZ CHROMATICITY DIAGRAM

where R_T is the total emitted radiation of the source, W_{λ_j} , $\Delta\lambda_j$, is the table entry for the wavelength interval $\Delta\lambda_j$, and $\sum W_{\lambda_j} \Delta\lambda_j$ is the sum of all table entries. Substituting Eq. (44) into (43), rearranging, and dividing by $K_m \sum W_{\lambda_j} \Delta\lambda_j / R_T$, there is obtained a set of relative tristimulus values

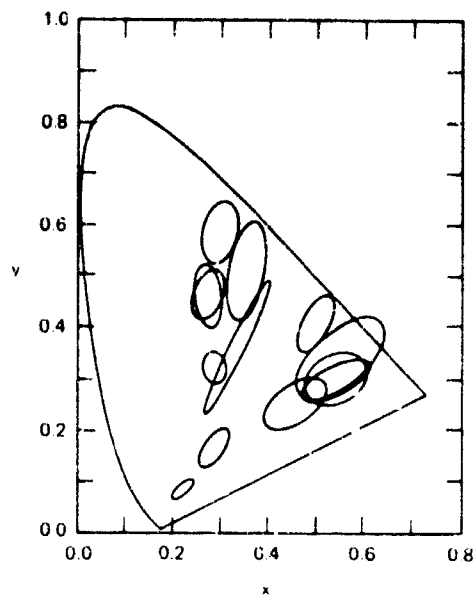
$$\begin{aligned} x'_s &= \sum_j \bar{x}_{\lambda_j} W_{\lambda_j} \Delta\lambda_j \\ y'_s &= \sum_j \bar{y}_{\lambda_j} W_{\lambda_j} \Delta\lambda_j \\ z'_s &= \sum_j \bar{z}_{\lambda_j} W_{\lambda_j} \Delta\lambda_j \end{aligned} \quad (45)$$

which can be used to compute chromaticity coordinates and compare unit luminosities. Values of W_{λ_j} for Standard illuminants A and C are summarized in Table A-5 of Annex A.

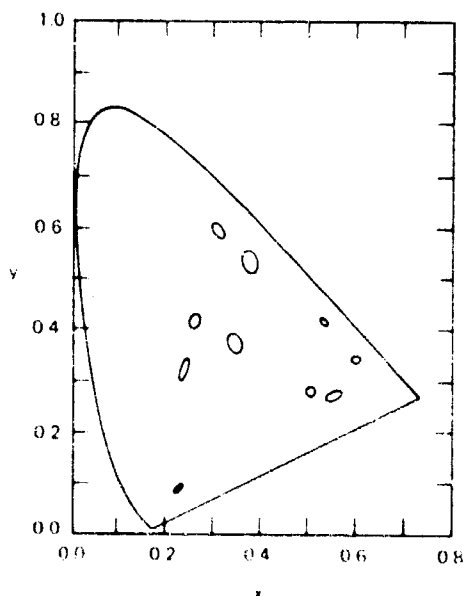
f. Detectable Chromaticity Differences

Studies of detectable differences in chromaticity have been made by MacAdam,⁴⁻⁶ Brown,⁷ and others.⁸ Of these efforts, the most significant is the work of MacAdam⁶ in which he compared the ability of visual observers to detect chromaticity differences for 3' and 4.2° fields of view. Figure 4 summarizes the result of his studies. For the smaller fields of view, which correspond to a man at a range of approximately 2 kilometers from an observer, colors having chromaticity-coordinate differences of the order of 10^{-2} units are differentiable by the average observer; for larger fields of view, differentiable differences are of the order of 10^{-3} chromaticity coordinate units.

It is interesting that the apparent color of an object is a function of the field of view subtended by the object at the observer's position. Middleton quotes Wright, who found that by the time a field has been reduced to 15' of arc, the mixture data (chromaticity coordinates) had changed markedly from the actual color mixture data.⁹ Middleton and Holms¹⁰ showed that when observers identified colored test patches subtending fields of view of 2' of arc, the coordinates of the patches called by the observers were offset from the actual values, with the



(a) CONSTANT LUMINANCE-DISCRIMINATION
ELLIPSES FOR 3° FIELD (ELLIPSES
ENLARGED 10 TIMES)



(b) CONSTANT LUMINANCE-DISCRIMINATION
ELLIPSES FOR 44° FIELD (ELLIPSES
ENLARGED 10 TIMES)

FIGURE 4 DISCRIMINATION ELLIPSES FOR
TWO FIELDS OF VIEW

yellow, green, and yellow-greens being called more blue than they actually were; the blues, violets, and crimsons being called less blue than they were; and the reds, oranges, and blue-greens being called essentially the same as the actual colors. In general, the color-mixture data called by the observers for the small patches were offset from the actual coordinates along a line roughly parallel to the y coordinate axis toward a line intersecting the monochromatic locus at approximately 490 and 600 mμ. In all instances, the change in color was dependent on the observer and varied significantly with specific individuals. However, despite these apparent changes in color data with object size, the observers maintained an ability to detect relatively small chromatic differences.

3. The Color and Luminance of Distant Objects

a. General

The apparent luminance of an object in a specific wavelength interval at a distance is determined by two concurrent processes: light emanating from the object is attenuated by scattering and absorption in the atmosphere over the path distance, and atmospheric or "air light" is scattered into the line of sight of the observer from other regions of the atmosphere all along the path of sight. The sum of radiation striking the observer's retina determines the apparent luminance of the object at the observer's position.

The atmosphere can be regarded as a material that diffuses light and is illuminated throughout by natural sources, such as the sun or moon. Many models have been developed concerned with the reduction of luminance by the atmosphere¹¹ and the detection of military targets.^{12,13} However, only limited treatments have been given to the effect of the atmosphere on the colors of distant objects. Described below are some of the effects the atmosphere has on color and luminance.

b. The Reduction of Luminance by the Atmosphere

With reference to Figure 5, let an extended source at O having a luminance, $L_{\lambda}(0)$, in the wavelength interval, $\Delta\lambda$, in the direction, θ , be observed by an observer at P. The path of sight, OP, can be divided into a large number of infinitesimally small slabs of atmosphere, whose faces are normal to the line of sight. At a distance, r , from the source, the luminance, $L_{\lambda}(r)$, is diminished by scattering and absorption in passing through thickness, dr , the magnitude of the

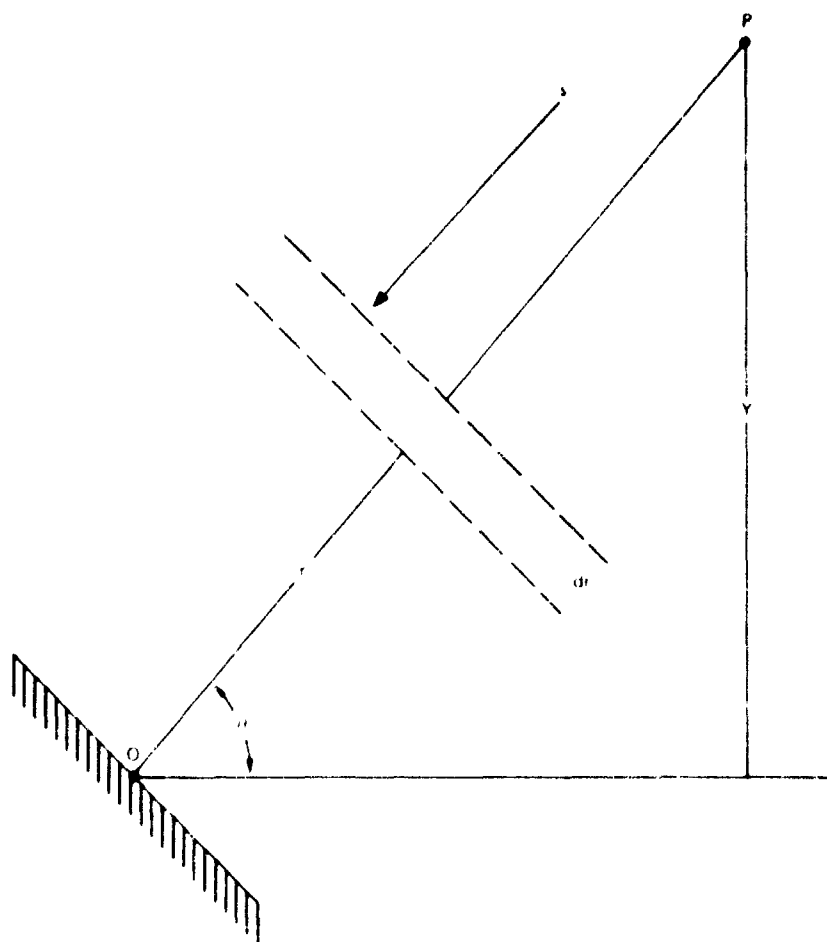


FIGURE 5 MODEL FOR LUMINANCE REDUCTION IN ATMOSPHERE

change being proportional to the luminous flux. At the same time, the flux is augmented in the lamina of atmosphere by air light, $l_\lambda(r)$, and by backscattering from the flux, s_λ , moving in the direction toward the source. The total change in flux becomes

$$\frac{dL_\lambda(r)}{dr} = -\beta_\lambda(r) L_\lambda(r) + l_\lambda(r) + b_\lambda(r) s_\lambda, \quad (46)$$

where $\beta_\lambda(r)$ is the atmospheric extinction coefficient (see Annex B), and $b_\lambda(r) s_\lambda$ is the backscattered energy from the flux.

The term $l_\lambda(r)$ is a function of the luminous density of the atmosphere, and the backscattering from the flux, $b_\lambda(r) s_\lambda$, makes a negligible contribution to the luminous density of the lamina, except for backscattered energy arising from objects that are very much brighter than the air light. Accordingly, the sum $l_\lambda(r) + b_\lambda(r) s_\lambda$ can be replaced by $\gamma_\lambda(r) q_\lambda(r)$, where $\gamma_\lambda(r)$ is the scattering coefficient and $q_\lambda(r)$ is the luminous density of the atmosphere. Substituting into Eq. (46), there results

$$\frac{dL_\lambda(r)}{dr} = -\beta_\lambda(r) L_\lambda(r) + \gamma_\lambda(r) q_\lambda(r). \quad (47)$$

For a homogeneous atmosphere that is uniformly illuminated, $\beta_\lambda(r)$, $\gamma_\lambda(r)$, and $q_\lambda(r)$ are constant, and the integrated form of the equation over the distance R becomes

$$\int_{L_\lambda(0)}^{L_\lambda(R)} \frac{dL_\lambda(r)}{-\beta_\lambda(r) L_\lambda(r) + \gamma_\lambda q_\lambda} = \int_0^R dr, \quad (48)$$

which yields

$$L_\lambda(R) = L_\lambda(0) e^{-\beta_\lambda R} + \left(1 - e^{-\beta_\lambda R}\right) \frac{\gamma_\lambda q_\lambda}{\beta_\lambda}. \quad (49)$$

At large values of R , the equation reduces approximately to

$$L_{\lambda}(R) = \frac{\gamma_{\lambda} q_{\lambda}}{\beta_{\lambda}} = L_{\lambda}(m) \quad , \quad (50)$$

where $L_{\lambda}(m)$ is the luminance of the attenuating atmosphere.* Equation (49) then becomes

$$L_{\lambda}(R) = L_{\lambda}(O) e^{-\frac{\gamma_{\lambda}}{\beta_{\lambda}} R} + \left(1 - e^{-\frac{\gamma_{\lambda}}{\beta_{\lambda}} R}\right) L_{\lambda}(m) \quad . \quad (51)$$

c. Luminance and Color Contrast

1) Luminance Contrast

Let $L_{\lambda}(R)$ and $L'_{\lambda}(R)$ be the apparent luminance of an object and its background at range R , and let $L_{\lambda}(O)$ and $L'_{\lambda}(O)$ be the inherent contrast of the object and its background at range 0. Define the inherent contrast of the object against its background as

$$C(O) = \frac{\sum_j \left[L_{\lambda_j}(O) - L'_{\lambda_j}(O) \right]}{\sum_j L'_{\lambda_j}(O)} \quad (52)$$

and the apparent contrast at range R as

$$C(R) = \frac{\sum_j \left[L_{\lambda_j}(R) - L'_{\lambda_j}(R) \right]}{\sum_j L'_{\lambda_j}(R)} \quad (53)$$

*For most situations, the luminance of the attenuating atmosphere is the luminance of the horizon sky. However, in some military situations, e.g., smoke screens, and under conditions of fog and dust, the more general term "attenuating atmosphere" is applicable.

Substituting Eqs. (51) and (52) into (53), there obtains

$$C(R) = C(0) \left[\frac{\sum_j L'_{\lambda_j}(0) e^{-\beta_{\lambda_j}(R)}}{\sum_j L'_{\lambda_j}(R)} \right] \quad (54)$$

which is a general law for the reduction of contrast by an attenuating atmosphere. When the background is the horizon and the atmosphere is uniform, we have

$$\sum_j L'_{\lambda_j}(0) = \sum_j L'_{\lambda_j}(R)$$

and

$$C(R) = C(0) e^{-\beta_{\lambda_j} R} \quad (55)$$

2) The Ideal White Surface

For many situations, the incorporation of the contrast of a white surface against its background permits a major reduction of computational effort. Accordingly, consider a perfectly diffusing and reflecting white surface. Define the inherent contrast of the white surface against its atmospheric background at wavelength λ as

$$C_{\lambda}(w) = \frac{L_{\lambda}^w(w) - L_{\lambda}(m)}{L_{\lambda}(m)} \quad (56)$$

where $L_{\lambda}^w(w)$ is the inherent luminance of the white surface. Defining

$$\rho_{\lambda} = \frac{L_{\lambda}(0)}{L_{\lambda}^w(w)} \quad (57)$$

and summing over all wavelength bands, Eq. (51) becomes

$$L_T = \sum_j L_{\lambda_j}(R) = \sum_j \left(\alpha_{\lambda_j} \left[C_{\lambda_j}(W) + 1 \right] L_{\lambda_j}(m) e^{-\frac{\rho_{\lambda_j} R}{L_{\lambda_j}(m)}} + L_{\lambda_j}(m) \left(1 - e^{-\frac{\rho_{\lambda_j} R}{L_{\lambda_j}(m)}} \right) \right), \quad (58)$$

where L_T is the total luminance of the body at the observer's position. For nonself-luminance bodies illuminated by some source, α_{λ_j} is equal to the spectral reflectance.

3) Chromaticity Coordinates and Range

Combining Eqs. (57) and (51) yields

$$L_{\lambda_j}(R) = L_{\lambda_j}(m) \left[1 + \left(\frac{\alpha_{\lambda_j} L_{\lambda_j}^{\infty}(W)}{L_{\lambda_j}(m)} - 1 \right) e^{-\frac{\rho_{\lambda_j} R}{L_{\lambda_j}(m)}} \right]. \quad (59)$$

The quantity in the parentheses can be written in the form

$$\frac{\alpha_{\lambda_j} L_{\lambda_j}^{\infty}(W) - L_{\lambda_j}(m)}{L_{\lambda_j}(m)}, \quad (60)$$

which, upon adding and subtracting $\alpha_{\lambda_j} L_{\lambda_j}(m)$ in the numerator, becomes

$$\frac{\alpha_{\lambda_j} L_{\lambda_j}^{\infty}(W) - L_{\lambda_j}(m)}{L_{\lambda_j}(m)} = \frac{\alpha_{\lambda_j} L_{\lambda_j}^{\infty}(W) - \alpha_{\lambda_j} L_{\lambda_j}(m)}{L_{\lambda_j}(m)} + \frac{\alpha_{\lambda_j} L_{\lambda_j}(m) - L_{\lambda_j}(m)}{L_{\lambda_j}(m)} = \frac{\alpha_{\lambda_j} L_{\lambda_j}^{\infty}(W) - \alpha_{\lambda_j} L_{\lambda_j}(m)}{L_{\lambda_j}(m)} + \alpha_{\lambda_j} - 1. \quad (61)$$

Substituting back into Eq. (59) yields

$$L_{\lambda_j}(R) = L_{\lambda_j}(m) \left[1 + \left(\frac{\alpha_{\lambda_j} L_{\lambda_j}^{\infty}(W) - \alpha_{\lambda_j} L_{\lambda_j}(m)}{L_{\lambda_j}(m)} + \alpha_{\lambda_j} - 1 \right) e^{-\frac{\rho_{\lambda_j} R}{L_{\lambda_j}(m)}} \right]. \quad (62)$$

But

$$L_{\lambda}(m) = K_m V_{\lambda} E'_{\lambda} \Delta\lambda \quad (63)$$

where $E'_{\lambda} \Delta\lambda$ is the spectral radiation of the air light. Thus, the luminance of the object at range R is

$$L_{\lambda}(R) = K_m V_{\lambda} E'_{\lambda} \Delta\lambda \left[1 + \left(\gamma_{\lambda} C_{\lambda}(W) + \alpha_{\lambda} - 1 \right) e^{-\frac{S_{\lambda} R}{\Delta\lambda}} \right] \quad (64)$$

From Eq. (13), the luminance of the object in terms of chromaticity coordinate, $\bar{y}_{\lambda}$, is $K_m \bar{y}_{\lambda} E'_{\lambda} \Delta\lambda$. Remembering that $\bar{y}_{\lambda} = V_{\lambda}$, we have

$$K_m V_{\lambda} E'_{\lambda} \Delta\lambda = K_m \bar{y}_{\lambda} E'_{\lambda} \Delta\lambda \left[1 + \left(\gamma_{\lambda} C_{\lambda}(W) + \alpha_{\lambda} - 1 \right) e^{-\frac{S_{\lambda} R}{\Delta\lambda}} \right] \quad (65)$$

and

$$E'_{\lambda} \Delta\lambda = E'_{\lambda} \Delta\lambda \left[1 + \left(\gamma_{\lambda} C_{\lambda}(W) + \alpha_{\lambda} - 1 \right) e^{-\frac{S_{\lambda} R}{\Delta\lambda}} \right] \quad (66)$$

Substituting in Eq. (13) and using the same methods that were used to develop Eq. (15), the relative tristimulus values become

$$\left. \begin{aligned} X' &= \sum_j W'_{\lambda_j} \bar{x}_{\lambda_j} \left[1 + \left(\gamma_{\lambda_j} C_{\lambda_j}(W) + \alpha_{\lambda_j} - 1 \right) e^{-\frac{S_{\lambda_j} R}{\Delta\lambda_j}} \right] \Delta\lambda_j \\ Y' &= \sum_j W'_{\lambda_j} \bar{y}_{\lambda_j} \left[1 + \left(\gamma_{\lambda_j} C_{\lambda_j}(W) + \alpha_{\lambda_j} - 1 \right) e^{-\frac{S_{\lambda_j} R}{\Delta\lambda_j}} \right] \Delta\lambda_j \\ Z' &= \sum_j W'_{\lambda_j} \bar{z}_{\lambda_j} \left[1 + \left(\gamma_{\lambda_j} C_{\lambda_j}(W) + \alpha_{\lambda_j} - 1 \right) e^{-\frac{S_{\lambda_j} R}{\Delta\lambda_j}} \right] \Delta\lambda_j \end{aligned} \right\} \quad (67)$$

where W'_{λ_j} is the relative energy distribution of the atmospheric light in wavelength band $\Delta\lambda_j$. For an ideal white surface it can be assumed that

$$C_{\lambda_1}(W) = C_{\lambda_2}(W) = C(W)$$

and the equations for the relative tristimulus values can be written

$$\left. \begin{aligned} X' &= \sum_j w'_{\lambda_j} \bar{x}_{\lambda_j} \left[1 + \left(\alpha_{\lambda_j} C(W) + \alpha_{\lambda_j} - 1 \right) e^{-\frac{\theta_{\lambda_j} R}{\lambda_j}} \right] \Delta\lambda_j \\ Y' &= \sum_j w'_{\lambda_j} \bar{y}_{\lambda_j} \left[1 + \left(\alpha_{\lambda_j} C(W) + \alpha_{\lambda_j} - 1 \right) e^{-\frac{\theta_{\lambda_j} R}{\lambda_j}} \right] \Delta\lambda_j \\ Z' &= \sum_j w'_{\lambda_j} \bar{z}_{\lambda_j} \left[1 + \left(\alpha_{\lambda_j} C(W) + \alpha_{\lambda_j} - 1 \right) e^{-\frac{\theta_{\lambda_j} R}{\lambda_j}} \right] \Delta\lambda_j \end{aligned} \right\} \quad (68)$$

Illuminant C in Table A-5 of Annex A resembles air light on a bright overcast day. The chromaticity coordinates can be computed directly from Eq. (68).

d. The Probability of Detecting a Color and Luminance Difference between Two Objects

Let $P_c(R)$ and $P_l(R)$ be the probabilities of detecting a chromatic and luminance contrast difference between two objects at range R. The probability of detecting either a chromatic or luminance difference between the objects at range R is

$$P_d(R) = P_c(R) + P_l(R) - P_{cl}(R) \quad (69)$$

where $P_{cl}(R)$ is the probability of detecting both a chromatic and a luminance contrast simultaneously. Since chromatic differences are independent of luminance contrast differences, we have

$$P_{cl}(R) = P_c(R) \left[1 + P_l(R) \right] \quad (70)$$

and

$$P_d(R) = P_c(R) + P_l(R) \left[1 + P_c(R) \right] \quad (71)$$

The determination of $P_c(R)$ is made possible by the work of MacAdams.⁶ If it is assumed that MacAdams' color ellipses can be approximated by circles, the value of $P_c(R)$ can be determined from

$$P_c(R) \begin{cases} = 1.0 : d \geq 0.02, \phi \leq 15'; & d \geq 0.002, \phi > 15' \\ = 0 : d < 0.02, \phi \leq 15'; & d < 0.002, \phi > 15' \end{cases}, \quad (72)$$

where

$$d = \left(\left[x_2(R) - x_1(R) \right]^2 + \left[y_2(R) - y_1(R) \right]^2 \right)^{\frac{1}{2}} \quad (73)$$

ϕ = angle subtended by the smallest object at range R , and $x_i(R)$, $y_i(R)$ = chromatic coordinates of the i^{th} object at range R .

The detection of luminance contrast is somewhat more involved. Blackwell and his coworkers¹⁵ have shown that changing the stimulus contrast by a factor of four corresponds to a change in probability of detecting a luminous contrast difference from 10 to 95 percent.

This experimental finding permits the probability of detecting a luminance contrast difference to be determined, if the detection probability is known at one value of stimulus contrast. The result of Blackwell's research is shown in Figure 6, in which the detection probability is plotted as a function of relative contrast, i.e., the ratio of the stimulus contrast to the contrast at the 50-percent detection level. The results of tests to determine threshold (50-percent detection level) contrasts for circular stimuli of various sizes and background luminance relations are shown in Figure A-1 of Annex A. Although the values shown in that figure were determined for stimulus areas brighter than the background, subsequent experiments showed that they were also valid for stimulus areas darker than the background, except for large areas at low luminance levels, for which the values shown are 20 percent too high. The dashed portion of the curves are extrapolated values for situations normally encountered in military operations.¹² Also shown in Annex A are the angular subtenses of selected military targets (Figure A-2) and the luminance levels of the sky under various cloud conditions and times of day (Table A-6).

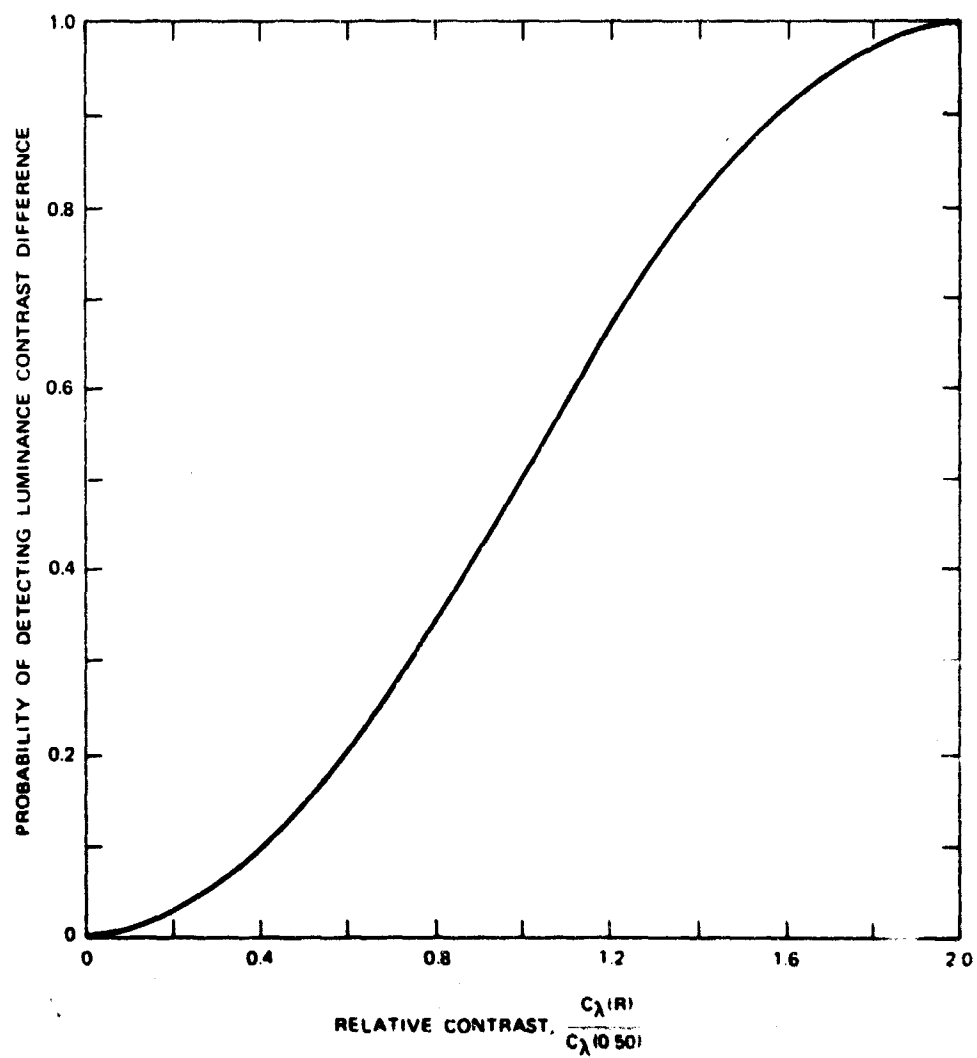


FIGURE 6 PROBABILITY OF DETECTION OF AN ACHROMATIC STIMULUS

4. Sample Computations

The computation of chromatic and luminance contrasts and the resulting probabilities of detection follow directly from an application of the relationships that have been developed. The use of these equations is illustrated below.

a. The Computational Model

1) The Color Equations

a) Tristimulus Values

The tristimulus values are given by:

$$\left. \begin{aligned} X &= \sum_j W_{\lambda_j} \bar{x}_{\lambda_j} \left[1 + Q_j e^{-\frac{\rho_{\lambda_j} R}{\lambda_j}} \right] \Delta\lambda_j \\ Y &= \sum_j W_{\lambda_j} \bar{y}_{\lambda_j} \left[1 + Q_j e^{-\frac{\rho_{\lambda_j} R}{\lambda_j}} \right] \Delta\lambda_j \\ Z &= \sum_j W_{\lambda_j} \bar{z}_{\lambda_j} \left[1 + Q_j e^{-\frac{\rho_{\lambda_j} R}{\lambda_j}} \right] \Delta\lambda_j \end{aligned} \right\} \quad (74)$$

where

$$Q_j = \frac{\rho_{\lambda_j}}{\lambda_j} C(W) + \frac{\rho_{\lambda_j}}{\lambda_j} - 1 \quad (75)$$

Values of W_{λ_j} are obtained from tables of spectral energy distributions (Table A-5), and values for $\bar{x}_{\lambda_j}$, $\bar{y}_{\lambda_j}$, and $\bar{z}_{\lambda_j}$ are obtained from tables of illuminant distribution coefficients (Tables A-2, A-3, and A-4). For nonself-luminous bodies, values for ρ_{λ_j} are obtained from spectral reflectance tables (Tables A-7 through A-12). For self-luminous bodies, the values of ρ_{λ_j} must be determined from the ratio of the luminance of the body to that of a perfectly white diffusing surface. The value of $C(W)$ must be estimated.

The values for the atmospheric attenuation coefficient, β , can be determined in two ways. For situations in which the meteorological visibility, V_R , is known, i.e., the range at which the contrast of a black body against the horizon is 0.02, the value of β is given by

$$\beta_h = \frac{3.9}{V_R} \quad (76)$$

For situations in which the meteorological visibility is not known, the attenuation is given by

$$\beta_m = \frac{3W}{dp} \quad (\text{homogeneous aerosols}) \quad (77)$$

or

$$\beta_m = \frac{3W}{p} \sum_i \frac{v_i}{d_i} \quad (\text{heterogeneous aerosols}) \quad (78)$$

where W and p are the weight concentration and density of the aerosol material, d is the diameter of the homogeneous aerosol particle, d_i is the diameter of the i^{th} particle in the heterogeneous aerosol, and v_i is the weight fraction of the particle having a diameter of d_i .

b) Chromaticity Coordinates

The chromaticity coordinates are computed directly from the tristimulus values

$$\left. \begin{aligned} x &= \frac{X}{X + Y + Z} \\ y &= \frac{Y}{X + Y + Z} \\ z &= 1 - (x + y) \end{aligned} \right\} \quad (79)$$

2) Luminance and Chromatic Contrast

a) Luminance Contrast

The relative luminances of an object, i , and its background, j , are equal to the Y tristimulus values. Thus, for object i against background j , the inherent contrast is

$$C_{ij}(0) = \frac{Y_i(0) - Y_j(0)}{Y_j(0)}, (R = 0) \quad (80)$$

For object i against the horizon, we have

$$C_i(0) = \frac{Y_i(0)}{\sum_j w_{\lambda_j} \bar{y}_{\lambda_j} \Delta \lambda_j} - 1, (R = 0) \quad (81)$$

For contrast at a range R from the observer, the contrast equations become

$$C_{ij}(R) = C_{ij}(0) \left(\frac{Y_i(0)}{Y_j(R)} \right) e^{-\beta R}, \quad (82)$$

and

$$C_i(R) = C_i(0) e^{-\beta R} \quad (83)$$

b) Chromatic Contrast

The chromatic contrast between two bodies, i and j , is defined as the absolute difference between the chromaticity coordinates of the bodies. Thus, the chromaticity contrast is given by

$$D_{ij} = \left| \left[(x_i - x_j)^2 + (y_i - y_j)^2 \right]^{1/2} \right| \quad (84)$$

3) Probabilities of Detection

a) Luminance Contrast

The probability of detecting a luminance contrast between an object and a background is a function of the angle subtended by the object, and the luminance level of the environment. The angle subtended by the object is determined from the range and longest division of the body (Figure A-2). The liminal (threshold) contrast value for a 50-percent detection probability is then determined from relationships among liminal contrast, stimulus angle, and adaptation brightness values (Figure A-1). The probability of detecting a luminance difference, P_l , between the body and its background is then determined from the ratio of the computed contrast to the liminal contrast for that size body (Figure 6).

b) Chromatic Contrast

Owing to the limited experimental data that are available, the probabilities of detecting a chromatic difference between an object and its background must be treated as a step function. Accordingly, the probabilities can be determined from

$$P_C(R) = \begin{cases} 1.0: & D_{ij} \geq 0.02, \phi \leq 15' \\ & D_{ij} \geq 0.002, \phi > 15' \\ 0: & D_{ij} < 0.02, \phi \leq 15' \\ & D_{ij} < 0.002, \phi > 15' \end{cases} \quad (85)$$

where ϕ is the angle subtended by the object at range R.

c) Probability of Detecting an Object

The probability of detecting an object is given by

$$P_d(R) = P_C(R) + P_l(R) \left(1 - P_C(R) \right) \quad (86)$$

4) Chromatic Combination

When the color pattern making up an object's surface is too small to be resolved by the human eye, the color observed by a human observer will appear as a weighted mix of the colors comprising the pattern. For equal pattern areas of two colors, the chromaticity coordinates of the resulting mix can be determined from

$$\left. \begin{aligned} x_{i+j} &= \frac{X_i + X_j}{X_i + X_j + Y_i + Y_j + Z_i + Z_j} \\ y_{i+j} &= \frac{Y_i + Y_j}{X_i + X_j + Y_i + Y_j + Z_i + Z_j} \\ z_{i+j} &= 1 - (x_{i+j} + y_{i+j}) \end{aligned} \right\} \quad (87)$$

The probabilities of detecting such an object against its background can be determined from the previous equations using the combined values of the tristimulus values and coordinates for the object.

b. Sample Computations

1) Example Cases

A number of sample computations were made to illustrate the use of the model. All calculations were made assuming clear, bright, daylight conditions (Type C Illuminant, 10 candles/m), a contrast, $C(W)$, of a white surface against the horizon of 0.5, and spectral reflectivities as defined in Air Force Avionics Laboratory computations. The specific spectral reflectivity data used are summarized in Tables A-7 through A-12 in Annex A. Computations were done for the following targets and backgrounds:

<u>Target (man)</u>	<u>Background</u>
Fatigue uniform	Meadow in bloom
Fatigue uniform	Fresh snow
Olive drab uniform	Fresh snow
Fatigue uniform	Men in olive drab uniforms
International orange clothes	Meadow in bloom

* In cases where the background of the object is another object, ϕ is the angle subtended by the smallest object.

All computations were made using the total visible waveband (380 mμ - 780 mμ). Two additional computations were made assuming an observer using filters: the first was made for the man in fatigue uniform against a meadow background using a filter that limited observable radiation to the region of 500-600 mμ; the second was made for a man in international orange clothes against a meadow background using a filter that limited observable radiation to the region of 600-700 mμ.

The results of the computations are shown in Figures 7 through 13 for meteorological visibilities of 5 kilometers and in Figure 14 for one case at a meteorological visibility of 18 kilometers. It is interesting that with the exception of the man in fatigues against a meadow background, color differences were evident in all cases. In this one case, color differences become significant as the meteorological visibility increased.

It is also interesting to note the effects of the filtered versus the unfiltered views. In the case of the man in fatigues against the meadow background (Figures 7 and 12), the use of filters enhances the color differences but not the probability of detecting a chromatic or luminance difference. However, in the case of the man in international orange against a meadow (Figures 11 and 13), the filters degrade the chromatic differences but enhance the overall probability of detecting a chromatic or luminance contrast.

One of the most surprising results of the computations was the slight differences in detectivity between the man in fatigues and the man in olive drab uniform. Figures 8 and 9 show the chromatic range and probabilities of detection of these targets against fresh snow backgrounds. When the man in fatigues is viewed against a background of olive drab uniforms, the results are those shown in Figure 10. Thus, it can be concluded that under the visibility conditions specified, small differences in uniform color appear to produce small but significant changes in detectability.

The apparent change in chromaticity coordinates for the various targets and backgrounds are shown in Figure 15. Included in that figure is the color resulting from the mix of an international orange target and a meadow background. Range marks for 0, 1, and 10 km have been added.

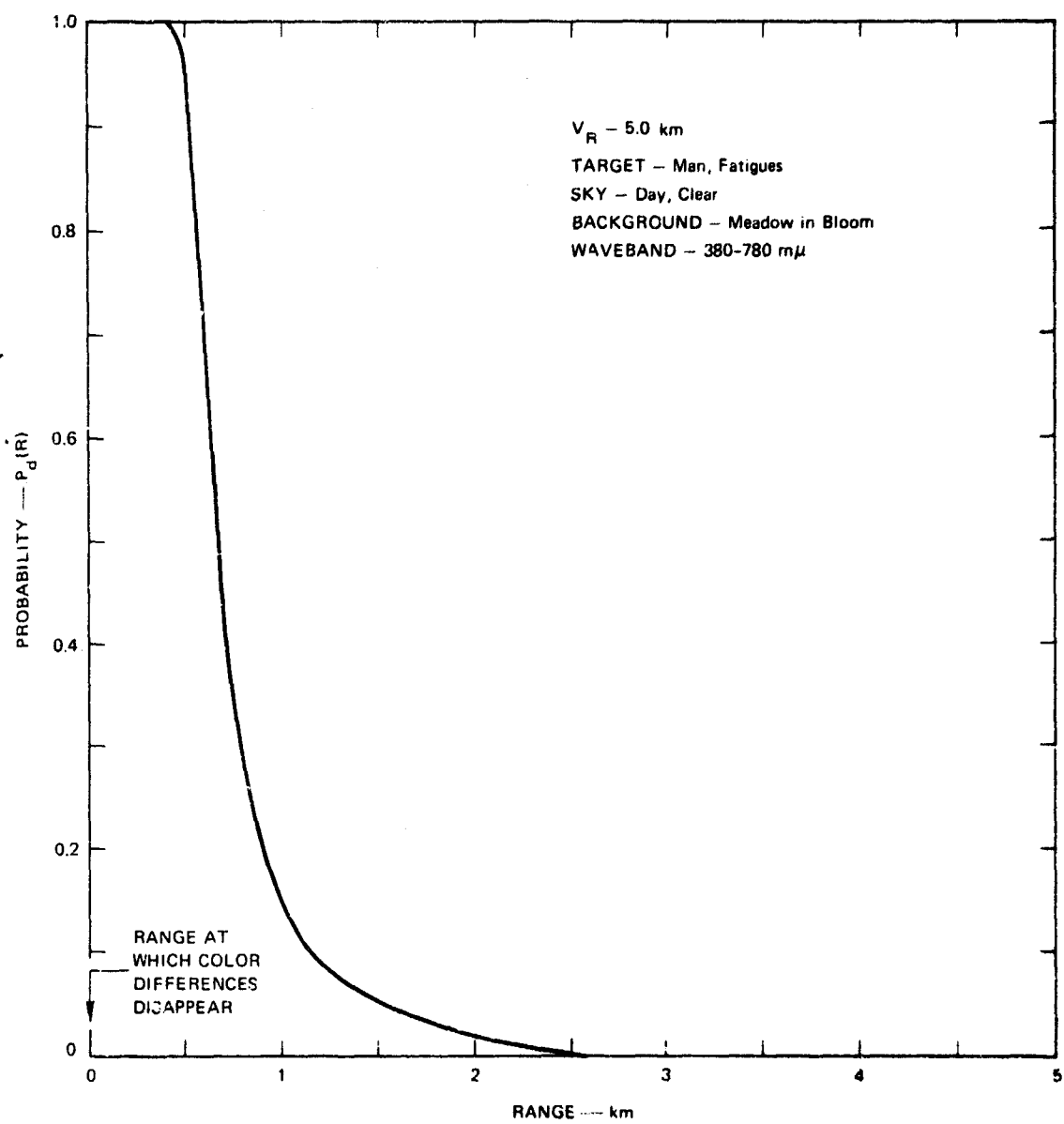


FIGURE 7 PROBABILITY OF DETECTING LUMINANCE OR CHROMATIC CONTRAST

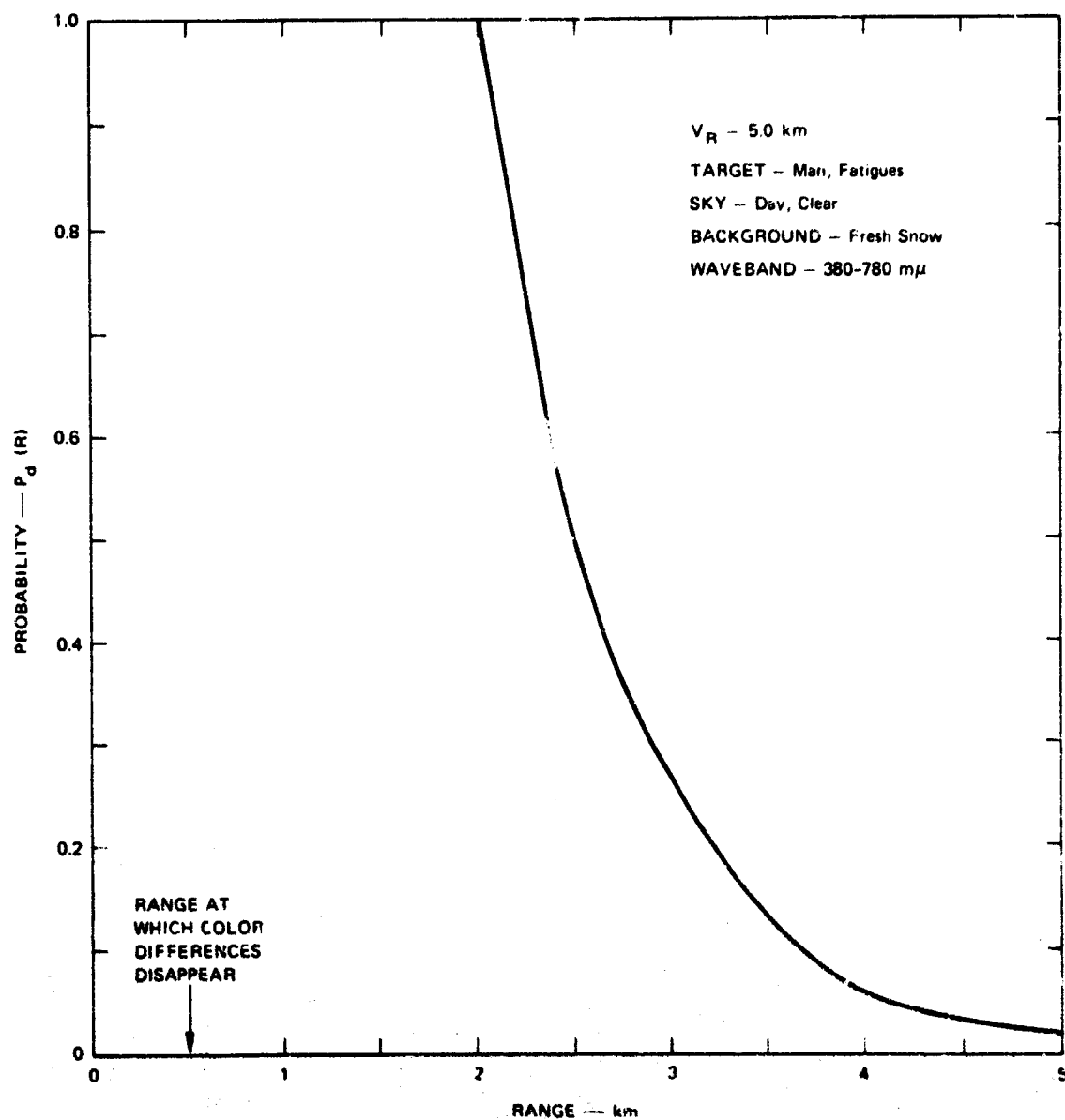


FIGURE 8 PROBABILITY OF DETECTING LUMINANCE OR CHROMATIC CONTRAST

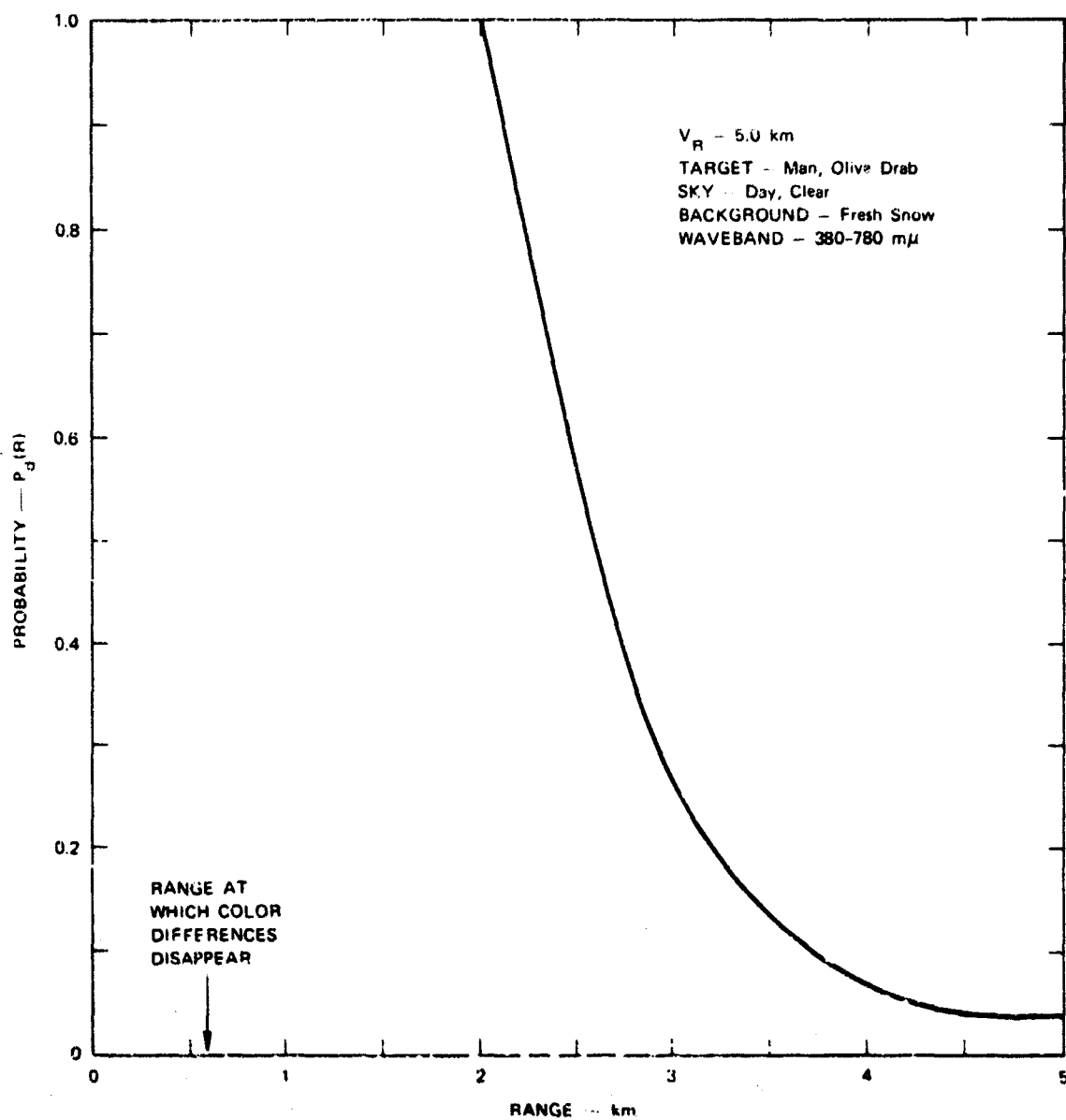


FIGURE 9 PROBABILITY OF DETECTING LUMINANCE OR CHROMATIC CONTRAST

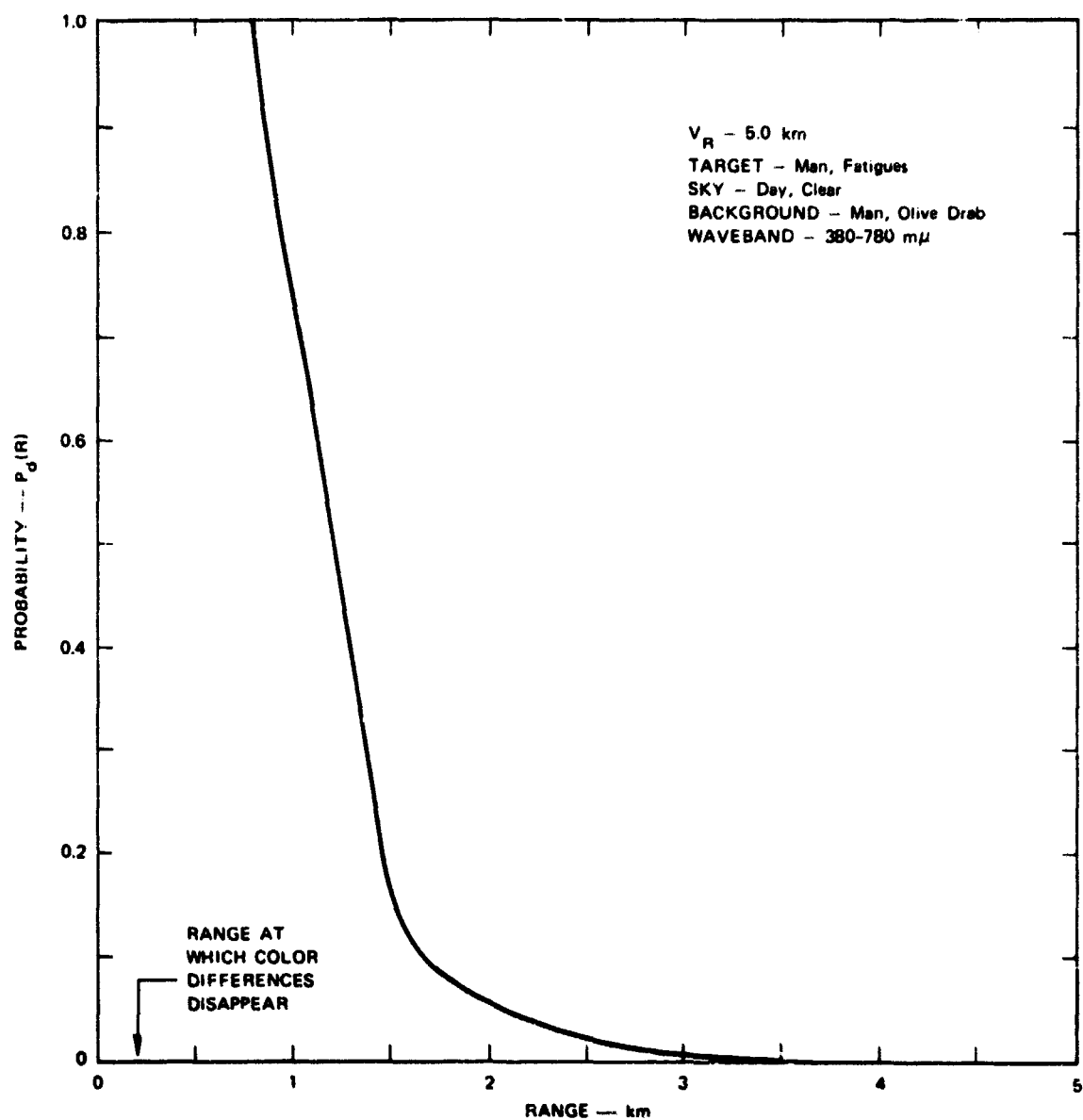


FIGURE 10 PROBABILITY OF DETECTING LUMINANCE OR CHROMATIC CONTRAST

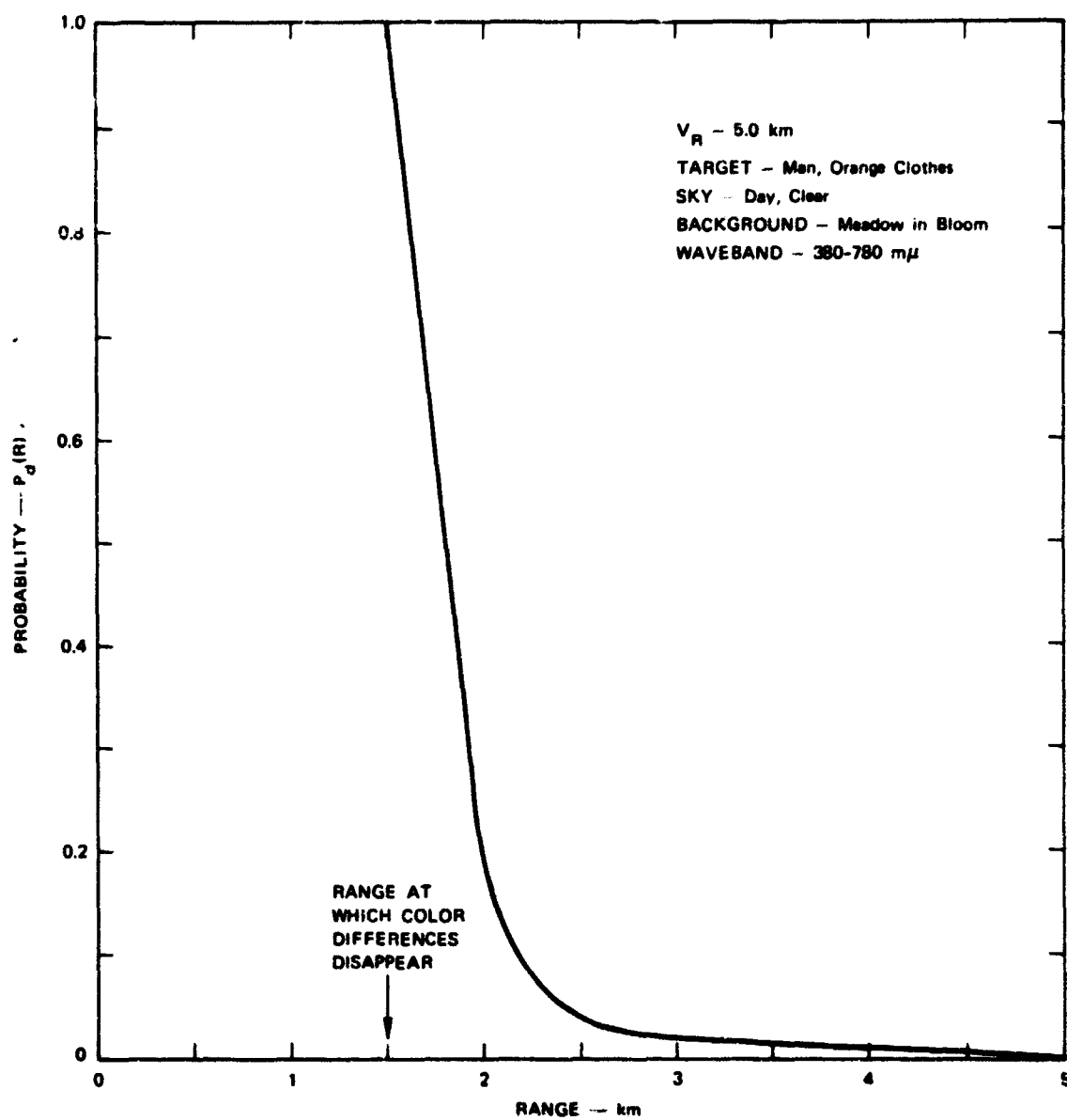


FIGURE 11 PROBABILITY OF DETECTING LUMINANCE OR CHROMATIC CONTRAST

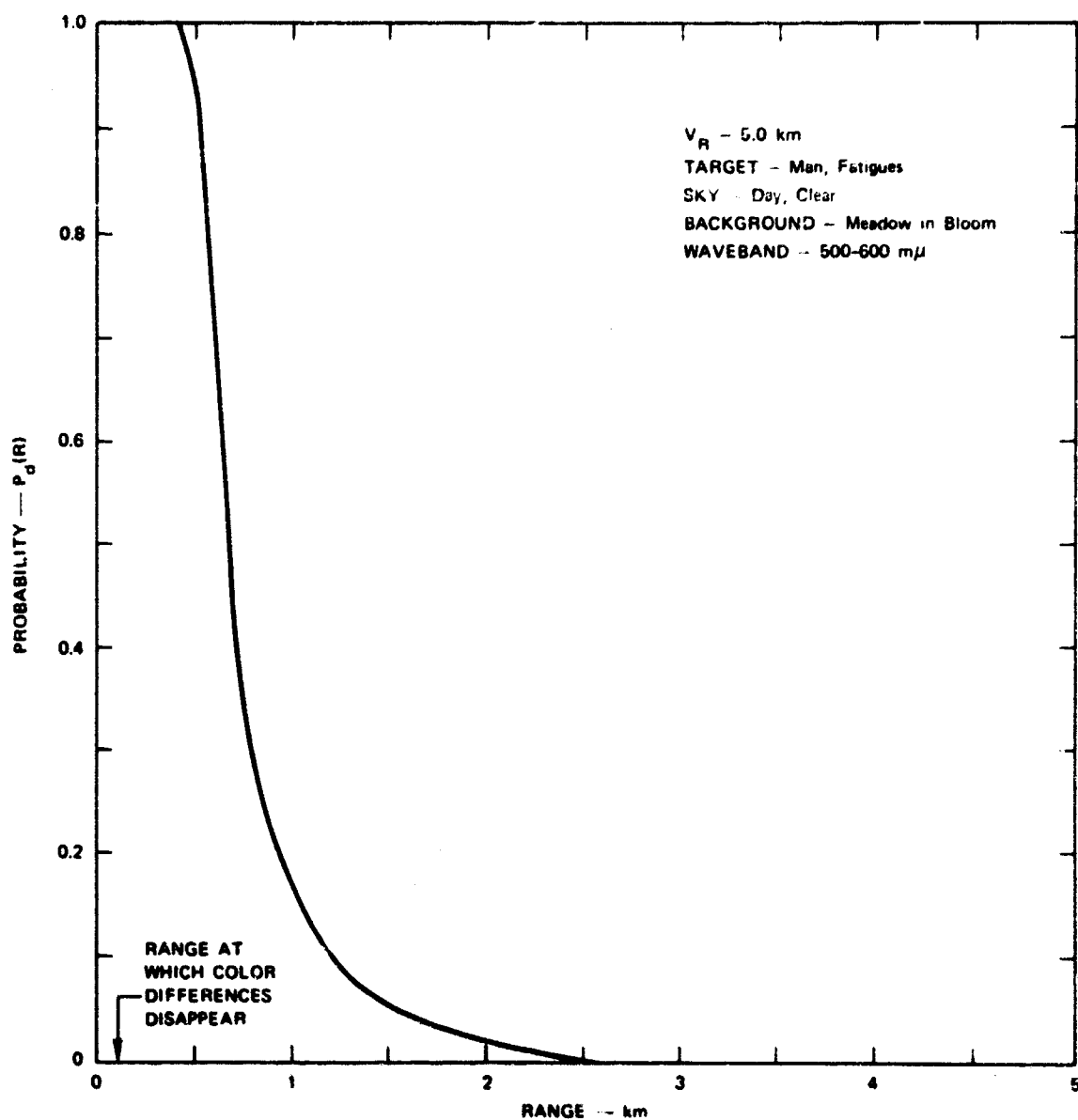


FIGURE 12 PROBABILITY OF DETECTING LUMINANCE OR CHROMATIC CONTRAST

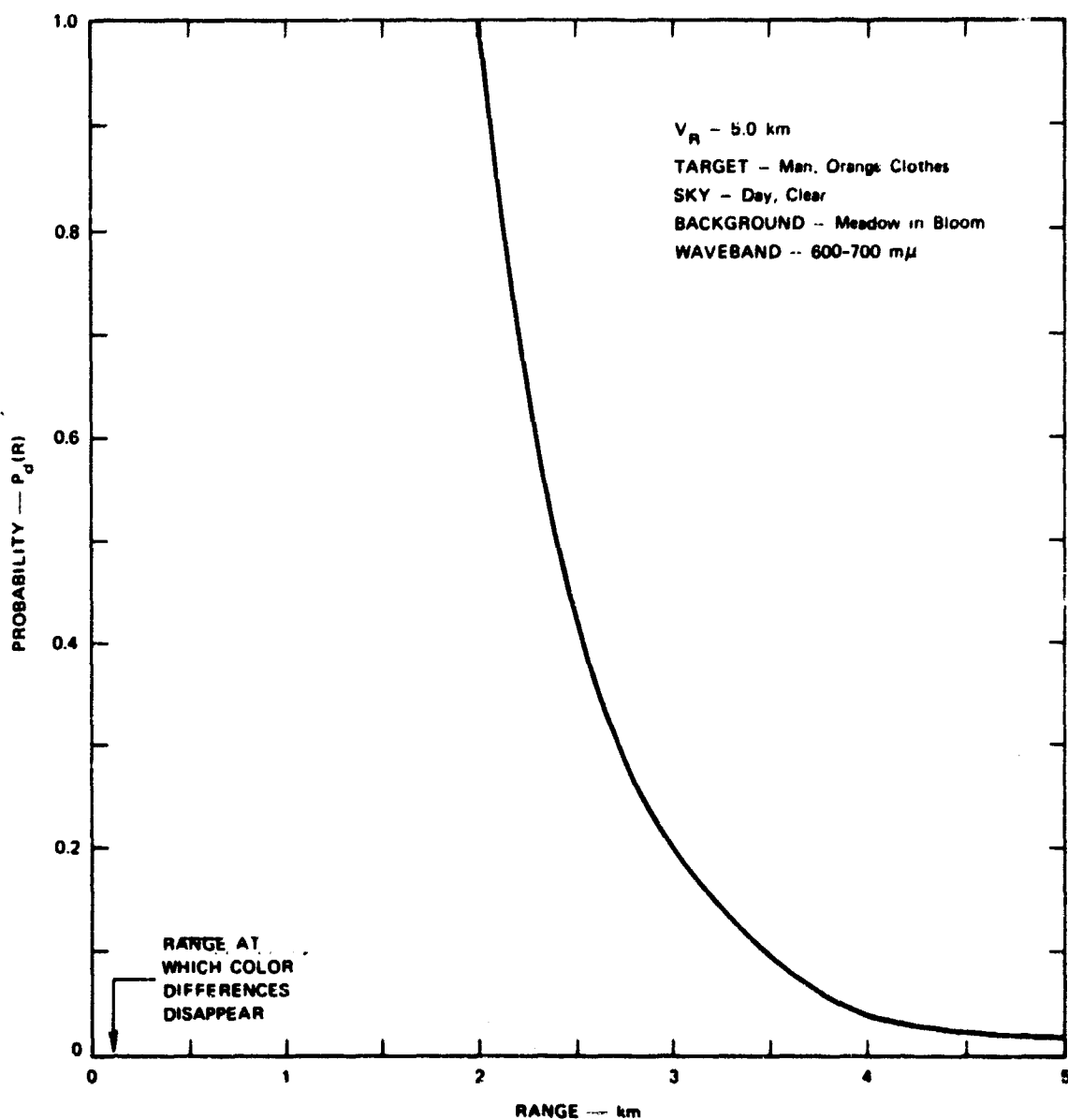


FIGURE 13 PROBABILITY OF DETECTING LUMINANCE OR CHROMATIC CONTRAST

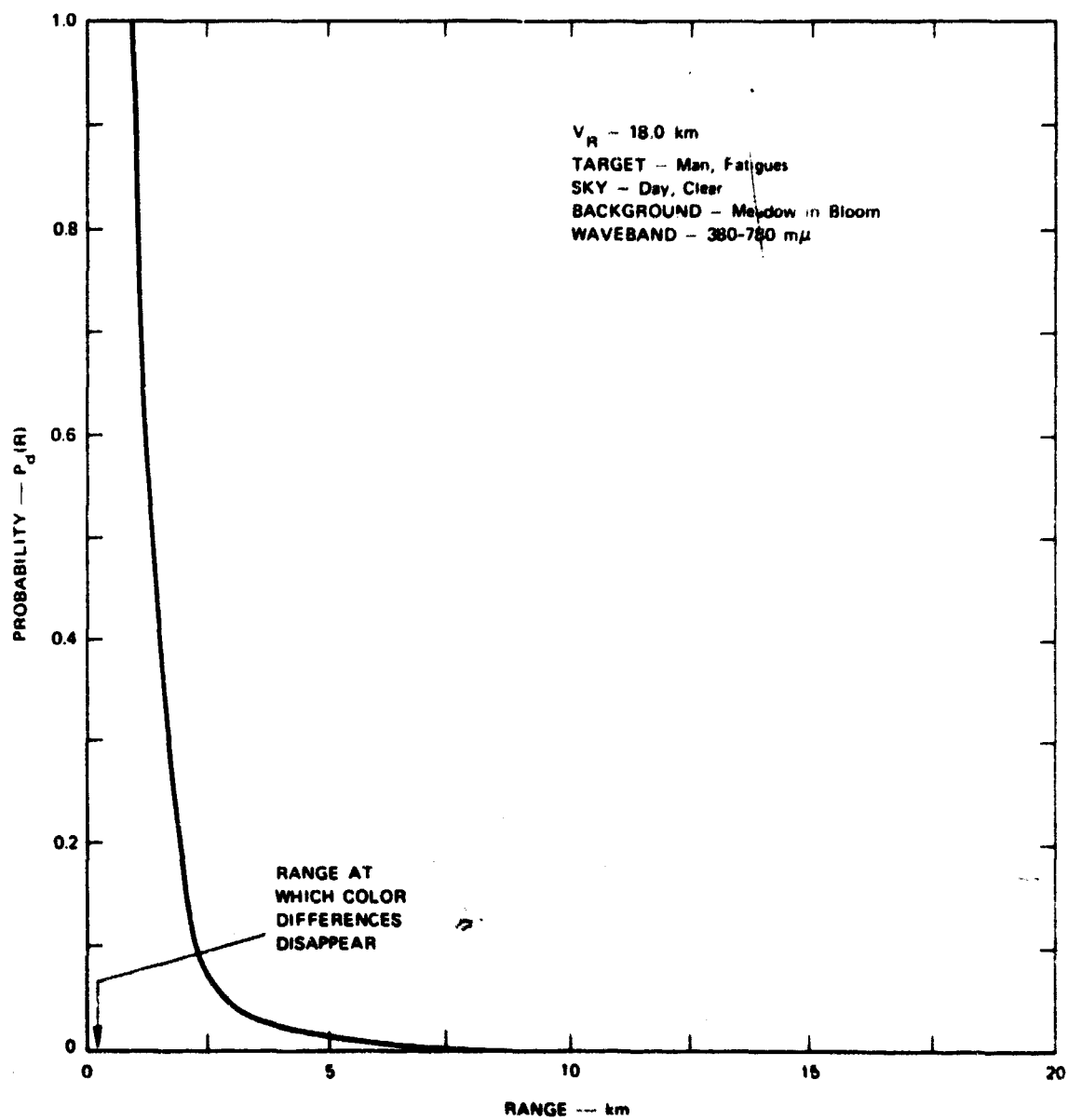


FIGURE 14 PROBABILITY OF DETECTING LUMINANCE OR CHROMATIC CONTRAST

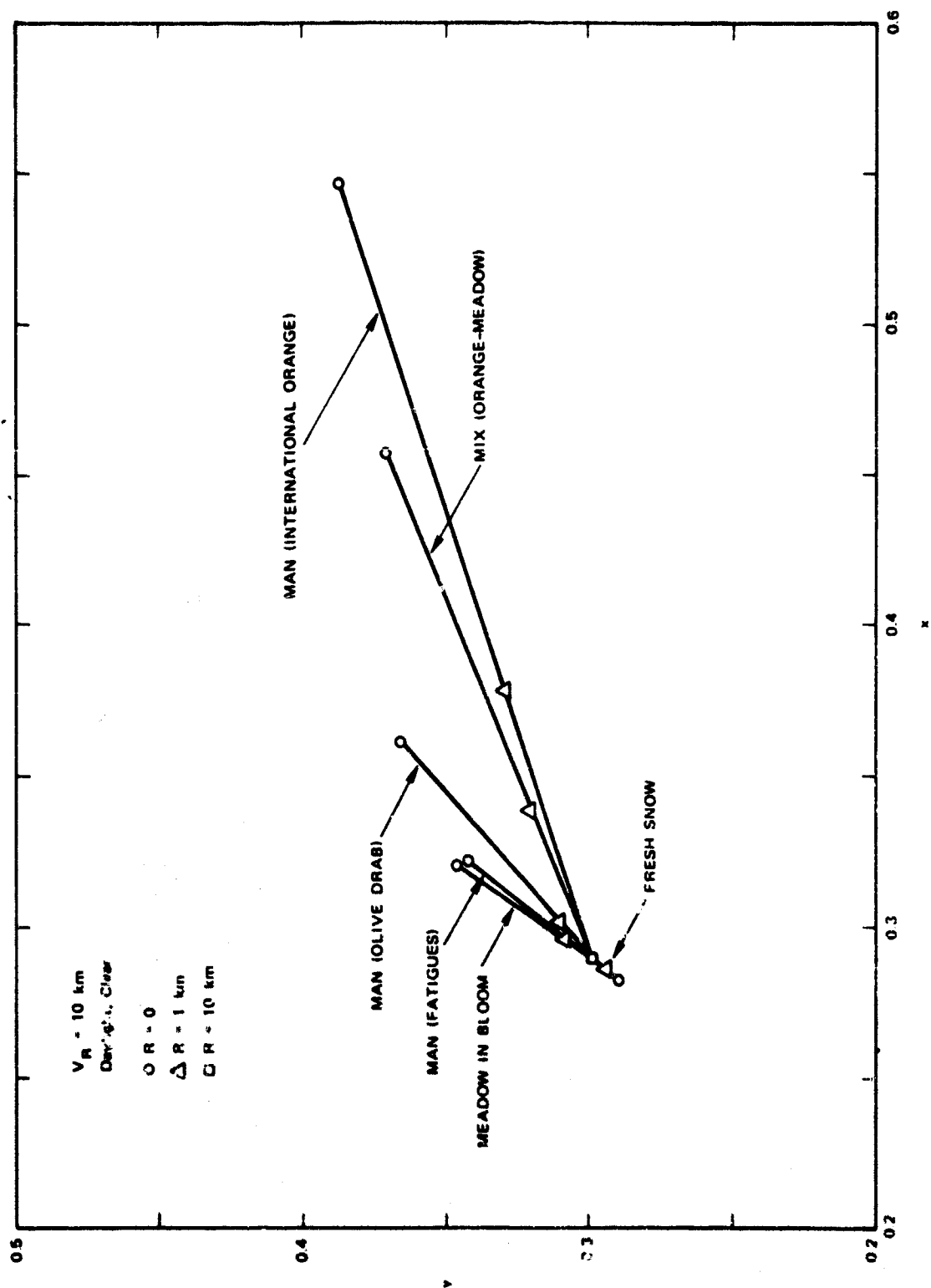


FIGURE 15 CHROMATICITY COORDINATES

5. Limitations and Potential Applications of the Model

a. Model Limitations

The model that has been developed is designed for use in the analytical rather than the military planning process, and is based on relatively limited empirical data. Accordingly, any particularly interesting and potentially usable results obtained from the application of the model will require some form of field test evaluations. Since the chromatic treatment stems from theoretical work concerned with color matching, hue, and saturation, some caution must be exercised in application.

One of the most significant limitations of the model is concerned with the range over which the model is used. Since the model is designed to estimate the capabilities of human observers over short ranges in atmospheres containing relatively large diameter scatterers, only Mie scattering has been treated. No attempt is made to treat the scattering of radiation of wavelengths of the same order or larger than the scattering particle diameter (Rayleigh scattering), nor is any

treatment of absorption of radiation by the attenuating atmosphere included. Most important, the model treats only homogeneous scattering atmospheres. Accordingly, the use of the model should be restricted to ranges up to 3-5 kilometers, ranges that encompass most of the capability of a visual observer searching for individual soldiers and small vehicles.

b. Potential Applications

The model appears to provide a mechanism for the determination of chromatic and luminance differences between a target and its background over portions or all of the visible spectrum. It also has the capability to produce information on colors resulting from the mixing of two or more different colors.

These capabilities imply a potential utility for the model in a number of activities ranging from target detection to the examination of visual countermeasure systems such as smoke screening. Specifically, some of the potential applications are:

- (1) **Target Detection.** The determination of chromatic and/or luminance differences between a target and its background.

- (2) Analysis of Field Uniform Colors. The determination of the field uniform color(s) that provide the greatest potential for concealment within a specific combat environment.
- (3) Camouflage Patterns and Colors. The analysis of camouflage colors and patterns for determining the implication of pattern size and colors (both individually and as mixes) on object detectability within the environment and as a function of range.
- (4) Visual Filtering Systems. The analysis of filtering systems that might aid visual observers in the detection of targets of military interest, an application of potential use in counter-countersurveillance.
- (5) Visual Screening Studies. In conjunction with filter-system studies, the model offers the capability to examine methods of contending with visual screening systems such as smoke systems.
- (6) Signal System Studies. The use of colored signal flags and colored distress and rescue signals in combat environments is widespread. The model offers the capability for the analysis and determination of the colors of such devices that provide the highest probabilities of being seen within a specific environment.

* The extension of scattering models to atmospheres containing varying concentrations of scatterers, although resulting in a somewhat more complex set of equations¹² can be accomplished by relatively simple algebraic manipulations. It was not believed that this additional detail would add to the model utility, since the ranges over which a visual observer can see an individual soldier are usually short enough to be considered as containing a homogeneous atmosphere.

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Annex A

**TABLES OF DISTRIBUTION COEFFICIENTS AND CHROMATICITY COORDINATES,
RADIANT EMISSION DATA FOR SELECTED SOURCES, AND PHOTOMETRIC TERMINOLOGY**

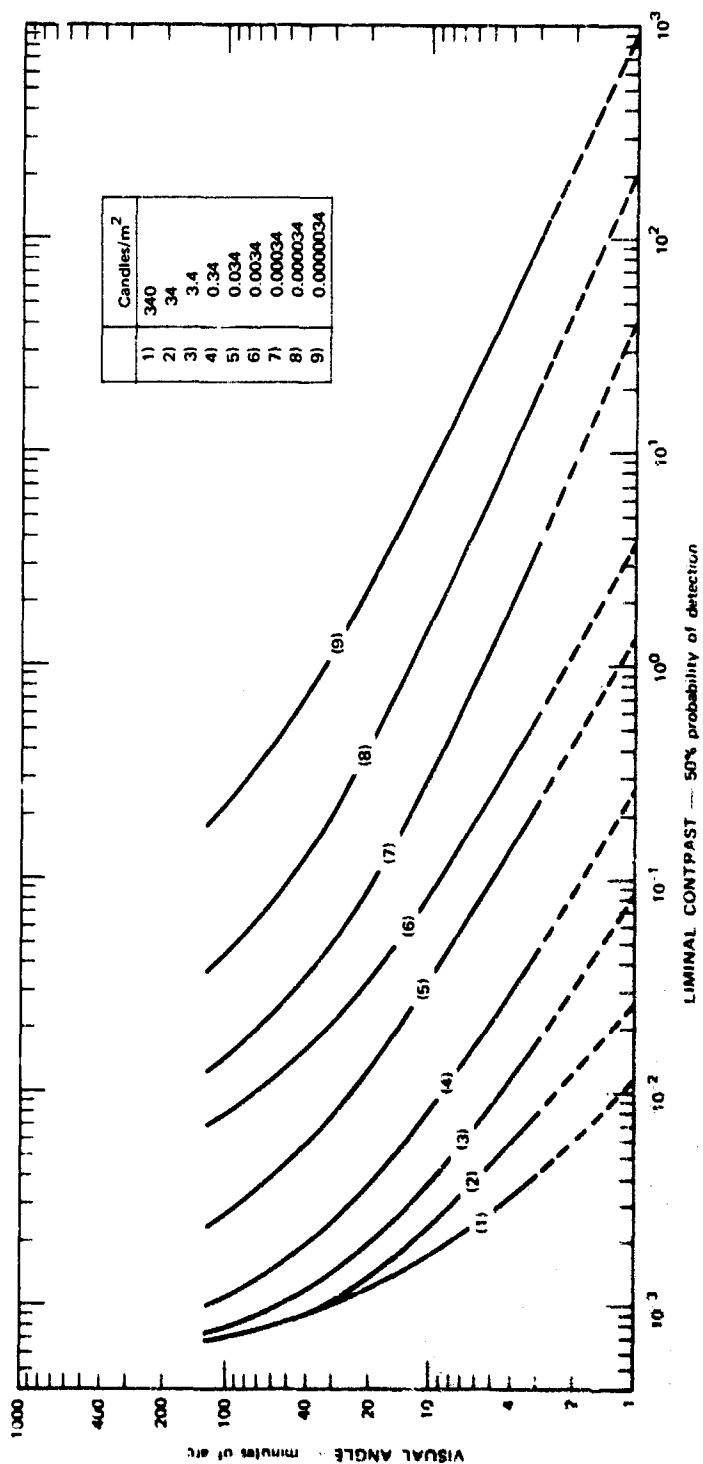


FIGURE A-1 RELATIONSHIP BETWEEN LIMINAL CONTRAST, STIMULUS AREA, AND ADAPTATION BRIGHTNESS

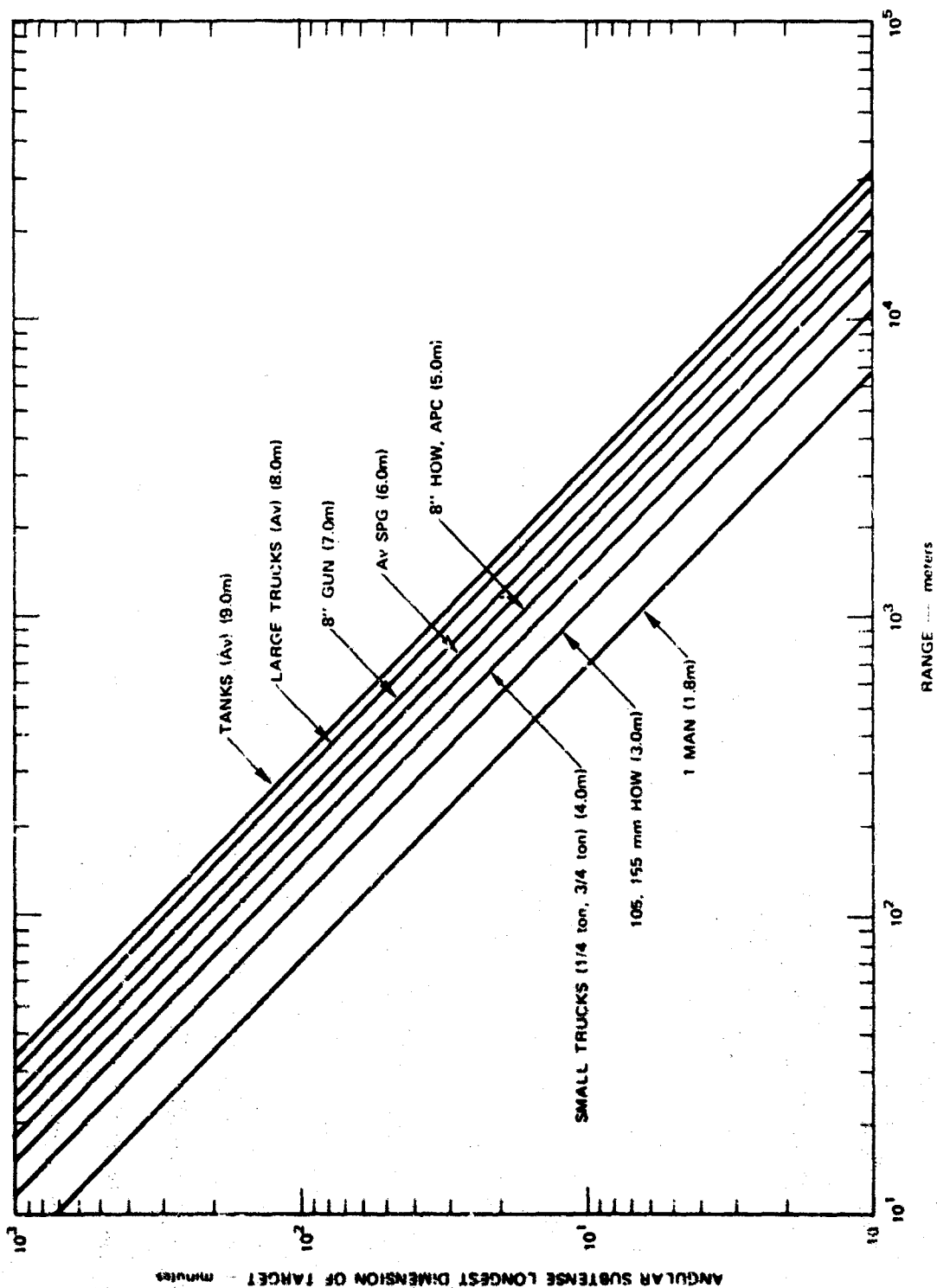


FIGURE A 2 ANGULAR SUBTENSE OF MILITARY TARGETS

Table A-1

CHROMATICITY COORDINATES--VISIBLE WAVELENGTHS³

λ	x	y	z	λ	x	y	z
380	0.1741	0.0050	0.8209	545	0.2658	0.7243	0.0099
385	0.17398	0.00495	0.82107	550	0.3016	0.6923	0.0061
390	0.1738	0.0049	0.8213	555	0.3373	0.6589	0.0038
395	0.17358	0.00484	0.82158	560	0.3731	0.62448	0.00242
400	0.1733	0.0048	0.8219	565	0.4078	0.58968	0.00162
405	0.17299	0.00478	0.82223	570	0.4441	0.55470	0.00120
410	0.1726	0.0048	0.8226	575	0.4788	0.52022	0.00098
415	0.1721	0.0048	0.8231	580	0.5125	0.48664	0.00086
420	0.1714	0.0051	0.8235	585	0.5448	0.45445	0.00075
425	0.1703	0.0058	0.8239	590	0.5752	0.42415	0.00065
430	0.1689	0.0069	0.8242	595	0.6029	0.39655	0.00055
435	0.1669	0.0086	0.8245	600	0.6270	0.37255	0.00045
440	0.1644	0.0109	0.8247	605	0.6482	0.35145	0.00035
445	0.1611	0.0138	0.8251	610	0.6658	0.33395	0.00025
450	0.1566	0.0177	0.8257	615	0.6801	0.31970	0.00020
455	0.1510	0.0227	0.8263	620	0.6915	0.30834	0.00016
460	0.1440	0.0297	0.8263	625	0.7006	0.29927	0.00013
465	0.1355	0.0399	0.8246	630	0.7079	0.29200	0.00010
470	0.1241	0.0578	0.8181	635	0.7140	0.28593	0.00007
475	0.1096	0.0868	0.8306	640	0.7190	0.28095	0.00005
480	0.0913	0.1327	0.7760	645	0.7230	0.27697	0.00003
485	0.0687	0.2007	0.7306	650	0.7260	0.27399	0.00001
490	0.0454	0.2950	0.6596	655	0.7283	0.2717	
495	0.0235	0.4127	0.5628	660	0.7300	0.2700	
500	0.0082	0.5384	0.4534	665	0.7311	0.2689	
505	0.0039	0.6548	0.3413	670	0.7320	0.2680	
510	0.0139	0.7502	0.2359	675	0.7327	0.2673	
515	0.0389	0.8120	0.1491	680	0.7334	0.2666	
520	0.0743	0.8338	0.0919	685	0.73397	0.26603	
525	0.1142	0.8262	0.0596	690	0.7344	0.2656	
530	0.1547	0.8059	0.0394	695	0.73461	0.26539	
535	0.1929	0.7816	0.0255	700	0.73467	0.26533	
540	0.2296	0.7543	0.0161	780	0.73467	0.26533	

Table A-2

DISTRIBUTION COEFFICIENTS OF THE EQUAL ENERGY SPECTRUM

λ	$\bar{x}$	$\bar{y}$	$\bar{z}$	λ	$\bar{x}$	$\bar{y}$	$\bar{z}$
380	0.00139	0.00004	0.0066	580	0.9162	0.8700	0.00154
385	0.00226	0.00006	0.0107	585	0.9785	0.8163	0.00135
390	0.00426	0.00012	0.0201	590	1.0266	0.7570	0.00116
395	0.00771	0.00022	0.0365	595	1.0566	0.6949	0.00096
400	0.0144	0.00040	0.0685	600	1.0620	0.6310	0.00076
405	0.0233	0.00064	0.1105	605	1.0453	0.5668	0.00056
410	0.0432	0.00120	0.2056	610	1.0028	0.5030	0.00038
415	0.0780	0.00218	0.3730	615	0.9387	0.4412	0.00028
420	0.1344	0.00400	0.6459	620	0.8545	0.3810	0.00020
425	0.2132	0.0073	1.0317	625	0.7515	0.3210	0.00014
430	0.2839	0.0116	1.3856	630	0.6424	0.2650	0.00009
435	0.3268	0.0168	1.6142	635	0.5419	0.2170	0.00005
440	0.3469	0.0230	1.7402	640	0.4479	0.1750	0.00003
445	0.3483	0.0298	1.7840	645	0.3609	0.1382	0.00002
450	0.3362	0.0380	1.7727	650	0.2835	0.1070	
455	0.3193	0.0480	1.7472	655	0.2186	0.0816	
460	0.2909	0.0600	1.6693	660	0.1649	0.0610	
465	0.2509	0.0739	1.5268	665	0.1212	0.0446	
470	0.1951	0.0910	1.2880	670	0.0874	0.0320	
475	0.1422	0.1126	1.0427	675	0.0637	0.0232	
480	0.0956	0.1390	0.8128	680	0.0468	0.0170	
485	0.0580	0.1693	0.6163	685	0.0329	0.0119	
490	0.0320	0.2080	0.4651	690	0.0227	0.0082	
495	0.0147	0.2586	0.3532	695	0.0158	0.00572	
500	0.0049	0.3230	0.2720	700	0.01135	0.00410	
505	0.0024	0.4073	0.2123	705	0.00806	0.00291	
510	0.0093	0.5030	0.1582	710	0.00581	0.00210	
515	0.0291	0.6082	0.1117	715	0.00411	0.00148	
520	0.0633	0.7100	0.0783	720	0.00291	0.00105	
525	0.1096	0.7932	0.0572	725	0.00204	0.00074	
530	0.1655	0.8620	0.0421	730	0.00144	0.00052	
535	0.2258	0.9149	0.0299	735	0.00100	0.00036	
540	0.2904	0.9540	0.0204	740	0.00069	0.00025	
545	0.3597	0.9802	0.0134	745	0.00048	0.00017	
550	0.4335	0.9950	0.00877	750	0.00033	0.00012	
555	0.5120	1.0002	0.00577	755	0.00023	0.00008	
560	0.5945	0.9950	0.00386	760	0.00017	0.00006	
565	0.6783	0.9786	0.00269	765	0.00012	0.00004	
570	0.7622	0.9520	0.00206	770	0.00008	0.00003	
575	0.8425	0.9154	0.00172	sum	21.3683	21.3714	21.3531

Table A-3

DISTRIBUTION COEFFICIENTS FOR STANDARD ILLUMINANT A³
(Equivalent to full radiation at 2854° K)

λ	x_A	y_A	z_A	λ	x_A	y_A	z_A
380	0.0006		0.0030	580	4.8590	4.6139	0.0082
385	0.0012		0.0054	585	5.3545	4.4665	0.0074
390	0.0024		0.0113	590	5.7910	4.2703	0.0065
395	0.0048	0.0001	0.0226	595	6.1393	4.0381	0.0056
400	0.0098	0.0003	0.0467	600	6.3504	3.7733	0.0045
405	0.0174	0.0005	0.0827	605	6.4280	3.4852	0.0035
410	0.0354	0.0010	0.1685	610	6.3361	3.1780	0.0024
415	0.0697	0.0020	0.3334	615	6.0894	2.8625	0.0018
420	0.1308	0.0039	0.6286	620	5.6868	2.5357	0.0013
425	0.2252	0.0077	1.0895	625	5.1271	2.1901	0.0010
430	0.3246	0.0133	1.5841	630	4.4904	1.8523	0.0006
435	0.4034	0.0208	1.9928	635	3.8776	1.5528	0.0004
440	0.4614	0.0306	2.3145	640	3.2787	1.2812	0.0002
445	0.4980	0.0426	2.5504	645	2.7011	1.0347	0.0001
450	0.5155	0.0583	2.7183	650	2.1683	0.8183	
455	0.5239	0.0788	2.8671	655	1.7072	0.6369	
460	0.5098	0.1052	2.9256	660	1.3143	0.4861	
465	0.4685	0.1380	2.8513	665	0.9847	0.3622	
470	0.3882	0.1808	2.5588	670	0.7241	0.2651	
475	0.3000	0.2376	2.1995	675	0.5376	0.1961	
480	0.2138	0.3108	1.8175	680	0.4019	0.1461	
485	0.1370	0.4005	1.4578	685	0.2875	0.1042	
490	0.0800	0.5196	1.1619	690	0.2017	0.0729	
495	0.0388	0.6812	0.9306	695	0.1433	0.0518	
500	0.0136	0.8960	0.7545	700	0.1043	0.0377	
505	0.0071	1.1876	0.6190	705	0.0752	0.0272	
510	0.0285	1.5398	0.4842	710	0.0551	0.0199	
515	0.0935	1.9519	0.3584	715	0.0395	0.0143	
520	0.2126	2.3854	0.2629	720	0.0284	0.0102	
525	0.3850	2.7858	0.2010	725	0.0202	0.0073	
530	0.6068	3.1609	0.1545	730	0.0144	0.0052	
535	0.8635	3.4988	0.1141	735	0.0101	0.0037	
540	1.1566	3.7998	0.0811	740	0.0071	0.0026	
545	1.4905	4.0616	0.0555	745	0.0050	0.0018	
550	1.8663	4.2840	0.0378	750	0.0035	0.0013	
555	2.2884	4.4702	0.0258	755	0.0025	0.0009	
560	2.7548	4.6109	0.0179	760	0.0018	0.0006	
565	3.2557	4.6974	0.0129	765	0.0013	0.0005	
570	3.7856	4.7284	0.0102	770	0.0009	0.0003	
575	4.3259	4.7001	0.0089	SUMS	109.8439	100.0000	35.5641

Table A-4

DISTRIBUTION COEFFICIENTS FOR STANDARD ILLUMINANT C²
 (A filtered version of Illuminant A corresponding to clearest daylight)

λ	$\bar{x}_C$	$\bar{y}_C$	$\bar{z}_C$	λ	$\bar{x}_C$	$\bar{y}_C$	$\bar{z}_C$
380	0.0022		0.0101	580	4.2081	3.9958	0.0070
385	0.0042	0.0001	0.0200	585	4.3853	3.6580	0.0061
390	0.0095	0.0003	0.0448	590	4.4932	3.3132	0.0051
395	0.0200	0.0006	0.0945	595	4.5261	2.9770	0.0041
400	0.0429	0.0012	0.2036	600	4.4735	2.6580	0.0032
405	0.0784	0.0022	0.3727	605	4.3605	2.3643	0.0023
410	0.1633	0.0046	0.7784	610	4.1632	2.0881	0.0015
415	0.3279	0.0091	1.5681	615	3.8875	1.8275	0.0011
420	0.6193	0.0184	2.9755	620	3.5351	1.5763	0.0008
425	1.0595	0.0361	5.1258	625	3.1076	1.3275	0.0006
430	1.4989	0.0612	7.3138	630	2.6549	1.0952	0.0004
435	1.8070	0.0931	8.9263	635	2.2357	0.8954	0.0002
440	1.9794	0.1312	9.9292	640	1.8466	0.7216	0.0001
445	2.0194	0.1730	10.3424	645	1.4912	0.5713	
450	1.9578	0.2213	10.3227	650	1.1744	0.4432	
455	1.8554	0.2786	10.1418	655	0.9056	0.3378	
460	1.6818	0.3469	9.6501	660	0.6808	0.2518	
465	1.4527	0.4278	8.8404	665	0.4963	0.1825	
470	1.1359	0.5291	7.4882	670	0.3542	0.1297	
475	0.8287	0.6563	6.0761	675	0.2552	0.0931	
480	0.5565	0.8088	4.7295	680	0.1845	0.0671	
485	0.3346	0.9774	3.5578	685	0.1269	0.0460	
490	0.1815	1.1790	2.6361	690	0.0854	0.0309	
495	0.0808	1.4195	1.9391	695	0.0582	0.0210	
500	0.0259	1.7004	1.4320	700	0.0407	0.0147	
505	0.0122	2.0460	1.0665	705	0.0281	0.0101	
510	0.0048	2.4165	0.7599	710	0.0198	0.0071	
515	0.1352	2.8224	0.5183	715	0.0136	0.0049	
520	0.2879	3.2309	0.3561	720	0.0093	0.0034	
525	0.4983	3.6050	0.2601	725	0.0063	0.0023	
530	0.7615	3.9671	0.1940	730	0.0044	0.0016	
535	1.0598	4.2941	0.1401	735	0.0030	0.0011	
540	1.3923	4.5742	0.0976	740	0.0020	0.0007	
545	1.7561	4.7852	0.0654	745	0.0014	0.0005	
550	2.1414	4.9156	0.0433	750	0.0009	0.0003	
555	2.5409	4.9636	0.0286	755	0.0006	0.0002	
560	2.9397	4.9203	0.0191	760	0.0005	0.0001	
565	3.3161	4.7847	0.0131	765	0.0003	0.0001	
570	3.6616	4.5736	0.0099	770	0.0002	0.0001	
575	3.9624	4.3052	0.0081	sums	98.0535	100.0000	118.1305

Table A-5

SPECTRAL ENERGY DISTRIBUTIONS OF THE TWO STANDARD ILLUMINANTS A AND C³

Wavelength (m μ)	Relative Energy		Wavelength (m μ)	Relative Energy	
	A	C		A	C
380	9.79	33.00	580	114.44	97.80
385	10.90	39.92	585	118.08	95.43
390	12.09	47.40	590	121.73	93.20
395	13.36	55.17	595	125.39	91.22
400	14.71	63.30	600	129.04	89.70
405	16.15	71.81	605	132.70	88.83
410	17.68	80.60	610	136.34	88.40
415	19.29	89.53	615	139.99	88.19
420	21.00	98.10	620	143.62	88.10
425	22.79	105.80	625	147.23	88.06
430	24.67	112.40	630	150.83	88.00
435	26.64	117.75	635	154.42	87.86
440	28.70	121.50	640	157.98	87.80
445	30.85	123.45	645	161.51	87.99
450	33.09	124.00	650	165.03	88.20
455	35.41	123.60	655	168.51	88.20
460	37.82	123.10	660	171.96	87.90
465	40.30	123.30	665	175.38	87.22
470	42.87	123.80	670	178.77	86.30
475	45.52	124.09	675	182.12	85.30
480	48.25	123.90	680	185.43	84.00
485	51.04	122.92	685	188.70	82.21
490	53.91	120.70	690	191.93	80.20
495	56.85	116.90	695	195.12	78.24
500	59.86	112.10	700	198.26	76.30
505	62.93	106.98	705	201.36	74.36
510	66.06	102.30	710	204.41	72.40
515	69.25	98.81	715	207.41	70.40
520	72.50	96.90	720	210.36	68.30
525	75.79	96.78	725	213.26	66.30
530	79.13	98.00	730	216.12	64.40
535	82.52	99.91	735	218.92	62.80
540	85.95	102.10	740	221.66	61.50
545	89.41	103.95	745	224.36	60.20
550	92.91	105.20	750	227.00	59.20
555	96.44	105.67	755	229.58	58.50
560	100.00	105.30	760	232.11	58.10
565	103.58	104.11	765	234.59	58.00
570	107.18	102.30	770	237.01	58.20
575	110.80	100.15	775	239.37	58.50
580	114.44	97.80	780	241.67	59.10

Table A-6

LUMINANCE LEVELS OF SKY^{1,2}

Sky Condition	Luminance Level (Candles/m ²)
Day, Clear	10^4
Day, Overcast	10^3
Day, Heavy Overcast	10^2
Sunset, Heavy Overcast	10^1
Sunset, Clear, 1/4 hour after	10^0
Sunset, Clear, 1/2 hour after	10^{-1}
Night, Clear, Bright Moon	10^{-2}
Night, Clear, Moonless	10^{-3}
Night, Overcast, Moonless	10^{-4}

Table A-7

SPECTRAL REFLECTANCE

Fresh Snow

Wavelength (m μ)	Reflectance (percent)	Wavelength (m μ)	Reflectance (percent)	Wavelength (m μ)	Reflectance (percent)	Wavelength (m μ)	Reflectance (percent)	Wavelength (m μ)	Reflectance (percent)
380	0.838	385	0.836	390	0.834	395	0.832	400	0.830
395	0.828	410	0.826	415	0.824	420	0.822	425	0.820
430	0.818	435	0.816	440	0.814	445	0.812	450	0.810
455	0.808	460	0.806	465	0.804	470	0.802	475	0.800
480	0.798	485	0.796	490	0.794	495	0.792	500	0.790
505	0.788	510	0.786	515	0.784	520	0.782	525	0.780
530	0.778	535	0.776	540	0.774	545	0.772	550	0.770
555	0.768	560	0.766	565	0.764	570	0.762	575	0.760
580	0.758	585	0.756	590	0.754	595	0.752	600	0.750
605	0.748	610	0.745	615	0.743	620	0.741	625	0.739
630	0.736	635	0.734	640	0.732	645	0.730	650	0.727
655	0.725	660	0.723	665	0.721	670	0.718	675	0.716
680	0.714	685	0.712	690	0.709	695	0.707	700	0.705
705	0.703	710	0.700	715	0.698	720	0.696	725	0.694
730	0.691	735	0.689	740	0.687	745	0.685	750	0.682
755	0.680	760	0.678	765	0.676	770	0.673	775	0.671
780	0.669								

Table A-8

SPECTRAL REFLECTANCE
Mn (Favagie Shirts)

Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)
380	0.100	390	0.100	395	0.100	400	0.100	400	0.100
400	0.100	415	0.100	420	0.100	425	0.100	425	0.100
420	0.100	440	0.100	445	0.100	450	0.100	450	0.100
440	0.100	460	0.106	465	0.109	470	0.112	475	0.115
460	0.118	485	0.121	490	0.124	495	0.127	500	0.130
480	0.131	510	0.136	515	0.139	520	0.142	525	0.145
500	0.148	535	0.151	540	0.154	545	0.157	550	0.160
520	0.160	560	0.159	565	0.159	570	0.159	575	0.158
540	0.177	585	0.158	590	0.157	595	0.157	600	0.157
560	0.186	610	0.156	615	0.156	620	0.155	625	0.155
580	0.188	635	0.151	640	0.151	645	0.151	650	0.152
600	0.183	660	0.153	665	0.153	670	0.152	675	0.152
620	0.181	685	0.151	690	0.151	695	0.150	700	0.150
640	0.182	710	0.150	715	0.150	720	0.160	725	0.162
660	0.180	735	0.167	740	0.170	745	0.172	750	0.175
680	0.177	760	0.180	765	0.183	770	0.185	775	0.188
700	0.180								

Table A-9

SPECTRAL REFLECTANCE

Men (Olive Drab Clothes)

Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)
380	0.050	400	0.050	495	0.059	400	0.050
410	0.050	415	0.050	420	0.050	425	0.050
430	0.050	440	0.050	445	0.050	450	0.050
450	0.052	465	0.053	470	0.055	475	0.058
480	0.060	490	0.061	495	0.069	500	0.078
500	0.062	510	0.087	520	0.091	525	0.100
530	0.100	540	0.100	545	0.100	550	0.100
560	0.100	565	0.100	570	0.100	575	0.100
580	0.100	590	0.100	595	0.100	600	0.100
600	0.110	615	0.120	620	0.130	625	0.150
630	0.140	640	0.170	645	0.180	650	0.200
660	0.210	665	0.220	670	0.230	675	0.250
680	0.260	690	0.270	695	0.280	700	0.300
700	0.310	710	0.326	720	0.339	725	0.365
730	0.370	740	0.391	745	0.404	750	0.430
760	0.411	765	0.456	770	0.469	775	0.495

Table A-10

SPECTRAL REFLECTANCE

Track 6 covered with green camouflage (100%)

Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)
380	0.060	395	0.060	410	0.060	425	0.060
440	0.060	455	0.060	470	0.060	485	0.060
500	0.060	515	0.060	530	0.060	545	0.060
560	0.060	575	0.060	590	0.060	605	0.060
620	0.060	635	0.060	650	0.060	665	0.060
680	0.060	695	0.060	710	0.060	725	0.060
740	0.060	755	0.060	770	0.060	785	0.060
800	0.060	815	0.060	830	0.060	845	0.060
860	0.060	875	0.060	890	0.060	905	0.060
920	0.060	935	0.060	950	0.060	965	0.060
980	0.060	995	0.060	1010	0.060	1025	0.060
1040	0.060	1055	0.060	1070	0.060	1085	0.060
1100	0.060	1115	0.060	1130	0.060	1145	0.060
1160	0.060	1175	0.060	1190	0.060	1205	0.060
1220	0.060	1235	0.060	1250	0.060	1265	0.060
1280	0.060	1295	0.060	1310	0.060	1325	0.060
1340	0.060	1355	0.060	1370	0.060	1385	0.060
1400	0.060	1415	0.060	1430	0.060	1445	0.060
1460	0.060	1475	0.060	1490	0.060	1505	0.060
1520	0.060	1535	0.060	1550	0.060	1565	0.060
1580	0.060	1595	0.060	1610	0.060	1625	0.060
1640	0.060	1655	0.060	1670	0.060	1685	0.060
1700	0.060	1715	0.060	1730	0.060	1745	0.060
1760	0.060	1775	0.060	1790	0.060	1805	0.060
1820	0.060	1835	0.060	1850	0.060	1865	0.060
1880	0.060	1895	0.060	1910	0.060	1925	0.060
1940	0.060	1955	0.060	1970	0.060	1985	0.060
2000	0.060	2015	0.060	2030	0.060	2045	0.060
2060	0.060	2075	0.060	2090	0.060	2105	0.060
2120	0.060	2135	0.060	2150	0.060	2165	0.060
2180	0.060	2195	0.060	2210	0.060	2225	0.060
2240	0.060	2255	0.060	2270	0.060	2285	0.060
2300	0.060	2315	0.060	2330	0.060	2345	0.060
2360	0.060	2375	0.060	2390	0.060	2405	0.060
2420	0.060	2435	0.060	2450	0.060	2465	0.060
2480	0.060	2495	0.060	2510	0.060	2525	0.060
2540	0.060	2555	0.060	2570	0.060	2585	0.060
2600	0.060	2615	0.060	2630	0.060	2645	0.060
2660	0.060	2675	0.060	2690	0.060	2705	0.060
2720	0.060	2735	0.060	2750	0.060	2765	0.060
2780	0.060	2795	0.060	2810	0.060	2825	0.060
2840	0.060	2855	0.060	2870	0.060	2885	0.060
2900	0.060	2915	0.060	2930	0.060	2945	0.060
2960	0.060	2975	0.060	2990	0.060	3005	0.060
3020	0.060	3035	0.060	3050	0.060	3065	0.060
3080	0.060	3095	0.060	3110	0.060	3125	0.060
3140	0.060	3155	0.060	3170	0.060	3185	0.060
3200	0.060	3215	0.060	3230	0.060	3245	0.060
3260	0.060	3275	0.060	3290	0.060	3305	0.060
3320	0.060	3335	0.060	3350	0.060	3365	0.060
3380	0.060	3395	0.060	3410	0.060	3425	0.060
3440	0.060	3455	0.060	3470	0.060	3485	0.060
3500	0.060	3515	0.060	3530	0.060	3545	0.060
3560	0.060	3575	0.060	3590	0.060	3605	0.060
3620	0.060	3635	0.060	3650	0.060	3665	0.060
3680	0.060	3695	0.060	3710	0.060	3725	0.060
3740	0.060	3755	0.060	3770	0.060	3785	0.060
3800	0.060	3815	0.060	3830	0.060	3845	0.060
3860	0.060	3875	0.060	3890	0.060	3905	0.060
3920	0.060	3935	0.060	3950	0.060	3965	0.060
3980	0.060	3995	0.060	4010	0.060	4025	0.060
4040	0.060	4055	0.060	4070	0.060	4085	0.060
4100	0.060	4115	0.060	4130	0.060	4145	0.060
4160	0.060	4175	0.060	4190	0.060	4205	0.060
4220	0.060	4235	0.060	4250	0.060	4265	0.060
4280	0.060	4295	0.060	4310	0.060	4325	0.060
4340	0.060	4355	0.060	4370	0.060	4385	0.060
4400	0.060	4415	0.060	4430	0.060	4445	0.060
4460	0.060	4475	0.060	4490	0.060	4505	0.060
4520	0.060	4535	0.060	4550	0.060	4565	0.060
4580	0.060	4595	0.060	4610	0.060	4625	0.060
4640	0.060	4655	0.060	4670	0.060	4685	0.060
4700	0.060	4715	0.060	4730	0.060	4745	0.060
4760	0.060	4775	0.060	4790	0.060	4805	0.060
4820	0.060	4835	0.060	4850	0.060	4865	0.060
4880	0.060	4895	0.060	4910	0.060	4925	0.060
4940	0.060	4955	0.060	4970	0.060	4985	0.060
5000	0.060	5015	0.060	5030	0.060	5045	0.060
5060	0.060	5075	0.060	5090	0.060	5105	0.060
5120	0.060	5135	0.060	5150	0.060	5165	0.060
5180	0.060	5195	0.060	5210	0.060	5225	0.060
5240	0.060	5255	0.060	5270	0.060	5285	0.060
5300	0.060	5315	0.060	5330	0.060	5345	0.060
5360	0.060	5375	0.060	5390	0.060	5405	0.060
5420	0.060	5435	0.060	5450	0.060	5465	0.060
5480	0.060	5495	0.060	5510	0.060	5525	0.060
5540	0.060	5555	0.060	5570	0.060	5585	0.060
5600	0.060	5615	0.060	5630	0.060	5645	0.060
5660	0.060	5675	0.060	5690	0.060	5705	0.060
5720	0.060	5735	0.060	5750	0.060	5765	0.060
5780	0.060	5795	0.060	5810	0.060	5825	0.060
5840	0.060	5855	0.060	5870	0.060	5885	0.060
5900	0.060	5915	0.060	5930	0.060	5945	0.060
5960	0.060	5975	0.060	5990	0.060	6005	0.060
6020	0.060	6035	0.060	6050	0.060	6065	0.060
6080	0.060	6095	0.060	6110	0.060	6125	0.060
6140	0.060	6155	0.060	6170	0.060	6185	0.060
6200	0.060	6215	0.060	6230	0.060	6245	0.060
6260	0.060	6275	0.060	6290	0.060	6305	0.060
6320	0.060	6335	0.060	6350	0.060	6365	0.060
6380	0.060	6395	0.060	6410	0.060	6425	0.060
6440	0.060	6455	0.060	6470	0.060	6485	0.060
6500	0.060	6515	0.060	6530	0.060	6545	0.060
6560	0.060	6575	0.060	6590	0.060	6605	0.060
6620	0.060	6635	0.060	6650	0.060	6665	0.060
6680	0.060	6695	0.060	6710	0.060	6725	0.060
6740	0.060	6755	0.060	6770	0.060	6785	0.060
6800	0.060	6815	0.060	6830	0.060	6845	0.060
6860	0.060	6875	0.060	6890	0.060	6905	0.060
6920	0.060	6935	0.060	6950	0.060	6965	0.060
6980	0.060	6995	0.060	7010	0.060	7025	0.060
7040	0.060	7055	0.060	7070	0.060	7085	0.060
7100	0.060	7115	0.060	7130	0.060	7145	0.060
7160	0.060	7175	0.060	7190	0.060	7205	0.060
7220	0.060	7235	0.060	7250	0.060	7265	0.060
7280	0.060	7295	0.060	7310	0.060	7325	0.060
7340	0.060	7355	0.060	7370	0.060	7385	0.060
7400	0.060	7415	0.060	7430	0.060	7445	0.060
7460	0.060	7475	0.060	7490	0.060	7505	0.060
7520	0.060	7535	0.060	7550	0.060	7565	0.060
7580	0.060	7595	0.060	7610	0.060	7625	0.060
7640	0.060	7655	0.060	7670	0.060	7685	0.060
7700	0.060	7715	0.060	7730	0.060	7745	0.060
7760	0.060	7775	0.060	7790	0.060	7805	0.060
7820	0.060	7835	0.060	7850	0.060	7865	0.060
7880	0.060	7895	0.060	7910	0.060	7925	0.060
7940	0.060	7955	0.060	7970	0.060	7985	0.060
8000	0.060	8015	0.060	8030	0.060	8045	0.060
8060	0.060	8075	0.060	8090	0.060	8105	0.060
8120	0.060	8135	0.060	8150	0.060	8165	0.060
8180	0.060	8195	0.060	8210	0.060	8225	0.060
8240	0.060	8255	0.060	8270	0.060	8285	0.060
8300	0.060	8315	0.060	8330	0.060	8345	0.060
8360	0.060	8375	0.060	8390	0.060	8405	0.060
8420	0.060	8435	0.060	8450	0.060	8465	0.060
8480	0.060	8495	0.060	8510	0.060	8525	0.060
8540	0.060	8555	0.060	8570	0.060	8585	0.060
8600	0.060	8615	0.060	8630	0.060	8645	0.060
8660	0.060	8675	0.060	8690	0.060	8705	0.060
8720	0.060	8735	0.060	8750	0.060	8765	0.060
8780	0.060	8795	0.060	8810	0.060	8825	0.060
8840	0.060	8855	0.060	8870	0.060	8885	0.060
8900	0.060	8915	0.060	8930	0.060	8945	0.060
8960	0.060	8975	0.060	8990	0.060	9005	0.060
9020	0.060	9035	0.060	9050	0.060	9065	0.060
9080	0.060	9095	0.060	9110	0.060	9125	0.060
9140	0.060	9155	0.060	9170	0.060	9185	0.060
9200	0.060	9215	0.060	9230	0.060	9245	0.060
9260	0.060	9275	0.060	9290	0.060	9305</	

Table A-11

SPECTRAL REFLECTANCE
Meadow with Abundant Bloom of Daisies

Wavelength (m μ)	Reflectance (percent)	Wavelength (m μ)	Reflectance (percent)	Wavelength (m μ)	Reflectance (percent)	Wavelength (m μ)	Reflectance (percent)	Wavelength (m μ)	Reflectance (percent)
380	0.023	385	0.030	390	0.037	395	0.043	400	0.050
405	0.057	410	0.063	415	0.070	420	0.077	425	0.085
430	0.090	435	0.090	440	0.090	445	0.090	450	0.090
455	0.090	460	0.090	465	0.090	470	0.090	475	0.090
480	0.090	485	0.090	490	0.090	495	0.096	500	0.102
505	0.109	510	0.115	515	0.121	520	0.127	525	0.134
530	0.140	535	0.140	540	0.139	545	0.139	550	0.139
555	0.138	560	0.138	565	0.138	570	0.137	575	0.137
580	0.137	585	0.136	590	0.136	595	0.136	600	0.135
605	0.135	610	0.134	615	0.134	620	0.131	625	0.133
630	0.133	635	0.133	640	0.132	645	0.132	650	0.132
655	0.131	660	0.131	665	0.131	670	0.130	675	0.130
680	0.155	685	0.181	690	0.206	695	0.232	700	0.257
705	0.282	710	0.308	715	0.333	720	0.358	725	0.384
730	0.409	735	0.435	740	0.460	745	0.467	750	0.475
755	0.482	760	0.490	765	0.498	770	0.505	775	0.512
780	0.520								

Table A-12

SPECTRAL REFLECTANCE
International Orange

Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)	Wavelength (nm)	Reflectance (percent)
380	0.021	550	0.080	635	0.632	720	0.620
390	0.021	555	0.128	640	0.637	725	0.615
400	0.021	560	0.176	645	0.641	730	0.610
410	0.023	565	0.224	650	0.645	735	0.605
420	0.023	570	0.272	655	0.644	740	0.600
430	0.023	575	0.320	660	0.641	745	0.597
440	0.023	580	0.368	665	0.643	750	0.593
450	0.026	585	0.416	670	0.643	755	0.590
460	0.026	590	0.464	675	0.642	760	0.587
470	0.026	595	0.512	680	0.642	765	0.583
480	0.026	600	0.560	685	0.641	770	0.580
490	0.027	605	0.575	690	0.641	775	0.577
500	0.027	610	0.590	695	0.640	780	0.573
510	0.027	615	0.605	700	0.640		
520	0.027	620	0.620	705	0.637		
530	0.028	625	0.624	710	0.630		
540	0.028	630	0.628	715	0.625		

Table A-13

PHYSICAL (RADIOMETRIC) CONCEPTS

	c.g.s. Unit	m.k.s. Unit
Radiator (source of radiant energy)		
Radiation (process)		
Radiant energy	erg	joule
Radiant density	erg/cm ³	joule/m ³
Radiant flux	erg/s	watt
Radiant emittance	erg/(s × cm ²)	watt/m ²
Radiant intensity	erg/(s × ω)*	watt/ω*
Radiance	erg/(s × ω × cm ²)	watt/(ω × m ²)
Irradiance	erg/(s × cm ²)	watt/m ²
Spectral reflectance		
Spectral transmittance		

* ω = unit solid angle. The unit is normally the steradian.

Table A-14

PSYCHOPHYSICAL (PHOTOMETRIC) CONCEPTS

	c.g.s. Unit	m.k.s. Unit
Luminator (source of luminous energy)		
Lumination (process)		
Luminous energy	lumerg	talbot
Luminous density	lumerg/cm ³	talbot/m ³
Luminous flux	lumerg/s	lumen
Luminous emittance	lumerg/(s × cm ²)	lumen m ²
Luminous intensity	lumerg/(s × ω)	lumen ω [candle]
Luminance	lumerg/(s × ω × cm ²)	lumen (ω × m ²) [candle m ²]
Illuminance	lumerg (s × cm ²)	lumen m ² [lux]
*Luminous reflectance		
*Luminous transmittance		

* The I.C.I. has adopted the collective term luminance factor for these.

Table A-15
PHOTOMETRIC CONCEPTS AND UNITS

	Dimensional Formula	Defining Equation	Metric Units	English Units
Luminous flux	$L^2 MT^{-3}$		lumen	lumen
Luminous intensity	$L^2 MT^{-3}$	$I = \frac{dF}{ds}$	candle	candle
Luminous emittance	MT^{-3}	$L = \frac{dF}{ds}$	$\left\{ \begin{array}{l} \text{lumen/m}^2 \\ \text{lumen/cm}^2 \text{ etc.} \end{array} \right.$	$\left\{ \begin{array}{l} \text{lumen/ft}^2 \\ \text{lumen/mile}^2 \text{ etc.} \end{array} \right.$
Illuminance	MT^{-3}	$E = \frac{dF}{ds}$	$\left\{ \begin{array}{l} \text{lumen/m}^2 \text{ (lux)} \\ \text{lumen/cm}^2 \text{ (phot) etc.} \end{array} \right.$	$\left\{ \begin{array}{l} \text{lumen/ft}^2 \\ \text{lumen/mile}^2 \text{ etc.} \end{array} \right.$
Luminance	MT^{-3}	$B = \frac{d^2F}{d\omega ds \cos \theta}$	$\left\{ \begin{array}{l} \text{candle/m}^2 \\ \text{candle/cm}^2 \text{ etc.} \end{array} \right.$	$\left\{ \begin{array}{l} \text{candle/ft}^2 \\ \text{candle/mile}^2 \text{ etc.} \end{array} \right.$
Luminous energy	$L^2 MT^{-2}$	$Q = F dt$	$\left\{ \begin{array}{l} \text{talbot} \\ \text{lumen-hour etc.} \end{array} \right.$	$\left\{ \begin{array}{l} \text{lumen-hour} \\ \text{lumen-s etc.} \end{array} \right.$
Luminous density	$L^{-1} MT^{-2}$	$q = \frac{dQ}{dv}$	$\left\{ \begin{array}{l} \text{talbot/m}^3 \end{array} \right.$	

*The lumen/ft² is frequently, though illogically, called the "foot-candle"; and the lumen/mile² the "mile-candle."

†The candle/cm² is also called the STILB.

Annex B

METHOD FOR THE DETERMINATION
OF ATMOSPHERIC EXTINCTION COEFFICIENTS

Annex B

METHOD FOR THE DETERMINATION OF ATMOSPHERIC EXTINCTION COEFFICIENTS

1. General

On passing through a medium, the energy contained in a beam of radiation may be scattered and/or absorbed by the particles comprising the medium. The quantity of energy that remains in the beam is dependent on the size, composition, and concentration of particles in the medium, and the path length of the radiation through the medium. Below are described the factors that affect attenuation and some methods for the determination of the degree of attenuations. The method that is given follows the treatment of Ref. 12.

2. The Extinction Coefficient and the Transmittance of Radiation

The change in the quantity of energy passing through a medium containing a homogeneous distribution of scattering bodies is proportional to the flux density of the radiation, and can be written

$$dE_{\lambda} = -\sigma_{\lambda} E_{\lambda} dr \quad (B-1)$$

where the scattering coefficient, σ_{λ} , is a proportionality constant and r is the path length through the medium. Integration over the range, R , yields

$$E_{\lambda}(R) = E_{\lambda}(0) e^{-\sigma_{\lambda} R} \quad (B-2)$$

where $E_{\lambda}(0)$ is the flux density at range zero. In the same manner, it is possible to define the absorption coefficient, k_{λ} , in terms of

$$E_{\lambda}(R) = E_{\lambda}(0) e^{-k_{\lambda} R} \quad (B-3)$$

If the medium contains both scattering and absorbing bodies, the two equations can be combined to yield

$$E_{\lambda}(R) = E_{\lambda}(0) e^{-(\sigma_{\lambda} + k_{\lambda})R} = E_{\lambda}(0) e^{-\beta_{\lambda}R}, \quad (B-4)$$

where β_{λ} is called the extinction coefficient. If the exponential is written as

$$e^{-\beta_{\lambda}R} = \tau_{\lambda}, \quad (B-5)$$

the symbol τ_{λ} is called the transmissivity, and the transmittance of the medium is defined by

$$T_{\lambda} = \tau_{\lambda}^R. \quad (B-6)$$

3. The Determination of Scattering Coefficients

a. The Scattering Function

Let an elementary volume, dv , of a medium containing a cross section, ds , of absorbing and scattering bodies be illuminated by a beam of energy of flux density E_{λ} . At an angle θ with the direction of the incident beam, the intensity of scattered radiation, $I(\theta)$, is

$$I_{\lambda}(\theta) = E_{\lambda} b_{\lambda}(\theta) ds, \quad (B-7)$$

where $b_{\lambda}(\theta)$ is an angularly dependent function called the scattering function and is defined as the intensity of scattered radiation of wavelength λ in the direction θ per unit of flux incident on the medium.

Where no absorption occurs, the total flux scattered into space is equal to the incident flux, so that

$$4\pi \int_0^{\pi} I_{\lambda}(\theta) \sin \theta d\theta = E_{\lambda} ds \quad (B-8)$$

where $2 \sin \theta d\theta$ is the solid angle subtended by an annular differential area at unit distance from the elementary volume. Substituting the value for $I_\lambda(\theta)$ from Eq. (B-7) yields

$$4\pi \int_0^\pi b_\lambda(\theta) \sin \theta d\theta = 1 \quad (B-9)$$

b. The Volume Scattering Function

When the nature of the attenuating bodies in the medium is unknown, it is expedient to define a volume scattering function,

$$I_\lambda(\theta) = E_\lambda b'_\lambda(\theta) v, \quad (B-10)$$

as the intensity of scattered radiation of wavelength λ in the direction θ per unit of flux incident on the volume, v , of medium. For a unit thickness of medium, integration over all space yields

$$4\pi \int_0^\pi E_\lambda b'_\lambda(\theta) \sin \theta d\theta = (1 - e^{-\sigma_\lambda}) E_\lambda, \quad (B-11)$$

where the right-hand term gives the difference between the incident and transmitted flux. Neglecting terms in σ_λ , and higher powers, and dividing by E_λ , the fraction of flux scattered is

$$4\pi \int_0^\pi b'_\lambda(\theta) \sin \theta d\theta = \sigma_\lambda. \quad (B-12)$$

c. The Determination of Scattering Coefficients from the Scattering Function

Let N be the number of attenuating particles per unit volume of medium, and $S'_\lambda(\theta)$ the scattering function per particle. The volume scattering function is

$$b'_\lambda(\theta) = NS'_\lambda(\theta) \quad (B-13)$$

which upon substitution into Eq. (B-12) yields

$$\sigma_{\lambda} = 4\pi \int_0^{\pi} N S'_{\lambda}(\theta) \sin \theta d\theta \quad (\text{B-14})$$

Letting σ_{λ}/N equal p and expressing $S'(\theta)$ as

$$S'_{\lambda}(\theta) = \frac{\lambda^2}{4\pi} S''_{\lambda}(\theta) \quad , \quad (\text{B-15})$$

there obtains

$$\begin{aligned} p &= 4\pi \int_0^{\pi} \frac{\lambda^2}{4\pi} S''_{\lambda}(\theta) \sin \theta d\theta \quad , \\ &= \frac{\lambda^2}{\pi} \int_0^{\pi} S''_{\lambda}(\theta) \sin \theta d\theta \quad , \end{aligned} \quad (\text{B-16})$$

which can be thought of as the radiation scattered per particle per unit of radiation. Dividing by the cross-sectional area of the particle, πa^2 , yields

$$K' = \frac{\lambda^2}{\pi^2 a^2} \int_0^{\pi} S''_{\lambda}(\theta) \sin \theta d\theta \quad . \quad (\text{B-17})$$

The theories developing $S'_{\lambda}(\theta)$ include consideration of polarization phenomena. Since it is normally not necessary to consider polarization in the scattering of visible light, the half sum, $S'_{\lambda}(\theta)/2$, can be used, and a scattering area ratio, K_{λ} , can be defined as

$$K_{\lambda} = \frac{2}{\alpha^2} \int_0^{\pi} S_{\alpha}(\theta) \sin \theta d\theta \quad . \quad (\text{B-18})$$

where

$$\begin{aligned} \alpha &= 2\pi a/\lambda \\ S_{\alpha}(\theta) &= S'_{\lambda}(\theta)/2 \quad . \end{aligned}$$

Table B-1 summarizes the values $S(\theta)$ for small water droplets (refractive index = 1.33) for various values of α . For small values of α these table values can be used for the integration required in (B-18). From Eqs. (B-16) and (B-18), we have

$$\alpha_{\lambda} = NK_{\lambda}\pi a^2 \quad (B-19)$$

If it is assumed that there is no absorption, the extinction coefficient, σ_{λ} , is also equal to $NK_{\lambda}\pi a^2$.

Equation (B-19) is valid only for homogeneous aerosols. For mediums containing particles of different sizes, Eq. (B-19) must be written

$$\sigma_{\lambda} = \sum_{i=1}^n N_i K_{i\lambda} \pi a_i^2 \quad (B-20)$$

where the subscript i refers to the particle having the i^{th} radius. For particle distributions that can be described by continuous functions, such as the normal or Rosin-Rammler distributions,¹⁵ the summation may be replaced by an integral sign, and the equation becomes

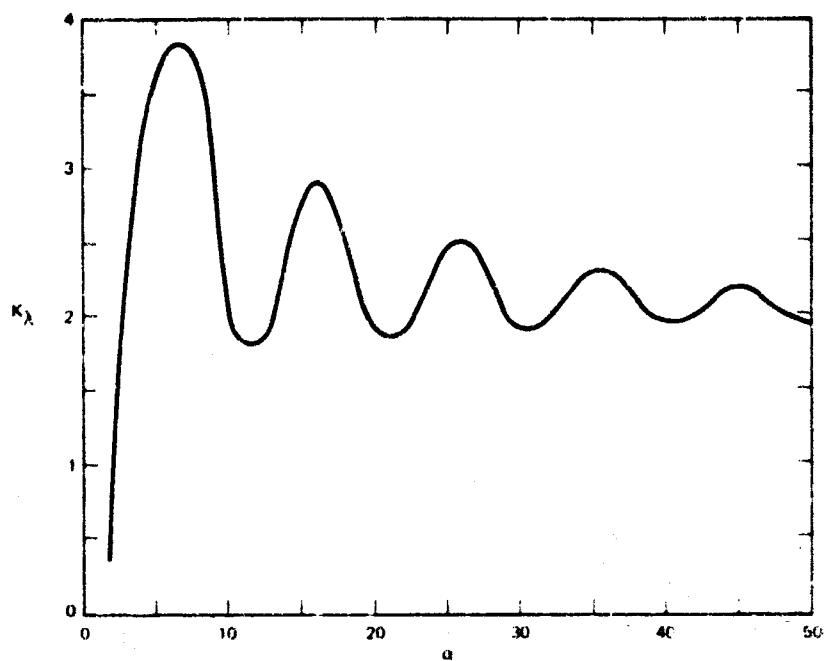
$$\sigma_{\lambda} = N \int_{a-\min}^{a-\max} f(a) k(a) \pi a^2 da \quad (B-21)$$

where $f(a)$ is the normalized distribution function, $k(a)$ is the form of K_{λ} as a function of a , and $a-\min$ and $a-\max$ are the smallest and largest radii in the system.

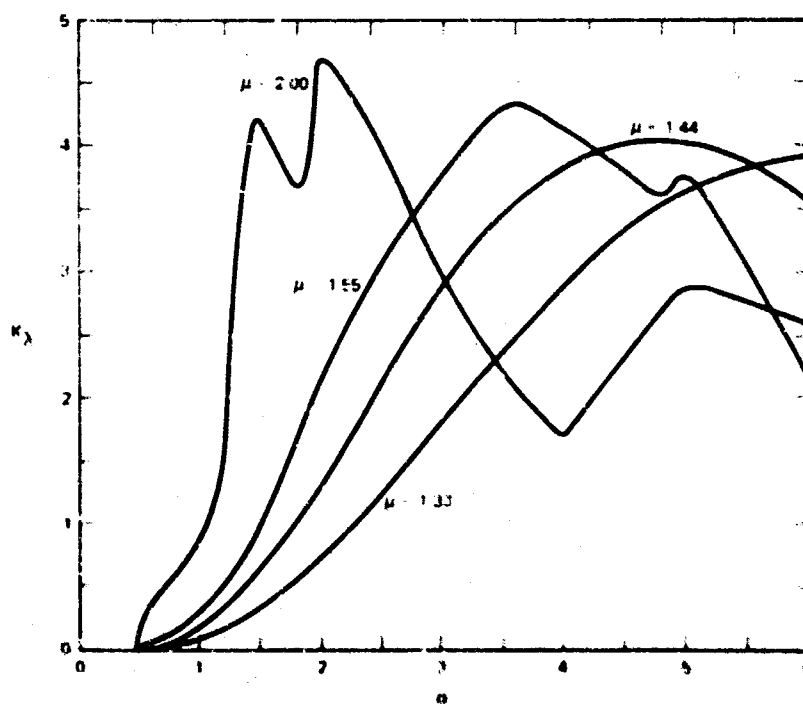
Values of K_{λ} have been determined by Haughton and Chalker¹⁵ for water droplets, and by LaMer and Sinclair¹⁶ for materials having other reflective indices. Some of these values are summarized in Figure B-1.

d. The Determination of the Extinction Coefficient

For relatively short ranges (3-5 km), the absorption of radiation (380-780 mμ) by most atmospheric contaminants encountered on a battlefield--water vapor and droplets, dust, and smoke-screen agents--



(a) VALUES FOR K_λ FOR WATER DROPLETS



(b) VALUES FOR K_λ FOR VARIOUS REFRACTIVE INDICES, μ

FIGURE 8-1 SCATTERING AREA RATIOS FOR VARIOUS MATERIALS

Table B-1

S(2) FOR WATER DROPLETS (REFRACTIVE INDEX = 1.33) IN UNITS OF $\frac{2}{\lambda^2}$ cm²

λ	0.5	1.0	1.5	2.0	2.5	3.0	4.0	5.0	6.0
0	0.00071	0.05260	0.6465	3.937	14.20	41.69	197.7	585.8	1253.
10	0.00069	0.05172	0.6288	3.790	13.45	38.68	173.7	478.0	927.1
20	0.00066	0.04816	0.5790	3.382	11.42	30.85	116.6	251.8	349.0
30	0.00061	0.04383	0.5054	2.800	8.705	21.00	57.71	76.70	56.58
40	0.00051	0.03827	0.4196	2.155	5.938	12.02	19.48	13.168	27.61
50	0.00040	0.03248	0.3331	1.546	3.626	5.646	4.333	9.441	28.16
60	0.00032	0.02706	0.2551	1.038	1.984	1.1549	2.064	10.234	9.396
70	0.00037	0.02253	0.19087	0.654	0.9808	0.6463	2.744	4.872	3.863
80	0.00033	0.01915	0.14213	0.3867	0.4519	0.3214	2.375	2.635	5.914
90	0.00032	0.01700	0.10765	0.21354	0.2149	0.3936	1.230	1.909	3.573
100	0.00032	0.01598	0.08472	0.10831	0.13202	0.4806	0.4746	2.390	1.5505
110	0.00031	0.01588	0.07025	0.1918	0.12225	0.4630	0.4771	1.354	3.052
120	0.00037	0.01615	0.06138	0.02028	0.14755	0.35880	0.8279	0.5854	2.730
130	0.00042	0.01741	0.05605	0.01096	0.19170	0.23317	1.0036	1.300	0.8624
140	0.00046	0.01951	0.05284	0.01370	0.2462	0.14452	0.8518	2.222	2.555
150	0.00050	0.01956	0.05088	0.02262	0.3034	0.1188	0.8302	2.065	4.647
160	0.00054	0.02042	0.04970	0.03288	0.3540	0.1446	0.6083	1.593	3.456
170	0.00056	0.02096	0.04906	0.04068	0.3888	0.1855	0.7196	1.829	2.880
180	0.00057	0.02115	0.04887	0.04358	0.4013	0.2042	0.8709	2.155	3.507

Source: From W. E. K. Middleton, Vision Through the Atmosphere, University of Toronto Press, 1952.

is small³, and the extinction coefficient, β_λ , can be set equal to the scattering coefficient, σ_λ . Moreover, in the particle size encountered in natural water droplet hazes and fogs (10-80 μ) and in fog-oil smoke screens (0.6-0.7 μ), the value of K_λ , assuming that the Haughton and Chalker data hold for values of α between 100 and 1000, is approximately equal to 2.0. Thus, if W and ρ are the total weight concentration and density of the atmospheric contaminants, and γ_i is the fraction of the weight of the contaminant with particle radius a_i , Eqs. (B-19) and (B-20) can be rewritten for all λ as

$$\beta_m = \frac{3W}{d\rho} \quad (\text{homogeneous aerosols}) \quad , \quad (B-22)$$

$$\beta_m = \frac{3W}{\rho} \sum_i \frac{\gamma_i}{d_i} \quad (\text{heterogeneous aerosols}) \quad , \quad (B-23)$$

where d is the diameter of the particle in the attenuating medium.

The value of the extinction coefficient may also be determined from the meteorological visibility. Since the luminance of a black body is zero, the inherent contrast of a black body against the horizon is -1. If the meteorological visibility, V_R , is defined as the range at which the apparent contrast of a black body is -0.02, Eq. (52) yields

$$e^{-\beta R} = 0.02 \quad (B-24)$$

and

$$\beta = \frac{3.9}{V_R} \quad (B-25)$$

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11. ABSTRACT Research was performed to (1) identify the essential elements and pertinent parameters for a visual model for surveillance of camouflaged personnel in various terrains, weathers, and combat environments, and (2) develop the mathematics and logic of the visual model. A model was developed to account for the effects of luminance and color contrasts in the detection process. It accounts for intrinsic luminance and color contrasts at the target and the effects of the atmosphere and range between the observer and the object. The state of knowledge concerning the effects of movement and form discrimination was found to be fairly primitive despite the extensive research that has been performed. It was not possible to develop a sufficiently detailed analytical model for the effects of either of these important parameters. Since it is considered necessary to include a human's judgment in modeling the process of recognizing military objects, empirical data derived from human observers' performance of form recognition, in conjunction with a classification system for backgrounds, are required for developing a realistic empirical model of form discrimination.			

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