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DEVELOPMENT OF THE U.S. WOODLAND BATTLE DRESS UNIFORM

by

Alvin O. Ramsley
William B. Bushnell

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This report describes the development of the Woodland camouflage pattern for the new US Army Battle Dress system. Guidance derived from combat experience, field trials and visual science is described. Rationale is given for selection of the fabric and specific pattern design, including the individual elements of color, infrared reflectance, and pattern size. Also described are the colorimetric and infrared properties of the standards selected and estimates of range of effectiveness from visual science. Dyeing and printing technology and relevant specifications are cited in the Appendix.

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PREFACE

This report summarizes the technical efforts to develop a new, more effective battle dress for the combat soldier. The major focus of the report is on the camouflage aspects of the clothing assembly and reflects the main purpose of the development. The report was prepared for presentation at the NATO Symposium on Countersurveillance in Brussels in the Spring of 1981.

The writers acknowledge the assistance they have received in preparation of the report. The standard fabrics to which reference is made were produced by Bradford Dyeing Associates, Westerly, Rhode Island, and the Riegel Corporation, Atlanta Georgia. Mr. George Arruda of the Natick R&D Laboratories provided the spectrophotometric data from which the reported colorimetric data were derived. Particular acknowledgement is made of the contributions of Mr. Kenneth A. Reinhart, Chief, Countersurveillance and Chemical Products Branch and Mr. Charles R. Williams, Chief, Textile Research and Engineering Division for their managerial guidance and review of the manuscript.

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1. INTRODUCTION

This paper describes the development of a battle dress clothing system for the infantryman. The primary intent of the system is to make it more difficult, both by day and night, for an enemy to detect, recognize and locate individual soldiers and to acquire them as targets. Other objectives include concealment during clandestine operations and minimizing the soldier's contributions to the signature of vehicles and other field equipment.

It is widely believed that disruptively patterned uniforms contribute to better camouflage. This is seen from the world-wide interest in and adoption of disruptively patterned clothing and equipment for combat troops. In the US the strongest support for patterned camouflage uniforms at this time comes from those with front-line combat experience in Vietnam. It was substantially on the basis of such experience that the US Marine Corps adopted the patterned uniform used in Vietnam for general use throughout the Corps. The rationale for adopting disruptive patterns for clothing by many foreign military forces is probably built on similar experience. Moreover, a number of years ago the US Army adopted multi-colored camouflage nets and pattern painting of vehicles on analagous subjective grounds. It is our opinion that the physics, psychology, and physiology that form the basis of visual science support the military judgment.

It appears that the question no longer is, "Should a disruptive pattern be used for camouflage," but "Which pattern is best and how much better?" Many field trials in several nations have attempted quantitative answers with mixed results. Some US trials, such as the USER Review at Fort Benning in 1962,[1] a US Army Test and Evaluation Command (TECOM) test in 1973,[2] and the 1975 MASSTER test,[3,4] gave equivocal results. Other tests have demonstrated clear advantages of some

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1. D.L. Gee and A.H. Humphreys, Use Review of Camouflage for the Individual Combat Soldier in the Field, Report No. 1834 ERDL (MERADCOM) Oct 65.

2. C.W. Quattlebaum and J.B. McAuley, Development Test II of Desert Uniform, TECOM Project NO. 8-EI-485 000-036, USAIB Project No. 3370, USA Infantry Board, Ft. Benning, Ga. Sep 73.

3. G. Marrero-Camacho and R.B. McDermott, Camouflage Evaluation Report (Phase I), MASSTER Test Report FM 153, Modern Army Selected Systems Test, Evaluation and Review, Ft. Hood, TX 76544, 21 Jan 74.

4. D.C. Cottington, C.H. Ulrich, and F.M. Wroblewski, MASSTER Camouflage Evaluation Program, Phase II; Verdant Camouflage Uniform Pattern Evaluation, MASSTER Test Report No. FM 204B, Modern Army Selected Systems Test, Evaluation and Review, Ft. Hood, TX 76544, 21 Nov 75.

patterns over others and over monotone colors. Such results were found in Australian[5] and German[6] trials with man-sized targets and a US test on vehicles.[7]

On the basis of all known tests, knowledge of the visual process and combat experience, the US Army adopted a variation of the pattern used in the tropics and already in the procurement system for wider use in temperate zones. This pattern has been named the Woodland Pattern.

2. <u>GENERAL CRITERIA</u>

Strict attention was given in the development to the guidance contained in STANAG 2333.[8] Other guidance has been derived from unofficial communication with the NATO Special Group of Experts on Camouflage, Concealment, and Deception and their individual members. Further general guidance is stated in US Army requirements derived from interaction between users and developers.

a. <u>Threats</u>

In the design of the pattern, the intent was to provide camouflage protection against major threats to the detection of personnel, both by day and night. It is universally conceded that visual observation is the major daytime surveillance threat to personnel. It is widely believed that the major present threats to personnel at night are the passive devices based on image intensification. Even though thermal imaging may ultimately challenge the starlight scope as the major night time battlefield surveillance threat, image intensifiers will long remain as significant threats to personnel.

Image intensifiers are sensitive to both visible and near-infrared radition. In the development work reported here we considered the upper limit of spectral sensitivity to be about 900 namometers for current instruments.

b. <u>Shape, Colors, and Size</u>

It was generally agreed within the US Army that the shapes of the pattern elements should be those of the current standard for the 1948 US Army four-color pattern now in the tropical uniform. The rationale for selection of

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[5] D. R. Skinner, A Pseudo-random Pattern Generator for Camouflage Research, Report No. 599 Australian Defense Scientific Service, Materials Research Laboratories, Maribyrnong, Victoria, Australia, Nov 74.

[6] A. Scharsich, Determination of Camouflage Effectiveness of Combat Uniforms with Disruptive Patterns, BWB Report FB-FE-IV-E91, Bundesant fur Wehrtechnik und Beschaffung, 23 Sep 75.

[7] Dual-textured Gradient Camouflage Paint Pattern (Dual-Tex), USACDEC and BDM Scientific Support Laboratory, CDEC Report No. 78-002, Ft. Ord, CA Nov 78.

[8] NATO Standardization Agreement (STANAG), Performance and Protective Properties of Combat Clothing, STANAG No. 2333, 16 Nov 77.

specific colors of the Woodland pattern is given below in Section 3. In order to extend the range of camouflage effectiveness as far toward 350 meters as possible, the decision was made to expand the 1948 pattern by 60 per cent. The rationale for this expansion is given in Section 5.

c. Selection of Colorants

The major consideration in choosing colorants for camouflage is that, as perceived in ultimate use, the contrast of a uniform with the background in which it exists be as low as possible. Because non-visual devices must also be considered, visually perceived color can not be the sole criterion. The most logical procedure is to select those colorants that will produce spectral reflectance factors on fabrics as close as possible to those of the major terrain elements. With respect to the starlight scope, this may be done directly because both target and background usually are similarly illuminated and their images similarly degraded by the device and atmosphere. This is a departure from the considerations involved in camouflage against active devices such as the old sniperscope. We therefore attempted to match the reflectance curves of major green, brown, tan, and black elements of the terrains that are typical of temperate zones.

In recommending dyes for industry to achieve these objectives, we are concerned that good colorfastness be attained. The recommended dyes have been selected as the result of a survey of a large number of commercial dyes. At the present time the Woodland pattern is built primarily around the use of vat dyes for nylon/cotton blended fabrics and acid dyes for all-nylon fabrics used in the clothing system. The procedure used in ultimate production of the standard for the coat and trousers is given in Appendix A.

All of the colors of the Woodland pattern can be achieved with appropriate infrared reflectance by using resin bonded pigments, a colorant system that could have good color fastness. This is being pursued as an alternative colorant system, especially for the all-nylon fabrics.

d. Fabrics

Based on earlier research,[9] the fabrics selected for the garment components of the system are equal blends of nylon and cotton. The reasons for this selection are consistent with the guidance from STANAG 2333 in regard to resistance to the thermal effects of nuclear weapons and for superior wear properties. The necessity for commercial availability of large quantities of fabrics at reasonable cost should also be appreciated.

For the coat, trousers, and helmet cover, the fabric chosen is an intimately blended nylon-cotton twill (ca 250 g/m^2). The field jacket and field trousers will be made of a similar fabric in a sateen construction (ca 300 g/m^2). A nylon filled cotton warp oxford fabric (ca 180 g/m^2) was selected for the cap. For the armored vest and various rainwear items, all-nylon fabrics were chosen. Although the camouflage objectives are the same, the development of the all-nylon fabrics is not discussed in this report.

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[9] E. T. Waldron, Textiles for Thermal Radiation Protection, Technical Report TS-132, US Army Natick Laboratories, Natick, MA 01760, Apr 65.

3. COLORS OF THE WOODLAND PATTERN

Selection of specific colors for each of the four areas of the pattern has evolved over the years. This process is described elsewhere in detail.[10] For reasons given there, the proportions of each colored area and the colors themselves were chosen with one psychophysical goal prominantly in mind. As the pattern is viewed at progressively longer ranges, the individual elements become progressively more difficult for the eye to resolve. At some distance the pattern elements have blended into a single monotone. It is our intent this monotone color be as close an approximation to the all-cotton sateen US Olive Green 107 as possible. The monotone colors used by NATO countries for field uniforms are very nearly the same. This suggests good agreement among nations that this color is probably the best single monotone camouflage color for European terrains.

Table 1 shows the tristimulus values for the US Standard Olive Green 107 and the various areas of both the present 1948 US four-color pattern and the new Woodland pattern. Table 2 gives the colorimetric data calculated for the blended colors of the two camouflage patterns as perceived at a distance, neglecting atmospheric effects. For both tables, the data were based on the use of a Macbeth MS-2000 spectrophotometer, the 1931 CIE Standard Observer, CIE Illuminant D65, and the 1976 CIE L*a*b* color spaces.[11] Also included in Table 2 are data for NATO I.R.R. Green (STANAG 2338) and the US Forest Green as references.

From the data of Tables 1 and 2 it may be seen that the blended color of the Woodland pattern differs from the others in one consistent respect; it is darker. Figure 1 is a chromaticity diagram in L*a*b* color space. It is seen there that the chromaticity of the blended color for the Woodland pattern falls almost in the center of the locus of points for the other reference colors.

Thus, the first objective in selecting colors that are compatible with a basic camouflage color has been achieved. Two practical reasons for choosing somewhat darker shades than those in the 1948 pattern were also considered. Large-scale production often results in fabrics somewhat lighter than the colorist's standard; lighter shades cost less. Secondly, colored fabrics fade in use, both from sunlight and laundering. Therefore, if the colors on a new garment are somewhat darker than the optimum target colors, they will tend to fade toward rather than away from the real target colors and thereby prolong useful life of the garment.

4. INFRARED PROPERTIES

The earlier 1948 pattern standard was developed to meet the threat of active near-infrared devices such as the sniperscope. The goal there was to achieve an overall reflectance of 20 to 25 per cent in the 900 to 1200-nm range. It is generally agreed that the passive devices based on image intensification are replacing the active devices as the significant threat to personnel. For that reason, entirely different near-infrared reflectance properties are needed.

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[10] A. O. Ramsley, Selection of Standard Colors for the Woodland Camouflage Pattern, USA Natick R&D Laboratories, Natick, MA 01760 (In preparation).

[11] International Commission on Illumination (CIE), Official Recommendations on Uniform Color Spaces, Color-Difference Equations, Metric Color Terms, Supplement No. 2 to CIE Publication No. 15, Colorimetry (E-1.3.1) 1971 published May 1976.

Table 1. Tristimulus Values for Olive Green 107, the 1948 US Present four-color Pattern, and the Woodland Pattern and Fractional Areas (f) of Each Color.

	f	L*	a*	b*
Olive Green 107	1.000	32.28	-2.86	11.87
1948 Pattern				
Light Green	0.195	45.42	-1.63	17.07
Dark Green	0.305	35.13	-8.98	10.58
Brown	0.370	29.84	1.95	11.17
Black	0.130	19.26	1.15	-0.34
Woodland				
Light Green	0.20	41.64	-1.27	14.55
Dark Green	0.30	31.22	-0.57	9.44
Brown	0.34	25.78	2.98	8.98
Black	0.16	15.81	2.34	-0.51

Table 2. Weighted Colorimetric Data for Olive Green 107, Current Standard for 1948 Four-Color Pattern and Woodland Pattern

	X	Y	Z	L*	a*	b*	ΔE*
OG107	6.57	7.21	4.95	32.28	-2.86	11.87	-
1948	7.48	8.16	5.77	34.31	-2.48	11.59	2.1
Woodland	5.88	6.40	4.71	30.40	-2.14	9.76	2.9
NATO IRR Green	8.81	9.53	7.87	36.98	-2.11	8.04	6.1
Forest Green	6.13	6.75	5.46	31.24	-3.06	7.69	4.3

Note: ΔE* is color difference from OG107 in CIE L*a*b* units. Color difference of the "blended" Woodland pattern from Forest Green is 2.4 units, being a bit darker and brighter; for Olive Green 107, the color difference from Forest Green is 4.3 units, being lighter and considerably yellower than Forest Green.

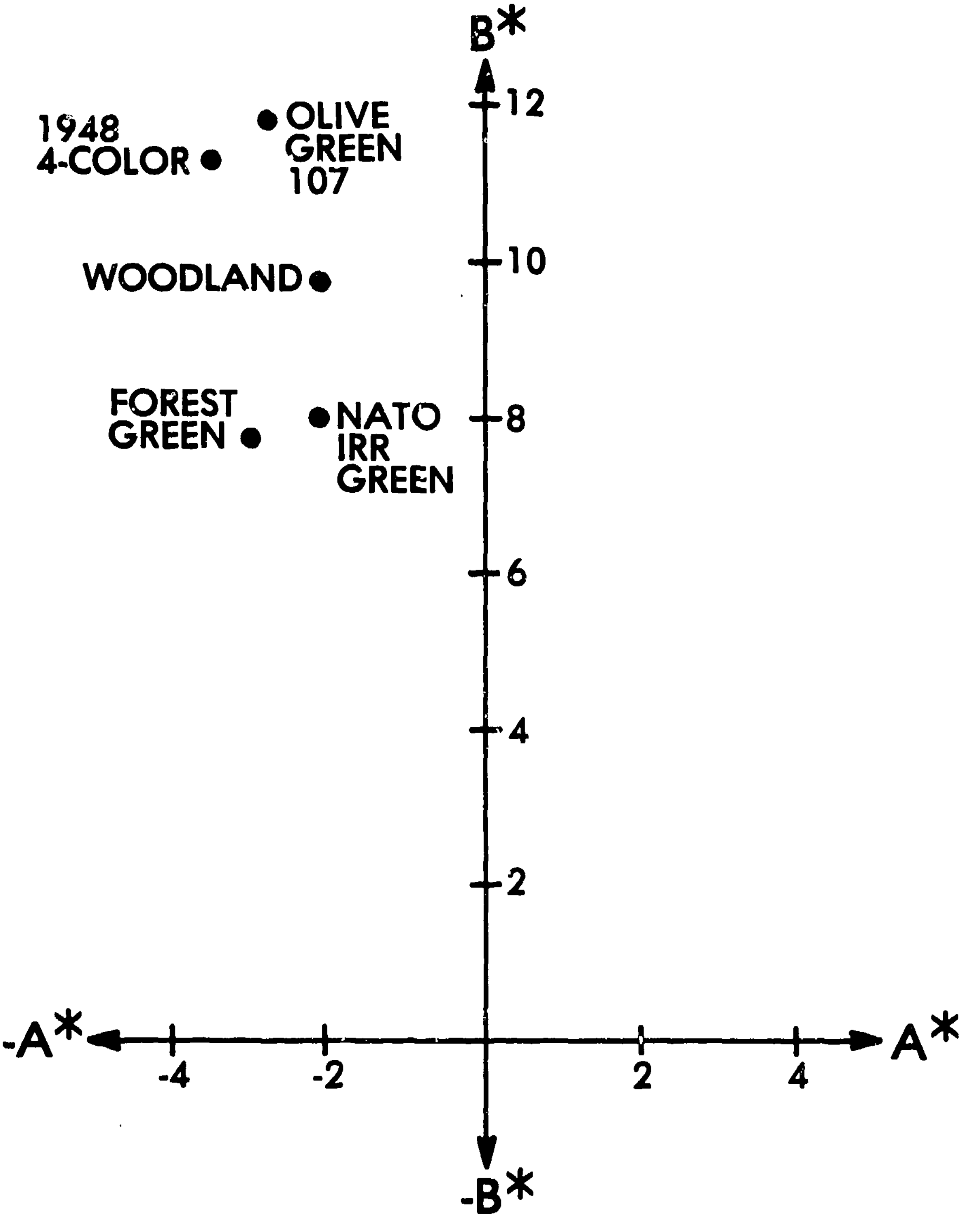

Figure 1. Chromaticity diagram in CIE L*a*b* color space showing locations for Olive Green 107, the blended (average) colors of the 1948 and Woodland patterns, NATO IRR Green and the US Army Forest Green.

Most terrain elements reflect more strongly in the near-infrared than in the visible region. Moreover, the passive devices operate by ambient light that equally illuminates both object and background, rather than by a projected beam that gets progressively weaker with distance. The objective, therefore, was to match reflectance curves of major elements of terrains for which a pattern is intended over the significant spectral range of sensitivity.

The spectral range that must be considered in the design of camouflage against image intensifiers is that represented by the devices' spectral sensitivity. For present image intensifiers we consider that range to be about 400 to about 900 nm. How the device operates within that range depends on the spectral power distribution of the ambient illumination that is available.

The normalized spectral power distribution of direct moonlight is nearly the same as that of sunlight. About one-third as much energy lies in the region from 700 to 900 nm (IR) as in the visible region from 400 to 700 nm. Thus, for objects viewed in direct moonlight, the image intensifier functions mostly as a "visible" device. But a well-trained soldier will seek to avoid being exposed in direct moonlight as conscientiously as he avoids direct exposure in daylight. He will seek out shadows and other cover as much as he can.

Image intensifiers function most advantageously within such shadows and on moonless nights. Under these conditions the illumination is from the sky and contains proportionately more infrared than visible light. Although the spectral power distribution of the night sky is widely variable, the infrared component is very significant in determining contrast as viewed with an image intensifier.

Figures 2 and 3 are photographs of three uniforms taken through a starlight scope on moonlit and moonless nights, respectively. The uniform in the center of both photographs is the new Woodland pattern flanked by the old 1948 patterned and the durable press Olive Green uniforms. In both cases, it is clear that contrast with the background is much less for the Woodland pattern. Figure 4 shows the spectral reflectance curves for all four colors used in the Woodland pattern.

5. SIZE OF THE PATTERN

It was mentioned earlier that a 60-per cent expansion of the 1948 pattern was adopted for the Woodland pattern. Although the reasons for the choice were mostly pragmatic and subjective, very good reasons from visual color science can be mobilized in support of that decision. The effects of pattern size and color on the range of camouflage effectiveness have been previously analyzed.[12] Our goals and those expressed in STANAG 2333 are to extend camouflage effectiveness of the pattern as close to 350 meters as possible. This means the elements of the pattern must be resolved by the unaided human eye at the maximum desired range. Beyond such range the pattern blends into a monotone shade.

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[12] A. O. Ramsley, Camouflage Patterns-Effects of Size and Color, NATICK/TR-79/030, (Confidential) US Army Natick R&D Laboratories, Jul 79.

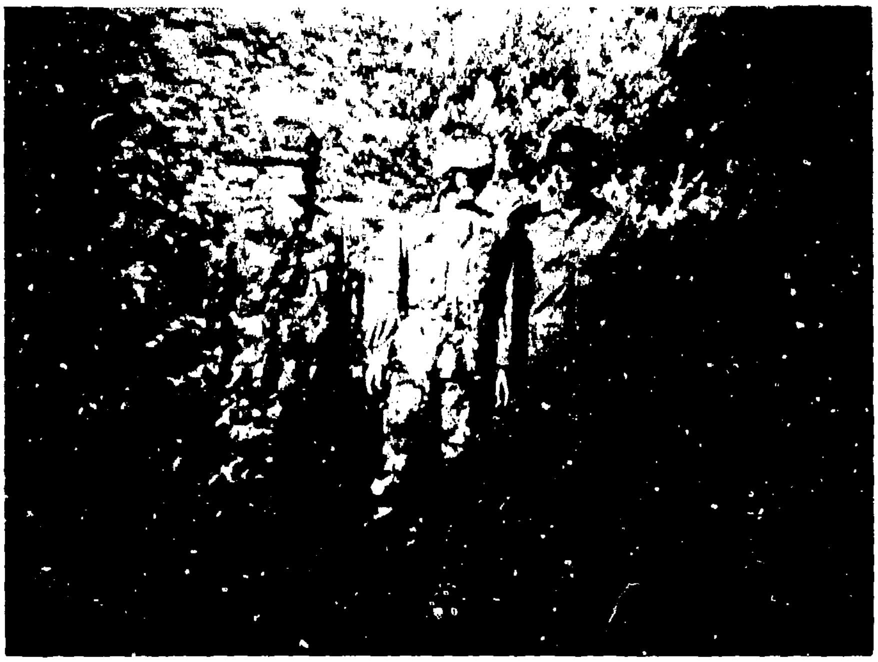

Figure 2. Photograph taken through a starlight scope on a moonlit night against a background of miscellaneous shrubs. The three uniforms are, left to right, the 1948 US Army pattern, the new Woodland pattern, and Olive Green 107.

Figure 3. Similar view to Figure 2 taken on a moonless night.

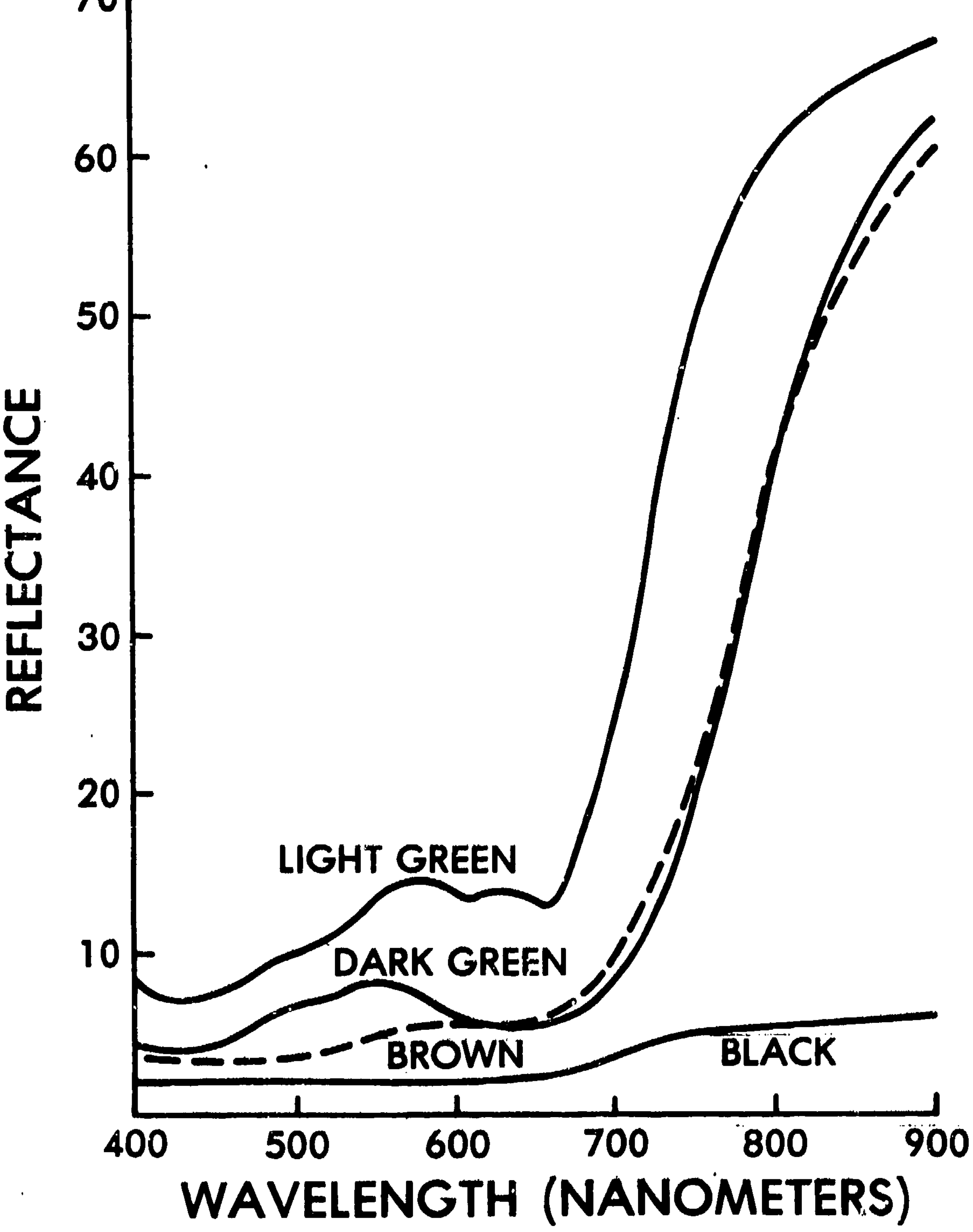

Figure 4. Spectral reflectance curves obtained with a Hardy spectrophotometer with polychromatic Source A illumination for the Light Green, Dark Green, Brown, and Black areas of the Woodland pattern.

The analysis[13] applied Judd's theoretical formulation on the ability of the eye to differentiate both lightness and chromatic differences of objects that subtend small angles (less than two degrees).[14] The Judd article furnishes quantitative predictions of the degree to which the eye is able to discriminate along the lightness axis and the red-green and yellow-blue axes. These axes are analagous to the L*, a*, and b* axes of the color space used throughout this paper. In calculating color differences, factors are applied to L*, a*, and b* as follows:

$$\Delta E^* = [k_1(\Delta L^*)^2 + k_2(\Delta a^*)^2 + k_3(\Delta b^*)^2]^{\frac{1}{2}}$$

where k_1, k_2, and k_3 depend differently from each other as functions of angular subtense between zero and two degrees.

Judd's basic formulation was applied to colorimetric data for the 1948 pattern expanded up to two times. The criterion for practical detection was one unit of color difference, a very stringent visual task in the field. The results showed that, for the pattern sizes considered, discrimination among the dark green, brown, and black areas disappear at relatively short ranges. Thus, at an intermediate range, the four-color pattern is perceived as a two-color. For the 60-per cent linear expansion, it was calculated that this transition should occur at about 150 meters. At some point beyond 250 meters, the eye can no longer distinguish this difference, and the pattern blends into a monotone.

One may ask why a pattern size even larger than a 60-per cent expansion could not be used. A major reason is that the patterns are of necessity printed on fabric, from which garments are later made. In cutting the fabric and sewing oddly shaped pieces together into garment form, the pattern is cut and fitted randomly together; many overlaps occur. Thus, the benefit in using a larger pattern is lost in the assembly process. To produce a larger pattern on a finished garment would entail very wasteful assembly procedures.

Even if a larger pattern could practically be used for uniforms, thereby extending the range of effectiveness, short range (e.g., 50 m) effectiveness may be degraded. This could be the underlying reason that the 1975 MASSTER test reported a somewhat lower detection rate for the 60 rather than the 100-per cent expansions. Results of that test was one of the factors in the decision on pattern size.

6. CURRENT STANDING

This report describes the criteria and research that have led to the development of the Woodland camouflage pattern for the new US Battle Dress uniform. Standards on the three nylon-cotton fabrics that meet the guide lines of STANAG 2333 have been procured. General procurement of fabric is now well-advanced and it is anticipated that initial issue of uniforms will begin early in 1982.

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[13] Ibid.

[14] D. B. Judd and G. T. Yonemura, Target Conspicuity and its Dependence on Color and Angular Subtense for Gray and Foliage Surround, NBS Report 10120, Nov 69.

Note: In references 13 and 14 a somewhat different color space is used, namely the 1964 u, v, W color space. This is similar in concept to the 1976 CIE L*a*b* color space used in this paper, but somewhat different quantitatively.

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APPENDICES

Appendix A.	Preparation, Dyeing, and Printing of Nylon-cotton for the Woodland Pattern
Appendix B.	Relevant Specifications for the US Woodland Patterned Battle Dress Uniform System

APPENDIX A

PREPARATION, DYEING, AND PRINTING OF NYLON-COTTON FOR THE WOODLAND PATTERN

Production of the Woodland pattern on nylon-cotton fabrics is basically the same whether applied on the twill or sateen fabrics. Because of differences in structure and weight, minor adjustments in processing is expected.

As part of the preparation, the fabric is given a conventional alkaline scour for 30 minutes at 100°C. This is followed by a cold rinse and bleach. The bleaching used depends on the quality of the greige goods. The last phase of fabric preparation is heat setting at about 190°C.

The next task is to produce a ground shade upon which the print will be applied. The first step is to dye by pad steaming the nylon component with acid dyes to a heavy shade, leaving the cotton undyed. This results in a gray colored fabric with an average visual reflectance of about 30 percent. The purpose of the heavy acid dyeing is threefold: provide a rapidly rising reflectance curve in the region between 650 and 750 nm; provide certain desired luminescence properties; and block the subsequently applied vat dyes from staining the nylon component. The dyes that have successfully been used for dyeing the nylon component are:

Acid Blue 258
Acid Orange 4R

The final stage in preparation of the ground shade is dyeing the cotton component with vat dyes to a shade approximating Light Green 354 of the final pattern. Dyes that have successfully been used are:

Vat Green 1
Vat Yellow 2
Vat Brown 57

The final step in producing the Woodland pattern is vat printing of the four colors of the pattern. During the early stages of large scale production, it appears to the authors that a better quality product results from use of rotary screens than engraved rollers. The following dyes have successfully been used in this printing step.

Light Green 354
  Vat Green 1
  Vat Yellow 2
  Vat Brown 57

Dark Green 355
  Vat Green 1
  Vat Yellow 2
  Vat Brown 57

Brown 356
  Vat Green 1
  Vat Yellow 2
  Vat Brown 57

Black 357
  Sulfur Black 6
  Vat Black 11
  Vat Green 1
  RB 10

It should be noted that although it is not a vat dye, carbon black has been approved for use in the Black 357 shade. It should also be noted that the sateen and nylon-filled oxford fabrics are given a water repellent treatment; allowance must be made for color changes that occur in that process such that the final colors and infrared reflectances are satisfactorily close to those of the twill fabric.

APPENDIX B

RELEVANT SPECIFICATIONS FOR THE US WOODLAND PATTERNED BATTLE DRESS UNIFORM SYSTEM

MIL-C-44031	Cloth, Camouflage Pattern, Woodland, Cotton and Nylon, 26 Sep 80.
MIL-C-3924E-Class 3	Cloth, Oxford, Cotton Warp and Nylon Filling, Quarpel Treated, 24 Apr 72 (being revised).
MIL-C-43191C, Class 3	Cloth, Wind Resistant Sateen, Cotton and Nylon, 17 Sep 74 (being revised).
MIL-C-43473D, Type III	Cloth Coated Nylon, Polyurethane Coated, 26 Feb 75.
MIL-C-43906, Type II	Cloth, Coated Nylon, Polyurethane Double Coated 4 Oct 74.
LP/PDES 23-71A Class 3	Cloth, Ballistic, Nylon, Lightweight, Water-Repellent Treated, 20 Feb 80.
MIL-C-508G, Type I Class 3, WRP	Cloth, Oxford Nylon, 3 ounce, 17 Sep 74.
MIL-C-43734, Class 2, WRP	Cloth, Duck, Nylon, 9 ounce, 27 Jan 71.