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DATE 22 November 1934

SUBJECT

Preliminary Report on Sky Camouflage of Naval Airplanes.

BY

NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

[redacted]

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NAVY DEPARTMENT

BUREAU OF ENGINEERING

Preliminary Report on Sky Camouflage of Naval Airplanes.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
Washington, D.C.

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(B) Army Report of June 21, 1932, Tests of Night Camouflage.

(C) Army Report of April 3, 1931, Specifications of Water Color Paint.

A B S T R A C T

The brightness of the light from the sun, sky and sea are analyzed to bring out the principles of day sky camouflage of airplanes. Rules are formulated, Chapter III, Section 3, which in simplest form are: paint upper surfaces with a dark gray blue; paint underneath surfaces, vertical surfaces, protuberances, with a light gray blue; all paint should be mat. Specific directions for painting the plane and experiments are outlined, Chapter VI.

Night sky camouflage is discussed merely by presenting the Army report of June 21, 1932, as a satisfactory solution, Chapter IV.

It is pointed out, Chapter V, that translucent fabric offers greater possibilities of low visibility camouflage than can be achieved by painting opaque fabric.

CHAPTER I

INTRODUCTION

1. Authorization - In a letter of August 1, 1934, file Aer-E-22-EP F39-5, from the Chief of the Bureau of Aeronautics to the Director, Naval Research Laboratory, the investigation of Naval Aircraft was directed with main attention to the visibility of aircraft when viewed from the ground.

2. Definitions - "Camouflaging" a plane means painting it with suitable colors and patterns to make it as invisible as possible. A plane viewed from the ground is seen against the sky as a background, so that this aspect of camouflage is usually referred to as "sky camouflage". Similarly, when the plane is viewed from above the ground or sea as a background and is painted to match the background, the camouflage is referred to as "ground camouflage" and "sea camouflage".

3. Scope of Present Report - In the following report various references have been consulted and from these together with the physics of the problem the general principles of sky camouflage are outlined and detailed recommendations are made for painting a Navy plane to achieve as far as possible a low visibility against the sky during the day and night.

A number of measurements of sea and sky brightness have been made and samples of color have been investigated under various lighting conditions. However, practically no experiments on painting planes have been done and therefore this report must be regarded as essentially preliminary.

4. Recording Color - In various places throughout this report the color and brightness of paints, natural scenes, etc., are referred to. In certain of the plates are given samples of various colors. These samples may fade or change with time, and at a later date may give the reader an erroneous impression. To insure as far as possible that the present work be reproducible and permanent, all colors are given in terms of the Munsell Book of Color, Abridged Edition, 1929, Munsell Color Company,Inc., Baltimore, Maryland. This little book contains on twenty pages twenty different colors. On each page are from five to thirty little paper rectangles painted with the color in various gradèd degrees of brightness and saturation. The notation is simple, for example, to specify that a certain sample of paint was "Munsell PB 6/4" means that under daylight illumination it matched in color and brightness the little colored rectangle in the Munsell Book of Color on page "Purple Blue", row 6, column 4.

CHAPTER II

HISTORY AND REFERENCES

1. Historical - Camouflage was initiated during the World War and dealt with terrain and structures on land, ships and aircraft. In the case of aircraft the main emphasis was on ground camouflage, or painting the upper surfaces of the aircraft to render them of low visibility when seen against the ground. The United States Army entered on the problem and in addition to ground camouflage experimented with the possibilities of sky camouflage with, as indicated by the reports, some success. The work of the Army falls into two periods, one from 1918 to about 1922, a gap of inactivity, and a recrudescence of activity beginning about 1930 and continuing until the present time. As far as is known, the U.S. Navy has done no work on air camouflage.

As may be supposed, practically all literature on the subject of air camouflage is to be found only in military reports. In the next section is given a list of the titles of the reports and references which have been consulted in the present connection. Most of these were assembled by the Bureau of Aeronautics. After each title is a short sentence or comment on the essential gist of the report. The references fall into two categories, those which deal with airplane camouflage, and those which deal with other types of camouflage such as of ships, terrain, hangars, etc., and therefore are of no interest here.

The references which treat of airplane camouflage fall into two classes, those which describe work accomplished during the World War and shortly thereafter, and those of work since about 1930. The first class comprise much preliminary work dealing with general principles. The second class is made up entirely of a series of recent Army reports and may be regarded as the most important here. Three of them, of dates February 16, 1933, June 21, 1932, and April 3, 1931, reproduced in full in Appendices A, B and C, respectively, give the most recent experience and comments of the Army on sky camouflage of airplanes for day and night conditions.

2. List of References

(A) Most important references:

Reference 1 - War Department Air Corps Material Division Engineering Section, Serial No. M-56-2272, February 16, 1933. "To determine from a service test conducted by a tactical unit the suitability of camouflage water paint and instructions contained in Technical Order No. 01-1-16 for preparation and use of this water paint".
Reproduced in full in Appendix A.

Reference 2 - War Department Air Corps Material Division Engineering Section, Serial No. M-56-2291, June 21, 1932. "To prepare a water paint suitable for night camouflage".
Reproduced in full in Appendix B.

Reference 3 - War Department Air Corps Material Division Engineering Section, Serial M-56-2542, June 9, 1933. "To discuss the application of, and the designs for, airplane camouflage at the Air Corps Anti-Aircraft Exercises held May 15 to 27, 1933".
Adds a few details to reference 1, such as the time taken to apply the paint, the fact that the sky camouflage effective against blue sky was not effective against a cloudy sky.

Reference 4 - War Department Air Corps Material Division Engineering Section, Serial M-56-2291, December 19, 1932. "To observe the tests of camouflage water paint, and confer with the authorities at Langley Field relative to the suitability of water paint in the camouflage of Army aircraft".
Preliminary to Reference 1. Otherwise of no interest.

Reference 5 - War Department Air Corps Material Division Engineering Section, Serial M-56-2291, August 10, 1932. "To determine suitable colors and shades of water paint for day camouflage".
Preliminary to Reference 1. Otherwise of no interest.

Reference 6 - War Department Air Corps Material Division Engineering Section, Serial M-56-2272, January 22, 1932. "A summary and bibliography of available information on aeronautical camouflage".
All of the references cited are given here.

Reference 7 - War Department Air Corps Material Division Engineering Section, U.S. Army Specification No. 14057, April 3, 1931. "Water Color".
Of value in ordering water color paint. Reproduced in full in Appendix C.

(B) Older references of general importance.

Reference 8 - War Department Air Corps Material Division Engineering Section, Serial No. 1591, March 22, 1921. "Preliminary report on laboratory investigation of colors used as a camouflage for the Breguet Airplane".
Description of laboratory photometric measurements of various paints. Of no interest.

Reference 9 - War Department Air Corps Material Division Engineering Section, Serial No. 1498, January 12, 1921. "Report on Camouflage of Day Airplanes".
Only of general interest. The first report of the Army on sky camouflage, in which it is pointed out that the under surfaces should be of light color, that the paints used should be mat and not shiny, etc.

Reference 10 - War Department Air Corps Material Division Engineering Section, Serial No. 1299, June 17, 1922. "Factors of Camouflage".
Deals mainly with ground camouflage. Of no direct interest.

Reference 11 - War Department Air Corps Material Division Engineering Section, Serial No. 1090, December 3, 1920. "Report on Aeronautical Camouflage".
Deals mainly with ground and terrain camouflage. Of no direct interest.

Reference 12 - Weigler, "Aeronautical Camouflage", Aerial Age Weekly, May 10, 1920, pages 288-300.
Of no interest.

Reference 13 - Bureau of Construction and Repair, "The Development of Marine Camouflage and Tests Relating Thereto" by Lieut. Harold Van Buskirk, Construction Corps., U.S.N.R.F., May 1, 1919, Volume II, Chapter G, "Aviation Camouflage".
Mostly ground camouflage. A single experiment on sky camouflage is mentioned (page 179) in which the under surface of a plane was painted black with white edges. At 4000 yards elevation the white blended out against the sky and the plane looked smaller, as though higher.

Reference 14 - Research Information Committee, Confidential Report No. 1. "The Visibility of Airplanes" by M. Luckiesh, 1918, 78 pages, 35 figures.
Assembles much useful data on brightness of land, sea and sky, the reflectivities of paints, fabrics, and materials. Gives a good theoretical discussion of the general principles of sky camouflage. No experiments on sky camouflage of airplanes.

Reference 15 - "Measurements of the Brightness of the Sky" by Kimball and Hand, Monthly Weather Review, 49, 483, 1921; 50, 618, 1922.
Gives measurements of the brightness of the sky at all points for various weather conditions and altitudes of the sun.

(C) Camouflage references of no interest to the present problem.

Reference 16 - War Department Air Corps Material Division Engineering Section, Serial 1646. "Report on Secret Insignia", June 14, 1921.
Mentions that under surfaces of planes should be painted a light color for day sky camouflage. For night camouflage the under surfaces should be painted with black.

Reference 17 - Priest, "Preliminary note on the relations between the quality of color and the spectral distribution of light in the stimulus", Journal Optical Society of America, 4, 388, 1920.
Of no interest.

Reference 18 - War Department, Engineer Field Manual, Vol. II, Military Engineering, Part two, Defensive Measures, 1932.
Nothing on sky camouflage.

Reference 19 - War Department, Training Regulations, No. 195-45, February 1, 1926. "Fortification, Camouflage for Artillery".
Nothing on sky camouflage.

Reference 20 - Luckiesh, "Color and its Applications". Book published 1915.
A condensed treatment of the science of color. Of no interest.

Reference 21 - Bureau of Standards, Division IV-3. "Final Report to the Director on Military Work during 1917 and 1918".
Of no interest.

Reference 22 - Bureau of Standards, Division IV-3. "Military and Naval Correspondence, 1917-1919. Visibility and Camouflage, Green Tape, Brock Goggles".

Reference 23 - S.J. Solomon. "Strategic Camouflage". Book published 1920, E.P. Dutton and Company.
Deals entirely with terrain camouflage

Reference 24 - The Submarine Defense Association, confidential report No. 467, 1918. "The science of low visibility and deception as an aid to the defense of vessels against attack by submarines" by L.A. Jones.
Of no interest.

Reference 25 - Naval Research Laboratory Report No. H-1036, March 7, 1934, "Report on the Problem of Visibility".
Deals mainly with visibility of ships. Of no interest.

CHAPTER III

DAY SKY CAMOUFLAGE OF AIRPLANES

1. General Principles of Day Sky Camouflage - An airplane aloft in the daytime is lighted from two sources of light: (1) light which comes down from above from the sun and the sky, i.e., the sunshine plus the sky shine, and (2) light which comes up from below from the surface of the earth, i.e., the earth shine. The earth shine is, of course, the sunshine and sky shine diffusely reflected by the earth. Since the reflectivity of the earth, either land or sea, is fairly low, the earth shine is always much less than the sunshine and sky shine.

In painting a plane to reduce its visibility when viewed from below the upper horizontal surfaces, as well as the under horizontal surfaces, must be considered, for the upper surfaces often come into the view of the ground observer due to the tilt of the plane and the slant of the wings. In order that the plane be of low visibility against the sky the under horizontal surfaces, being subjected to the fairly weak earth shine, must be painted a fairly light color, and the upper horizontal surfaces, being under more intense illumination, must be a somewhat darker color. Vertical surfaces present an almost unsolvable situation. Painting them dark enough to be correct in sunlight would make them too dark in shadow, and painting them light enough to be as satisfactory as possible in shadow would make them too bright in sunlight. It is suggested that the vertical surfaces be painted a light color.

2. Numerical Values of Sea and Sky Brightness and Reflectivities of Some Materials - In very clear, cloudless weather the sunshine falling on the surface of the earth is about 10 times the sky shine, i.e., the light from the total sky. This means that the shadow cast on the ground by an object is 10 times less intense than the region in sunshine around the shadow. Thus, of the total light coming down from above 9/10 comes from the sun and 1/10 from the blue sky. Haze makes the sky brighter and with slight haze the sky shine may contribute 1/4 of the total downward illumination, the sun contributing the other 3/4. It is usually stated that for a normally clear sky the sky shine is about 1/5 or 0.2 of the sunshine. Of course, when the haze and clouds are thick enough to obscure the sun, the sunshine is zero and the sky shine provides all of the down-coming light.

The brightness of an area of the normally clear blue sky varies with the angle from the sun, being theoretically darkest the farthest from the sun. Actually, as the horizon is neared the sky is usually brighter because of the finite thickness of the atmosphere and of haze which is usually present in the lower levels even on the clearest day. For example, with the sun at 45° altitude bearing south, the relative brightness in arbitrary units of a clear blue sky observed along a north-south meridian is given in Table 1. Many measurements of the

brightness at various points in the sky for various positions of the sun are given in reference 15, and merely show, in agreement with Table 1, that the brightness of a clear sky varies by a factor of 10 depending upon the position of the sun.

Table 1

Angle from sun measured toward north	Relative sky brightness
0° at sun	--
15°	8
30°	4
45° zenith	2
60°	1.6
75°	1.3
90°	1.0
105°	1.2
120°	1.7
135° horizon	2.5

The color and brightness of the blue sky overhead in clear weather is matched fairly well by Munsell PB 4/6, when the Munsell book is held in full sunlight. The sky near the horizon is brighter and whiter, as Munsell PB 7/2 or PB 8/2, the amount of brightness and whiteness depending on the amount of atmospheric haze and position of the sun.

A cloud illuminated by the sun, and hence white, is something like 10 times the brightness of the blue sky alongside of it.

The brightness of the sea is roughly 0.7 or 0.8 of the brightness of the darkest part of the blue sky, as shown by our own measurements and by Reference 14, Section 9, pages 23 to 26. This is only true for a wavy surface of the sea. If the sea is mirror calm, a case of perhaps no great importance, for such a sea is rare, the sea is a mirror for the sky of reflectivity 2% looking vertically down on the sea, increasing to 100% as one increases the angle of view to grazing incidence.

The color of the surface of the sea ruffled by moderate to fresh breezes as seen by an observer looking out over the surface from a surface ship is matched in cloudless weather by Munsell PB 3/6 to 3/10, the Munsell book being held in full sunlight. No measurements are available of the color and brightness of the sea made by an observer at a height looking down on the sea in various kinds of weather.

The diffuse reflectivity r of the surface of the earth is usually put down as about 1/10 or 0.1. This means that 0.1 of the light falling on the surface of the earth is diffusely reflected back again. The reflectivity varies with the nature of the surface as indicated in Table 2 given by Luckiesh, Reference 14, page 19. He further observed that for deep water the value r = 1/10 was a fair average.

Table 2

	Diffuse reflectivity r
Ploughed and barren land	0.10 - 0.20
Grass fields, etc.	0.05 - 0.10
Woods	0.03 - 0.05
Water	0.05 - 0.10

The diffuse reflectivity r of white paper and white paint are 0.7 to 0.8. Mixing colors with the paint reduces the reflectivity so that a light blue paint will probably not have reflectivity greater than 0.5 to 0.6. For "battleship gray" r is about 0.4.

3. Rules for Day Sky Camouflage - From the numerical values of the preceding section one can lay down the rules for day sky camouflage and discuss to what extent such camouflage can be effective.

Rule 1 - Upper Surfaces
Paint the upper horizontal surfaces a dark gray blue of diffuse reflectivity r about 0.15 to 0.20, as Munsell PB 5/2 or 5/4. A sample is shown in Plate 1a.

Rule 2 - Underneath Surfaces
Paint the underneath horizontal surfaces a light gray, or a light blue, or a light gray blue, of diffuse reflectivity r about 0.40, as Munsell PB 7/2 or 7/4. A sample is shown in Plate 1b.

Rule 3 - Vertical Surfaces
Paint vertical surfaces the light color of Rule 2.

Rule 4 - Miscellaneous Surfaces
Paint all miscellaneous structures, such as struts, etc., the light color of Rule 1. In case of doubt concerning any surface, protuberance, propeller, cowling, etc., use the light color rather than the dark color.

Rule 5 - Mat Paint
All paint should be mat, not glossy, and all visible portions of the plane which might exhibit shiny areas should be covered with the mat paint.

4. Discussion of Rule 1, Upper Surfaces - The dark gray blue paint of Plate 1a was chosen to be effective under sunlight illumination in clear weather. It was arrived at in the following way. The upper horizontal surfaces receive light from the sun and the blue sky, about 5 arbitrary units of light from the sun and 1 unit from the total sky, or 6 units altogether, see Section 2. The paint should have a reflectivity r = 16-2/3%; it will then have a brightness of 6 x 0.16-2/3 = 1 unit, and in sunlight will match approximately the average brightness of the blue sky.

Seen against a white cloud, or against the brighter regions of the sky near the sun, the dark gray blue paint will be darker than the background. This can not be avoided. To match a white cloud one should use pure white paint, which would perhaps be too visible against the blue sky.

The dark gray blue paint viewed from above against the sea should match the color and brightness of the sea surface fairly well, being a little brighter than the sea.

Perhaps a pure dark gray of r = 0.20 would be just as effective as the dark gray blue of Plate 1a. One cannot decide the question without experimental test. In all probability the exact shade of blue or gray is not important as long as the reflectivity, or brightness, is correct. A similar instance is found in the colors of the uniforms of the World War. The French used "bleu horizon", the Germans "field gray" and the English and Americans "olive drab". All were of about the same brightness and although differing in tint, were probably of equal average effectiveness for protective coloration.

In a biplane it is thought to be best to use the lighter paint on the upper surfaces of the lower wings.

5. Discussion of Rule 2, Underneath Surfaces - The light gray blue, Plate 1b, chosen for the underneath horizontal surfaces is the result of a compromise.

One should use as bright a paint as possible for the under surfaces and even then they will be darker than the sky background. The under surfaces receive the sky shine and the sunshine which is reflected by the sea. For sky shine 1 unit, sunshine 5 units and a reflectivity of the sea 1/10. This amounts to 0.6 units. If the under surfaces were painted with an ideal white paint of r = 1, their brightness would be 0.6 units, which is darker than the 1 unit brightness of the average blue sky. If the reflectivity of the paint is 0.4, as that of Plate 1b, the brightness of the under surfaces is 0.6 x 0.4 = 0.24 which is about 1/4 the brightness of the sky. Hence the under surfaces painted with the light gray blue paint of Plate 1b will always be darker than the sky.

Using pure white paint on the under surfaces would make them nearer to the brightness of the sky than the light gray blue paint does. But if the under surfaces got into the sunlight they would be very brilliant.

Thus the light gray blue paint of Plate 1b represents the compromise between the wish for a very light colored paint in the shadow and the fear of its being too conspicuous in the sunlight.

The color selected by the Army (Appendix A) is shown in Plate 1d. Just why the color was chosen is not known; perhaps the color was optically satisfactory and desirable because of permanence, ready availability commercially, etc.

Standard Navy gray, or battleship gray, is shown in Plate 1c.

Colors b, c and d, Plate 1, all have the same brightness. Only tests can show whether there is any choice between them for the under surfaces. Probably they are equally satisfactory.

In cloudy weather there is no direct sunshine and the light coming upward from the sea is about 1/10 of the light coming down from the clouds. So that the under surfaces, even if painted with white paint r = 1, will be 10 times as dark as the cloud background. This is illustrated in Plate 2, in which the small dark gray square is 10 times darker than the large light gray square. Therefore a plane seen overhead in cloudy weather always is much darker than the cloud background no matter what color the plane is painted. It needs only a glance at a plane or a white sea-gull under these conditions to confirm this statement.

6. Discussion of Rule 3, Vertical Surfaces - The vertical surfaces present a well nigh impossible problem. Unless the plane is directly overhead, some vertical surfaces, or those more or less vertical, will always be visible. And, since the sun in a majority of cases will not be directly overhead, the vertical surfaces will either be in sunshine or in shadow. In the sunshine they will be about 4 times as bright as in the shadow, as illustrated in Plate 3. Either condition could be met separately with some success, the one would call for a darkish color as Plate 1a and the other for as light a color as possible, but to cope with both conditions with the same paint can not be done with much success. Thus, in Rule 3 the light gray paint of Plate 1b with r = 0.40 was chosen as a poor sort of compromise.

The situation is much the same as the painting of surface ships to reduce their visibility. In sunny weather the sides of the ships in sunshine are too bright and in shadow are too dark. The "battleship gray", Plate 1c, now in use was chosen apparently not because it met sunny weather conditions particularly well, but because it gave the lowest visibility in thick, hazy or misty weather (Reference 13, Chapter H).

7. The Question of Pattern - In the past camoufleurs have often advocated a pattern of light and dark shades or of different colors for low visibility against a uniform background, based on plausible theories of "breaking up the outline", of "scintillation" or "vibration", etc. The Army made use of a spot pattern in its sky camouflage experiments (see Appendix A). It is true, however, that no empirical evidence exists to indicate that pattern is of real value. In a recent conference the Army stated that the pattern of smallish spots used on the underside of the plane was probably unimportant and that perhaps it would not be used in future experiments.

In an attempt to find out about pattern on the vertical surfaces a stripe of the dark gray blue of Plate 1a about 30 inches wide was painted on the fuselage of an aluminum painted plane. A photograph of the plane and stripe is given in Plate 4. When viewed in flight in a light gray day, the sky being covered with thin clouds, the stripe became indistinguishable to the unaided eye at about a mile and with six power binoculars at about four miles. The stripe did not appear to have much effect on the visibility of the plane. However, little confidence can be placed in a conclusion derived from a single experiment of this sort.

8. Illustrations of a Camouflaged Plane with Pattern - If pattern is used it should be bold and simple and made to compensate for shadows. All spots or stripes of the pattern should be at least 2 feet across. Plate 5 gives a photograph of paintings in plan and elevation of a plane with a pattern camouflage. (The original paintings of Plates 5, 6 and 7 accompany one copy of this report.) Only two paints a and b of Plate 1 are used, on the idea that the work of painting be as simple as possible and that the use of more shades of paint be useless anyhow.

In plates 6 and 7 are shown photographs of paintings of a biplane in flight in sunny weather camouflaged according to the rules of Section 3 and the pattern of Plate 5. In the paintings the attempt was made to depict, as far as imagination permitted, the correct relative brightnesses of the sea sky scene and the various portions of the plane. In Plates 6 and 7 there are to be noted the fairly good match of the upper horizontal surfaces with the sky, and the darkness of the under portions and the areas in shadow even though these are painted with the light paint. If the reader is somewhat disappointed with the effectiveness of the camouflage he will have received the impression which we wished to convey.

9. Discussion of Rule 5, Mat Paint - Assuming that camouflage is a temporary measure to be adapted to the particular mission of the plane, a paint is needed which can be readily applied and removed. For surfaces which do not get into salt water, water color paint is satisfactory. It has the desired mat surface; it is easy to put on and get off. Just what adhesive characteristics the paint should have will depend upon the conditions under which the camouflage is employed. With only a little adhesive the paint is easily removed but is also readily washed off by rain; with more adhesive the paint stands up better in rain but is more difficult to get off. The Army developed specifications (see Appendix C) for a water paint with a certain amount of adhesive, which would stand a half hour in heavy rain and which could be washed off from a plane by 3 men in 1 day (Appendix A, pages 6 and 13).

Water color paint in accord with the Army specifications, Appendix C, would seem to be suitable for Naval purposes. This can be obtained commercially in any color. For example, samples are shown in Plate 8, prepared by the Murallo Company, Staten Island, New York, which match the colors of Plate 1a and b. The water color paint in

quantity costs not more than 20 cents a pound and not more than 50 pounds, or $10 worth, are required for the largest plane.

Water color paint, of course, cannot be used on portions of the plane wetted by salt water. These must be covered with mat oil paints which are available commercially.

10. The Coloration of Soaring Birds of Prey - A bird which soars in the open watching for its prey would seem to be in much the same situation as the military plane. The one wishes to be of low visibility to small animals and the other to men; the visibility curves of the eyes of small beasts and of men are known to be similar[26]. Plates 9

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26 Nagel, Handbuch der Physiologie, Vol. 4, page 99, 1904

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and 10 are photographs of sketches of birds as seen overhead in soaring flight[27]. The swallow-tailed kite and vulture, Plate 9, are not birds of prey and are omitted from discussion. It is seen that the hawks are all a lighter color, usually grayish, underneath. They are darker on

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27 Roberts, The Birds of Minnesota, Vol. 1, page 330, 1932

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top. It is interesting to note that they possess the coloration proper for low visibility. The eagles, Plate 9, are black underneath and are more visible; this may be explained away by saying that the eagle is so powerful that concealing coloration is not important in his case.

The hawks possess no marked pattern on their under surfaces except a majority have dark tips to the wings. Whether this is an aid to sky camouflage or whether it is for some other reason, such as coloration when at rest, can not be said.

About the only conclusion that can safely be drawn is that certain soaring birds of prey do possess low visibility coloration, and it may be inferred that such coloration, although it can certainly not be very effective under all conditions, nevertheless is of some value.

CHAPTER IV

NIGHT SKY CAMOUFLAGE

1. Natural Illumination - Under night conditions with the natural illumination of the stars, moon or clouds, the day sky camouflage of Chapter III would, of course, be satisfactory.

2. Searchlight Illumination - Under searchlight illumination at night the light paint of day sky camouflage, Plate 1b, would be much more visible than a black paint. The Army experimented with a dull black water color paint spread on the under surfaces. Its excellent report, given in full in Appendix B, seems to cover the matter completely; we have nothing to add. The conclusions, stated in the first page of the report, are as follows:

> "An intense black water paint having a relative reflection of 0.035 was found to give a dull mat finish that was capable of rendering an observation airplane invisible while in the beam of a 36 inch, 150 ampere, arc searchlight at a range of about 3800 yards.
>
> "When the sky is overcast the airplane may be located if it passes between the observer and the illuminated area on the clouds produced by the searchlight beam.
>
> "When the sky is overcast the airplane may be located if it passes through the beam by the shadow cast on the illuminated area of the clouds, even though the color of the airplane is such as to render it invisible in the beam by direct illumination."

CHAPTER V

LOW VISIBILITY BY TRANSLUCENT FABRIC AND BY ARTIFICIAL ILLUMINATION

1. Low Visibility by Translucent Fabric - It was realized from the beginning that a translucent fabric on the wings and fuselage where possible would yield brighter under surfaces and a lowered sky visibility. Recently a transparent fabric has been under development[28] which consists of a stainless steel wire mesh coated with a more or less transparent

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28 Naval Aircraft Factory, Philadelphia. "Report on Wire Mesh Fabric for the Covering of Naval Aircraft", May 8, 1933, and "Report on Wire Mesh Fabric for the Covering of Naval Aircraft - Investigation of", January 20, 1933.

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dope or varnish. It was developed primarily for its fire resisting qualities. The fabric possesses, however, optical properties which have possibilities from the standpoint of low sky visibility.

A sample of the fabric is given in Plate 11a of 30 mesh wire of diameter 0.0037 inch coated with Dulux varnish. On turning the sample up from the page and holding to the light, it is seen to be fairly transparent and somewhat yellowish in color. The light transmission of the undoped wire mesh is 78%, and of the doped mesh, as Plate 11a, is about 60% for red, yellow and green light, and a little less for blue light. For light incident at 30° the light transmission of the doped fabric is about 35% becoming less as the light approaches grazing angles of incidence.

In the case of an airplane wing covered with the fabric there are two coatings of fabric, one on the upper and one on the lower surface. Light passing through these at angles not too near grazing is reduced 0.60 x 0.60 = 0.36 in intensity, or about 1/3 of the light is transmitted. Such a wing seen against the sky would appear about 1/3 as bright as the sky. The underneath brightness would be increased a little by any sunlight scattered by the meshes of the fabric. If, however, the fabric on the lower surface were made translucent, as a sheet of ground glass or white paper, the underneath brightness of the wing in sunlight would be much increased. For example, suppose, as is readily possible, that the translucency were such that 30% of the incident light were scattered upward and 30% downward, 40% being lost by absorption, etc. In sunny weather there are 6 units of light falling on the transparent upper fabric, 5 from the sun and 1 from the blue sky. 6 x 0.60 = 3.6 units pass through to fall on the lower translucent fabric. From the lower surface of this 3.6 x 0.30 = 1.08 units emerge scattered in all directions.

Thus the lower surface, and hence the wing seen from below in sunshine against the sky, would be of brightness 1.03 units, which is about the same as the 1 unit average brightness of the blue sky. In short, what the translucent fabric really does is to divert, by scattering, some of the sunlight to the eye of the observer which, if the lower fabric were transparent, would pass directly through and be lost to the observer.

In Plate 11b is given a sample of the fabric made translucent by sandpapering one side. It transmits diffusely about 30% of light incident on it. To simulate an airplane wing two squares of the mesh fabric were placed together, one half of one of them being made translucent by sandpapering. These were put in the sunlight and viewed against the blue sky. The transparent half was darker than the sky, and the translucent half was as bright as, or brighter than, the sky, the brightness depending on the angle of the sun and the angle of view. A photograph is shown in Plate 12, in which a is the two layers of the transparent fabric, Plate 11a, and b is two layers, one being the transparent fabric Plate 11a and the other the translucent fabric Plate 11b.

Plate 12 illustrates the very simple point that the under surfaces are made brighter if some of the sunlight incident on the upper surfaces is allowed to diffuse through. The color of b, Plate 12, was of course wrong, being yellowish against the blue sky. If a transparent dope for the wire mesh could be prepared impregnated with a slightly blue scattering pigment, low sky visibility could be achieved to a much greater extent than can be done with opaque fabrics. Of course, certain portions of the wings and fuselage will always be opaque, but any light which can diffuse through is so much clear gain.

2. Low Visibility by Artificial Illumination - The suggestion has often been made that the darker portions of a plane overhead, such as the under surfaces and the other regions in shadow, be lighted artificially so that they have approximately the brightness of the sky. Calculation (Reference 14, page 61) indicated that to do this would require from 100 to 300 pounds of electric light and power equipment. Besides, there would be difficulties of installation and operation to insure the desired effects. On the whole the suggestion has never seemed to be a very practical one.

CHAPTER VI

RECOMMENDED EXPERIMENTS

1. Material - The first experiments would be planned to demonstrate what colors and patterns are the most effective, and for this purpose it is not necessary to use paints which are somewhat troublesome to get off, as those of the Army Specifications, Appendix C. Ordinary commercial pigments mixed with water with a small amount of water soluble glue, less than 1/10 percent by volume, yield a paint with satisfactory adhesive qualities for dry weather. Tests have shown that it can be readily washed off and that it does not harm the fabric or other surfaces of the plane.

The following quantities are sufficient for water paint for at least 10 planes of the largest size:

Zinc white	200 pounds
Ivory black	80
Ultramarine blue	40
Light red	20
Yellow ochre	20
Purple	20
Fish glue (as LePage's)	20
TOTAL.....	400 pounds

Estimated price, $100 or less.

From these materials paint to match the colors of Plate 1, a, b, and c can readily be mixed. The materials can be obtained from any paint company, as:

The Muralo Company,
Staten Island,
New York.

The Alabastine Company,
Grand Rapids,
Michigan.

The Reardon Company,
2200 North 2nd Street,
St.Louis, Missouri.

For the wetted surfaces, such as the lower portions of pontoons, a mat oil paint is recommended. This would be made from any commercial mat white, with addition of Standard Navy gray and small amount of oil colors. Such paint probably would be available at any Navy depot.

2. Experiments on Day Sky Camouflage - It is recommended that three planes be painted as follows:

1st plane Paint entirely with Standard Navy gray color, as Plate 1c.

2nd plane Paint in accord with the rules of Section 3, Chapter III, i.e., paint all upper surfaces with the dark gray blue, Plate 1a, and all vertical and under surfaces, protuberances, struts, propellers, with the light gray blue, Plate 1b. In the case of a biplane paint the upper surface of the lower wing with the light color.

3rd plane Use the two paints a and b, Plate 1, and paint with the pattern of Plate 5, which is aimed to compensate for shadow effects to some extent.

Observe the three planes, either all three or two at a time, in the air simultaneously many times under various conditions of flight and weather.

The tests will point the way to further tests with such modification of color and pattern as may seem desirable.

It is believed that the best results will be achieved by having a person experiended in color advise during the painting and take part in the observations.

3. Experiments on Night Sky Camouflage - It is recommended that Army experiments,(Appendix B) be repeated. This amounts to painting a plane entirely with mat black and observing at at night under natural illumination and search light illumination. If it could be arranged, it would be best to have a second plane, painted in the present standard color, accompany the black plane, in order that the relative visibilities of the two planes be compared.

4. Experiments on Translucent Fabric - It is recommended that the low visibility possibilities of translucent covering of a plane be borne in mind. With the view that, if transparent or partially transparent fabrics are developed, experiments should be instigated to give them the proper color and translucency for low visibility purposes. It is probable that this suggestion is 10 years in advance of its time.

5. Suggested Experiment with Paint with Concealed Spectral Difference - An experiment may be mentioned which is a little outside of the immediate province of the present camouflage problem. If the camouflage experiments should be carried out at Coco Solo and if Mr. Bittinger should go there to assist in the work, it would seem to be of advantage to carry out the experiment. Especially so, since Mr. Bittinger is familiar with the experiment and since no additional material is required that is not already available in this Laboratory.

The experiment consists in preparing a paint which matches exactly the color of the dark gray blue of Plate 1a and the color of the sea, yet which has in it a certain amount of red. If some upper surfaces of a plane were painted with this color, the plane viewed from above against the sea would be barely visible. On looking through the proper filter the sea would appear dark blue and the plane light red, so that the plane would be much more visible. It would be of interest to do the experiment in order to find out to what extent the visibility of an otherwise invisible plane could be increased by this method.

APPENDIX--A

WAR DEPARTMENT
AIR CORPS
MATERIEL DIVISION
WRIGHT FIELD, DAYTON, OHIO

ENGINEERING SECTION MEMORANDUM REPORT

ON

CAMOUFLAGE WATER PAINT, WITH SERVICE TEST REPORT FROM LANGLEY FIELD, VA.

P. O.—Contract No. ..... Date **Feb. 16, 1933**

Expenditure Order **601-1-97** Serial No. **M-86-2272 Addendum II**

1. Object

To determine from a service test conducted by a tactical unit the suitability of camouflage water paint and instructions contained in Technical Order No. 01-1-16 for preparation and use of this water paint.

2. Conclusions and Recommendations

The system of camouflage described in Technical Order No. 01-1-16 (issued under date of January 23, 1933 as Technical Order No. 07-1-1) can be readily understood and carried out by unskilled personnel.

Water paint is now being procured and will be available from Air Corps stocks for use by tactical units in maneuvers and for special projects.

A shade of red which was requested by Langley Field for ground camouflage in the fall season will be added to the basic colors stocked.

A new project has been opened to determine the colors best suited for various sections of the United States and its foreign possessions for different seasons of the year, and also includes designs for all tactical types of aircraft. The data secured from this investigation will be included in a revised technical order No. 07-1-1 as soon as it has been determined.

The use of a long handled brush is being investigated to apply water paint to aircraft surfaces and it is believed this will eliminate to a great extent the requirements of ladders and scaffolding.

Under the new project mentioned above, additional tests are to be made to improve sky day camouflage and the use of scintillation effect with night camouflage.

Approved: **C. W. HOWARD, Major, Air Corps**
Chief, Engineering Section.

By **G. P. YOUNG, Asso.Aero.Chemist.**
J. B. JOHNSON
Chief, **Material** Branch

Distribution: Mat Br

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No. PAGES
PAGE 1

3. General

The problem of night camouflage divides itself into two aspects somewhat similar to those of day camouflage. One condition is the visibility of the airplane when viewed from above, illuminated by the light of the moon or sky; the other for the visibility of the airplane when in the beam of a powerful searchlight and viewed from the ground. It is the latter case that is the problem for this investigation.

The visibility of any object depends upon three factors, namely, (1) the size of the object or the angle subtended by the object from the point of observation; (2) the brightness of the object or its ability to reflect light from some source of illumination to the eye of the observer; (3) the contrast of the object with the background against which it is viewed.

The size of the object, an airplane in this study, cannot be reduced but the angle can be reduced by increasing the distance from the object to the point of observation. It is desired to have this distance as small as possible and the value of the camouflage is judged by the distance required to cause the airplane to become invisible.

The brightness of the airplane depends upon the relative reflection of the pigments used in the camouflage paint and the intensity of the illumination received from the searchlight at the distance of the object from the light source. In these tests the paint was varied but the same light was used for all flight tests. The amount of illumination received from the light source varies inversely as the square of the distance and directly as the intensity of the source.

The contrast depends upon the color of the paint used in camouflaging, the light illuminating the surface, and the background. Except in one case, that where the sky is clouded or overcast, the background at night is black.

4. Material and Equipment

The paint used for the tests was a material similar to calsomine, colored with inert pigments and mixed with water as a vehicle. This paint is readily mixed from a dry powder and applied either by brush or spray gun. It can be washed from the surfaces at any time with cold water and light rubbing.

The airplane used for the flight tests was an O25-A and the under surfaces of the wings, fuselage and tail group were finished in the water paint.

The searchlight used was a General Electric 36 inch, 150 ampere arc, rated at 300,000,000 beam candle-power.

5. Methods of Test

The first color used was made by adding lamp black to an olive drab, giving a dark gray color. This color and the standard colors, A-N yellow, and A-N olive drab were measured with the Keuffel & Esser Color Analyzer for reflection characteristics, and the results compared with those of black velvet. Black velvet being the blackest material available it was used as a

(1) Parallel to the azmuth observation point - sun towards the sun.
(2) At 45 degrees to the azmuth observation point - sun towards the sun.
(3) At 90 degrees to the azmuth observation point - sun.
(4) At 45 degrees to the azmuth, observation point - sun away from the sun.
(5) Parallel to the azmuth, observation point - sun away from the sun.

Day Camouflage

Visibility Against the Ground

A formation of three airplanes, two finished for day camouflage and one in the standard yellow and olive drab, should be piloted at 1000 feet altitude over a predetermined course and observed from another airplane flying over the same course at gradually increasing altitude, until the camouflaged airplanes are not longer visible. There will be an altitude at which the camouflaged airplanes can only be located by the shadows cast on the ground.

Tests should be made of this type on days of different atmospheric conditions, i.e. clear, no clouds; clouds at high altitude; and scattered clouds.

Change in the design layout may be made for both types of day camouflage in an effort to improve on the designs submitted or originally applied to the airplanes under test. Sketches of the designs used and changes made should be included in the final report. Outlined blueprints are included for these sketches.

Night Camouflage

Night camouflage tests are to determine the effectiveness of the black water paint as a concealment for airplanes when in the beam of a powerful searchlight. The searchlight should be fixed to throw its beam at 45 degrees elevation as at this angle the largest area is visible and illuminated by the light.

This test should be conducted along the same lines as the day camouflage tests, the formation being piloted to fly through the searchlight beam at increasing increments of altitude until ceiling is reached or the planes become invisible. The navigation lights should be turned out just prior to the formation entering the beam at each altitude and left burning at other times so that the ground observer may know their location and when to watch the beam for their passage.

These tests should be conducted on a clear night with no moon; clear night with moon one quarter [illegible] sky is overcast above 10,000 feet.

In order to save time and labor the day camouflage tests should be made first and the black water paint applied directly over the light blue

An advance copy of Technical Order No. 01-1-16 revised to include camouflage design and application of the water paint was forwarded with the above instructions. This Technical Order has since been printed and issued as Technical Order No. 07-1-1. A copy is attached as Appendix I to this report.

The following is a copy of the report submitted by the 2nd Bombardment Group, Langley Field, Virginia.

SERVICE TEST REPORT

Camouflage Water Paint

PREPARATION:

1. "In view of the increased training activities of the Group at this season (autumn) it was not considered practicable to camouflage a number of B-6a airplanes for this test as proposed by the Materiel Division. The period of time that these planes would have to be diverted from normal activities and the labor involved was an important consideration in view of the fact that planes of this type will not participate in the anti-aircraft exercises at Camp Knox, Ky. during May 1938. It was felt that information to be obtained by using one or more YIB-9a airplanes for these tests would be of greater value. This policy necessitated a delay until November when two of these airplanes were assigned to the Group.

After a brief preliminary service test, one of these planes (YIB-9a 31-305) was made available and was painted with top and bottom day camouflage. The instructions contained in T.O. 01-1-16 and accompanying diagrams were followed except for the following changes: Late autumn produces a large proportion of reddish tints in the landscape of Eastern Virginia; as no suitable color was included with the water paint received to duplicate this tint, some "Venetian" or "Brick" red pigment was procured locally and mixed with a small quantity of the O.D. paint to produce a light "reddish - brown" shade. This color was applied to approximately 80 percent of the area indicated for dark green on the diagram furnished by the Materiel Division. In addition, a small quantity of white was mixed with the O.D. provided to produce an "O.D. - buff" approximating the color of the soil of open ploughed fields which prevail in the locality around Langley Field. The underside of wings and fuselage were painted with unadulterated light blue pigment, as furnished, and a scallop effect of purple was added along the leading and trailing edges of the wings and sides of the fuselage as recommended in the directive.

CONDUCT OF THE TESTS:

2. In the case of both day and night tests the plane was flown back and forth along a designated course at increasing altitudes up to the service ceiling, the time of passage over the field being noted by both pilot and observers in order that the altitude could be accurately checked. Observations were made for 4000, 6000, 8000, 10,000 and 12,000 feet and for each 1000 feet thereafter until lost to view.

Observations of the top camouflage were made from another plane while the camouflaged plane was flying at altitudes varying from 1000 to 5000 feet and when parked on the ground. Photographs, a set of which are appended as Exhibit "B", were taken of the camouflaged plane to illustrate the pattern used and the degree to which the plane blends with the prevailing background.

For observation of bottom camouflage the plane was flown alternately toward and away from the sun so that the widest range of background conditions was obtained. The following results are summarized from the notes of the observers who witnessed the various tests:

a. Bottom Camouflage (Day)

Test I

Weather: Cloudless, sky deep blue. Atmosphere: Clear. Time: 2:30-3:30 P.M.

Altitude	4000	ft.	visibility	of	plane	reduced to 75%
	6000	"	"	"	"	" 70%
	8000	"	"	"	"	" 60%
	10000	"	"	"	"	" 50%
	12000	"	"	"	"	" 40%
	13000	"	"	"	"	" 40%
	14000	"	"	"	"	" 40%
	15000	"	"	"	"	" 40%
	16000	"	Observation ceased.			

Remarks:

At altitudes below 12,000 feet the camouflage was effective. As the altitude increased, however, it was noted that the plane appeared to increase in brightness to an extent that balanced the diminished visibility due to the increased perspective. It was evident that a great deal of light was being reflected by the propellers and the side of the fuselage as well as from the wing nearest the sun which, by reason of dihedral, received more direct light.

Test II

Weather: Cloudless, sky deep blue. Atmosphere: Clear. Time: 2:30-3:30 P.M.

This test was conducted in the same fashion as Test I, under exactly similar conditions and without change in the camouflage. YIB-9a #31-304, un-camouflaged, was flown in wide formation with the camouflaged plane. Results obtained were substantially the same as in Test I.

Observers stated that at the higher altitudes the un-camouflaged plane was appreciably harder to pick up than the camouflaged plane. The former appeared to melt from sight about 12,000 feet, while the other shone as bright speck. This observation confirmed the necessity for painting the propellers of the camouflaged plane to reduce reflection and to darken the blue of the under-side of wings and side of fuselage.

Test III

Weather: Overcast, occasional light rain, ceiling about 6000 feet.
Time: 11:30-12:30 P.M.

This test was made to determine the effectiveness of the camouflage against a cloud background. Results were unsatisfactory as the weather became very poor and it was not possible to get above 6000 feet. At that altitude the plane appeared as a dark grey silouette against the light background of clouds and mist. The camouflage was ineffective under these conditions. A plain white, silver, or light-grey camouflage might have reduced the visibility of the plane.

During this flight several heavy showers were flown through. It was found that the water paint was entirely washed off the leading edge of wings, stabiliser and fins, but intact elsewhere though moist. On a latter date this plane was flown for half-an-hour in a down-pour of tropical violence without serious damage to the camouflage except at leading edges, as noted above.

Test IV

Weather: Cloudless, sky deep blue. Atmosphere Clear. Time: 2:30-4:00 P.M.

Altitude	4000	ft.	visibility	of	plane	reduced	to 60%
	6000	ft.	"	"	"	"	" 55%
	8000	"	"	"	"	"	" 50%
	10000	"	"	"	"	"	" 40%
	12000	"	"	"	"	"	" 25%
	13000	"	"	"	"	"	" 10%
	14000	"	"	"	"	"	" 5%
	15000	"	"	"	"		Lost

Remarks:

Prior to this test a quantity of purple and blue pigment was mixed to make a pale "blue-mauve." The underside of wings and fuselage were dappled with this color in irregular patches of 2 to 4 square feet. About 50% of the total area was covered. This work was accomplished by three men, using 4" brushes, in 15 minutes. The propellers were painted with a coating of standard maroon anti-glare paint. The sides of the fuselage were darkened by use of the blue-mauve mixture. This camouflage proved very effective. The plane gradually lost visibility until around 10,000 feet it was very difficult to pick up if the eye was removed. When turning toward the sun it disappeared completely owing to the angle of bank. The plane was finally lost to view about 15,000 feet.

This test established the value of the darker tone. It was decided to further darken the plane by the addition of a larger proportion of purple, particularly the side of the fuselage which appeared to reflect light at the higher altitudes.

[redacted]

Test V

Weather: Cloudless, sky deep blue. Atmosphere clear. Time: 3:00-4:00 P.M.

Remarks:

On this test the un-camouflaged Y1B-9a was flown in company with the camouflaged plane. The latter had been further darkened in tone as described in the preceding "Remarks." The results obtained were much the same as in the previous test and the further darkening did not appear to have resulted in noticeable improvement. It was remarked by several observers, however, that at all times during the test the camouflaged plane appeared to be considerably higher than the other though both were, in fact, at the same altitude at all times.

Both planes were still visible at 16,000 feet due, probably to the fact that they reached that altitude late in the afternoon and the sun was approaching the horizon, giving a greater volume of light to the underside as contrasted to the dark blue of the sky background.

This test concluded the day tests of bottom camouflage.

b. Top Camouflage

During the intervals between the foregoing tests, observations and photographs were made of the top camouflage while the plane was in flight and on the ground. This camouflage appeared to be very effective and it was not considered necessary to make any changes with regard to the colors used or the relative proportion of the area covered. It is evident that for best results the camouflage must be varied with the seasons and the nature of the terrain over which the plane is operated.

c. Bottom Camouflage (Night)

The under surfaces of the camouflaged Y1B-9a were completely finished with black water paint. The propellers had previously been painted front and rear with standard maroon anti-glare paint. An 800,000,000 c.p. 60 inch, glass reflector searchlight, Sperry Arc, 150 amp. from Fort Monroe was used for illumination. The searchlight beam was set at 45° elevation, 270° azimuth, in fixed position. No attempt was made to follow the airplane in flight, the pilot being instructed to fly through the beam. He was further instructed to keep running light burning until just before entering beam.

Test I

Weather: Cloudy 9/10 thin alto-stratus at approximately 12,000 feet. A moon 5/8 full was visible through the clouds, having about 50% penetration. Time: 6:15-7:00 P.M.

The plane was observed from 4000 feet to 9000 feet. It was visible at all altitudes up to 7000 feet as a grey object in the beam. At 8000 and 9000 it was doubtful whether or not the plane itself was visible. The shadow

projected by the plane against the white ceiling of cloud illuminated by the searchlight appeared, however, as a black image. The test was curtailed by light rain which commenced to fall after the plane had reached 9000 feet. The conditions were unusually difficult from point of view of concealment and it is doubtful if any system of camouflage would have been effected.

Test II

Weather: Cloudless. Atmosphere clear. No moon. The same searchlight was used for this test as before. However, instead of using a fixed beam the plane was followed as closely as possible by normal control of the light. As in the previous test the plane was visible in the beam at all observed altitudes, appearing as an indistinct brown-grey shape of extremely low visibility. The searchlight operators had the greatest difficult in keeping the beam on the plane and it was necessary for the pilot to make repeated use of his running lights to indicate his position.

The test demonstrated that it will be necessary to use several searchlights to keep a plane constantly illuminated for it appears almost impossible for the crew operating one light to follow the very indistinct object afforded by the plane.

CONCLUSIONS:

a. That the system of camouflage described in T.O. 01-1-16 is very effective for top camouflage if applied with an understanding of the problem involved.

b. That the bottom camouflage for day use described in Test IV is effective, reducing the general visibility of the plane about 50% and creating the illusion that the plane is 500-1000 feet higher than is actually the case.

c. That a mottled pattern is more effective than uniform color.

d. That further experimentation should be carried on with the object of arriving at the color which is most effective against a varied sky background of different shades of blue and with different proportions of cloud.

e. That the dull black finish for night camouflage makes it extremely difficult for searchlight crew to catch and hold a plane in the beam and that more than one searchlight will have to be used to keep a plane constantly illuminated; that a cloud background against which the plane is silhouetted by the light makes it much easier to follow a plane, though the plane and its shadow may be confused to an extent that make it difficult to determine its correct altitude.

f. That the water paint is satisfactory for temporary camouflage use and lends itself to variations which can be rapidly and easily applied by anyone who understands the basic principles of the art; that the latter can be published in the form of T.O.'s which can be readily understood by unskilled personnel.

DISCUSSION:

Bombardment Aviation is interested in the reduction of visibility through camouflage as follows:

a. From above. For concealment when parked on the ground and when in flight at low altitudes.

b. From below. For reduced visibility against the background of the sky by day.

c. From below. For reduced reflection of the light of searchlight beams at night.

Concealment when parked on the ground is most important to prevent discovery and destruction by attack of hostile aircraft. Much can be accomplished by scattering aircraft in irregular fashion and by making use of mottling, tree branches, etc. it is also practicable, on occasion, to place aircraft in the shade of trees. A system of top camouflage suitable to the terrain will contribute more than any other item to effective concealment. A suitable system appears to have been achieved in T.O. 01-1-18 which can be applied by following simple principles readily understood by anyone. It appears desirable that a table be established to show the variations in camouflage for various sections of the U.S. at different seasons of the year. It would then appear desirable to standardize a neutral color such as dull or matt O.D. with which the upper surface of all aircraft should be painted in time of war. This solid color would then be broken by the application of water paint in accordance with the instructions contained in T.O. 01-1-18 as amplified by the above mentioned table.

The determination of a satisfactory system of day camouflage against ground observation involves a much greater problem in view of the fact that the heavens are the source of light whereas the plane is opaque object. Moreover an extremely wide range of sky backgrounds from white clouds to deep blue are encountered and a system suitable to the former would enhance rather than detract from visibility when viewed against the latter. Thus; if the plane is painted a light color which will blend with the cloud background, it will reflect light which will make it increasingly visible against the clear blue sky. The solution would appear to be a color and pattern of painting which will include both light and dark shades in equal proportions. The visibility of the plane should by this means be reduced by at least 50%.

The tests recently conducted appear to indicate that a dappled pattern of two shades is more effective than the two shades mixed to form a single color. It is believed that this should be further investigated and it is suggested that in the event a decision is arrived at as to which color is generally most effective, that this color be broken into its components of blue, red, green, etc. and that these colors be applied, pure, in a large checker pattern to areas proportionate to the percentage of these colors present in the basic shade. While at high altitude these colors will appear to blend to form the basic color, each one has a distinct wave length which may produce a "scintillation" more confusing to the eye of the observer than that produced by the component colors when blended and applied as a solid color.

Night camouflage appears to have been established by the use of the dull matt dead black which reduces a reflection to a minimum. Further improvement might be made by analyzing the light of the searchlight beam to determine its prevailing shade (which to the eye appears to be a greenish-blue). When this has been determined a test might be made mixing with the black a proportion of the complimentary color (red) which might tend to neutralise the reflection of blue from the plane and render its appearance more confusing if not actually less visible.

The service test of water paint demonstrated that this material can be quickly and easily applied and is sufficiently durable for practicable purposes.

RECOMMENDATIONS:

1. That water paint be furnished to tactical units for use in connection with Air Corps maneuvers and special projects.

2. That a shade of brick red be added to the colors provided for the service test.

3. That T.O. 01-1-16 be revised to include a table showing the colors best suited to the terrain of the various sections of the U. S. and its foreign possessions, for the various seasons of the year.

4. That long handled (about 3' 6") brushes such as are used by paper hangers be furnished for applying the water paint in the field.

5. That experimentation be continued at Wright Field to determine the most satisfactory shade of blue (blue-mauve), (blue-green, etc.) which will provide best concealment under average conditions of sky background.

6. That the value of "scintillation" effect suggested under "Discussion" be investigated.

7. That water paint similar to that provided for these service tests be provided for day and night bottom camouflage for the Camp Knox anti-aircraft exercises and that for daylight use a dappled camouflage similar to that developed in Test IV be utilized.

8. That for this and similar projects and individual familiar with the principles and problems involved be available to supervise the application of the camouflage and that he be provided the necessary assistance to effect changes as may appear desirable in accordance with weather forecasts, etc.

(Signed)
P. MELVILLE,
Captain, A. C.,
2nd Bomb. Gp. Eng. Off.

Incls:
Appendix A (Questionnaire)
Appendix B (Photographs)

QUESTIONNAIRE

PREPARATION OF WATER PAINT AND ITS APPLICATION

1. Was any difficulty experienced in mixing the dry water paint with water to a satisfactory consistency?

   No.

2. Was any difficulty experienced with the application by brush?

   No.

3. Give estimated amounts of dry water color required for finishing one LB-6 airplane for complete day camouflage.

   Weight in Pounds - Light Blue
   " " " - Dark Green
   " " " - Purple
   " " " - Olive Drab

   No LB-6a airplanes were camouflaged for reasons stated in the body of the report. One YlB-9a was camouflaged using approximately the following:

30	Pounds	Light Blue
7½	"	Dark Green
10	"	Purple
10	"	O.D.
1	"	White
½	"	Brick Red

4. Give the number of man hours required to actually apply the finish for day camouflage.

   Approximately 16 man hours.

5. Was it applied by brush or spray gun?

   Started with small spray gun. Finished with 4" brushes. Brush is much faster and does not require such careful mixing of paint to make it flow.

6. Give the number of man hours required to finish for night camouflage.

   Approximately 10 man hours.

7. Was it applied by brush or spray gun?

   By brush.

[redacted]

M-36-2272, Add. II
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RESULTS OF OBSERVATION

Day Sky Camouflage

1. What was found to be the effective altitude for day sky camouflage?

   As camouflaged for Test IV the plane disappeared from view of the naked eye at 12,000 feet.

2. What effect did the direction of approach have upon the effective altitude?

   The plane was most visible against the deep blue of the sky in the quarter away from the sun. It appeared as a bright speck because of reflected light. It is believed that the most effective system of camouflage will be that which reduces visibility in that quarter of the sky.

3. Did the results of these tests indicate that sky camouflage would be an aid in carrying out a day bombardment mission?

   Yes. Will make the plane very difficult to pick up and keep under observation. It further makes plane appear higher than it actually is.

4. State any comments or criticism you may have formed relative to the application and use of this scheme of camouflage.

   See remarks under "Discussion" in body of report.

Day Ground Camouflage

1. What was found to be the effective altitude for ground camouflage? This altitude should be expressed as the difference between the altitude of the camouflaged ship and the observation ship.

   This is not a good question as it is not so much a matter of decreasing visibility with altitude, as it is of concealment by blending with the prevailing background. If located the plane could be observed at altitudes up to 8,000 feet or more. However, it was extremely difficult to locate and keep it under observation due to the manner in which it tended to blend with the prevailing background. The scheme of camouflage used was very effective in this regard.

2. Give statement as to the relative visibility of the camouflaged airplane and the airplane with standard finish when viewed from above while the airplanes are at rest on the flying line.

   The camouflaged plane was relatively 50% less visible than the plane with standard finish at 5,000 feet.

[redacted]

Night Camouflage

1. What was the effective range for night camouflage? Altitude of the ship times 1.4 gives range or distance from light source when the searchlight beam is elevated 45 degrees.

   Approximately 16,000 feet.

2. What effect did moonlight have as compared to dark night?

   Special conditions existed (high layer of clouds) which prevented observation under the moonlight condition referred to. However, if the plane is flying in the vicinity of the moon it is believed that the greater luminosity in the sky which makes it appear blue-grey will favor the camouflage which in the searchlight beam appeared to give a mouse color.

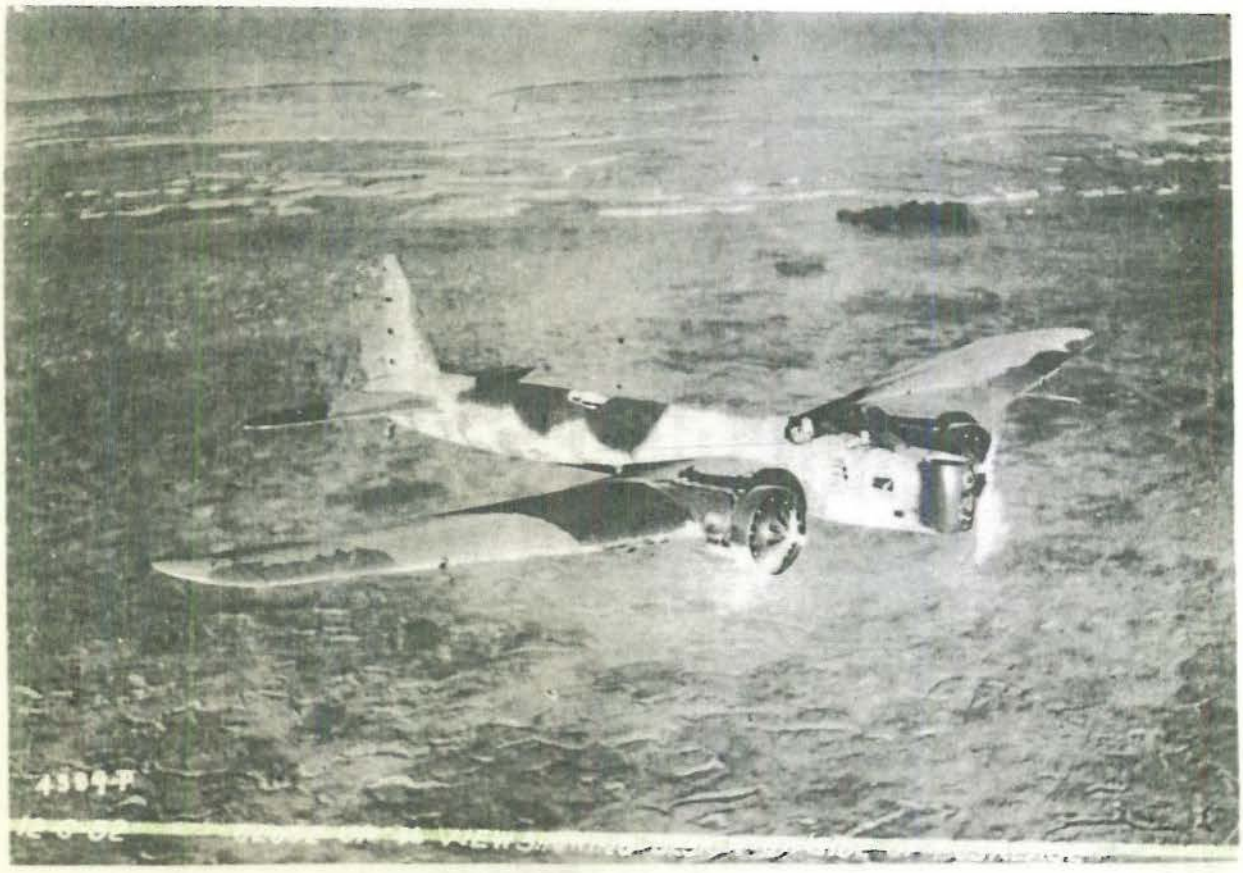
3. If different weather conditions gave different results, state results for each and the corresponding weather conditions.

   See "Conduct of the Tests" in the body of the report.

4. Give the number of man hours required to wash the water paint from one LB-6 airplane.

   With the aid of a Jenny cleaner it took three men one day to clean the plane of all water paint.

P. MELVILLE,
Captain, Air Corps,
2nd Bomb. Gp. Eng. Off.



SECTION II

AIRPLANE CAMOUFLAGE

4. **General.**—Camouflage, as applied to airplanes, is divided into the following classes:

(1) Sky camouflage—day.
(2) Sky camouflage—night.
(3) Ground camouflage.

5. **Sky Camouflage.**—*a. Sky Camouflage—Day.*—The bottom surfaces of the wings, empennage, and fuselage will be colored light blue, mottled with irregular patches of purple as shown in Fig. 1. If the fuselage section is oval or round, the purple mottling will also extend upward on the lower portion of the sides, with the upper portion of the sides colored for ground camouflage (see par. 6). Fuselages with square or rectangular cross-sections will have the entire surfaces of the sides finished for ground camouflage. The purple patches on the bottom of the wings will consist of from one to two-foot widths along the leading and trailing edges, with a like amount of the light blue spaced between, the purple to extend from one to three feet into the surface area. The bottom of the fuselage and tail surfaces will likewise be mottled although it may be necessary to vary the size and spacing of the purple so as to be proportional to the sizes of the surfaces being mottled. Obviously, there are parts of the surface of an airplane in flight that may be viewed from either the ground or the air; and with such marked differences between the two backgrounds, it is difficult to camouflage the same surface in a manner that will be equally effective from both points of observation. However, the main objective is to accomplish this insofar as possible, and to reduce to a minimum the visibility of the major portion of the airplane as viewed from either point of observation. Day sky-camouflage produces the illusion that the airplane is at a much higher altitude than that at which it is being flown. At altitudes above 10,000 feet, the airplane normally becomes invisible, or very difficult to locate, when viewed from on or near the ground.

b. Sky Camouflage—Night.—All portions of an airplane that are visible from beneath while in flight, will be painted black. This will also include the surfaces of the rudder and vertical stabilizer.

6. **Ground Camouflage.**—Ground camouflage is the term applied to the use of coloring to reduce the visibility of an airplane when viewed with the landscape as a background. This applies to airplanes either in flight or at rest on the ground. The following instructions for ground-camouflage coloring are for the purpose of furnishing tentative data, based on tests completed to date, to be used as required during forth-

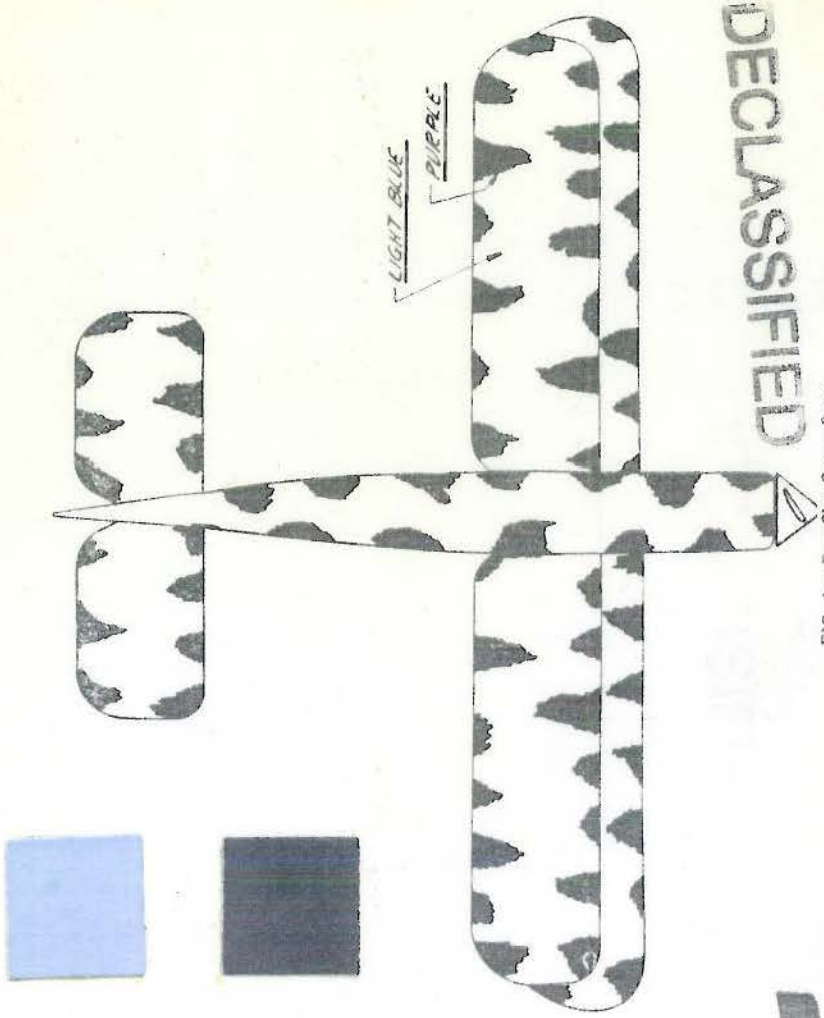


FIG. 1.—Day-Sky Camouflage.

APPENDIX--B

WAR DEPARTMENT

AIR CORPS

MATERIEL DIVISION

WRIGHT FIELD, DAYTON, OHIO

ENGINEERING SECTION MEMORANDUM REPORT

ON

SOME OBSERVATIONS AND TESTS MADE TO DEVELOP A SUITABLE WATER PROOF PAINT FOR NIGHT CAMOUFLAGE.

P. O.—Contract No. ..... Date June 21, 1932

Expenditure Order 601-1-97 Serial No. M-56-2291

1. Object

To prepare a water paint suitable for night camouflage.

An intense black water paint having a relative reflection of three and one-half percent was found to give a dull matt finish that was capable of rendering an observation airplane invisible while in the beam of a 36 inch, 150 ampere arc searchlight at a range of about 3800 yards.

When the sky is overcast the airplane may be located if it passes between the observer and the illuminated area on the clouds produced by the searchlight beam.

When the sky is overcast the airplane may be located if it passes through the beam by the shadow cast on the illuminated area of the clouds, even though the color of the airplane is such as to render it invisible in the beam by direct illumination.

Approved:

C. W. HOWARD, Major, Air Corps.
Chief, Engineering Section.

By O. P. YOUNG, Asso. Aero. Chemist.

J. B. JOHNSON
Chief, Material Branch

Distribution:

mch

[redacted]

3. General

The problem of night camouflage divides itself into two aspects somewhat similar to those of day camouflage. One condition is the visibility of the airplane when viewed from above, illuminated by the light of the moon or sky; the other for the visibility of the airplane when in the beam of a powerful searchlight and viewed from the ground. It is the latter case that is the problem for this investigation.

The visibility of any object depends upon three factors, namely, (1) the size of the object or the angle subtended by the object from the point of observation; (2) the brightness of the object or its ability to reflect light from some source of illumination to the eye of the observer; (3) the contrast of the object with the background against which it is viewed.

The size of the object, an airplane in this study, cannot be reduced but the angle can be reduced by increasing the distance from the object to the point of observation. It is desired to have this distance as small as possible and the value of the camouflage is judged by the distance required to cause the airplane to become invisible.

The brightness of the airplane depends upon the relative reflection of the pigments used in the camouflage paint and the intensity of the illumination received from the searchlight at the distance of the object from the light source. In these tests the paint was varied but the same light was used for all flight tests. The amount of illumination received from the light source varies inversely as the square of the distance and directly as the intensity of the source.

The contrast depends upon the color of the paint used in camouflaging, the light illuminating the surface, and the background. Except in one case, that where the sky is clouded or overcast, the background at night is black.

4. Material and Equipment

The paint used for the tests was a material similar to calsomine, colored with inert pigments and mixed with water as a vehicle. This paint is readily mixed from a dry powder and applied either by brush or spray gun. It can be washed from the surfaces at any time with cold water and light rubbing.

The airplane used for the flight tests was an O25-A and the under surfaces of the wings, fuselage and tail group were finished in the water paint.

The searchlight used was a General Electric 36 inch, 150 ampere arc, rated at 300,000,000 beam candle-power.

5. Methods of Test

The first color used was made by adding lamp black to an olive drab, giving a dark gray color. This color and the standard colors, A-N yellow, and A-N olive drab were measured with the Keuffel & Esser Color Analyzer for reflection characteristics, and the results compared with those of black velvet. Black velvet being the blackest material available it was used as a

standard with which to compare the other colors.

Plate I shows the reflection characteristics of these colors plotted on an equal division scale.

Plate II shows the reflection characteristics of these colors plotted on logarithmic scale.

Plate III shows the arbitrary sensation units of these colors plotted on equal division scale.

The flight tests were all made with the beam of the searchlight elevated to between 48 and 50 degrees. At this elevation the biplane type of airplane shows the largest amount of surface to an observer on the ground observing the plane in the searchlight beam.

Plate IV shows the relation of surface visible to angle of elevation or aspect.

Flight tests were made on nights of different atmospheric conditions. The searchlight was set in a fixed position elevation, 50 degrees, azmuth 270 degrees. The airplane finished with dark gray water paint was piloted to pass through the beam at altitudes of 4,000, 6,000, 8,000 and 10,000 feet, while on the assent, and at each 1,000 foot level on the descent.

This first flight was made on the evening of February 18, 1932. The time of the flight was from 7:35 to 8:10 P.M. The weather was clear with the moon about 3/4 full. The airplane passing through the beam was in good visibility at 4,000 feet; fair visibility at 6,000 feet; slight visible at 8,000 feet, and doubtful visibility at 10,000 feet. There was no visibility at the edge of the beam and no silhouette against the beam.

The second flight test was made on the evening of March 1, 1932. The time of the flight was from 7:30 to 8:15. The weather on this evening was slight ground haze with overcast sky and clouds at about 8,500 feet. There was no moon.

There were several interesting features noticeable on this occasion. This test was made under the conditions mentioned above as a special case, the background being white or light in color. Two conditions of visibility were noted on this time not present under other conditions, namely:

(1) When the sky was clouded or overcast the beam of the searchlight produced a large round light spot on the clouds. This spot acts as a white background and the airplane was distinctly visible, silhouetted against this light spot whenever it passed between the observer and the illuminated sky. The airplane did not have to pass through the beam to be located under these conditions.

(2) When the airplane passed through the beam it was visible as an illuminated object and also cast a shadow on the light spot or illuminated area of the sky.

Under these conditions even though the airplane were so camouflaged as to be invisible in the direct beam of the searchlight still it could be

located by the silhouette against the lighted clouds as an opaque object or by the shadow cast on the illuminated background.

As the color used for these two tests was only a dark gray, steps were taken to secure a more intense black and the next test was made using the intense black shown on the Plates I, II and III, Curve No. 2

The third flight test was made on the evening of May 2, 1932. The weather conditions for this test were clear sky, unlimited ceiling and no moon. The flight lasted from 8:30 to 10:15 P.M. The airplane was piloted to pass through the searchlight beam starting at 6,000 feet and at each 1,000 foot increased altitude up to 17,000 feet. On the descent the airplane passed through the beam at each 1,000 foot level.

The navigation lights were turned off just before the airplane entered the beam in each case and left on during the other period. This enabled the observers to follow the airplane at all times and to know when to watch the beam for the passage of the airplane.

Plate V shows two pictures made to represent the visibility of an airplane in the beam of a powerful searchlight and the contrast difference between the two views represents a distance of one and two. As the distance increases the size decreases in a direct relation and the illumination in an inverse square relation. Even though the beam looks light against the black sky still it is itself very dark in intensity. On a clear night stars of the second magnitude are easily seen through the beam.

6. Results

Flight Test No. 1.- Clear weather with moon 3/4 full, ceiling unlimited, finish used, a dark gray.

Visibility at	4,000 feet	-	Good, clear and distinct.
"	6,000 "	-	Fair, plainly visible.
"	8,000 "	-	Low but distinguishable.
"	10,000 "	-	Uncertain, existance doubtful.

Flight Test No. 2.- Cloudy and overcast ceiling 8,500 feet, finish used, a dark gray. Airplane visible at all altitudes in the searchlight beam. Airplane visible as silhouette against the illuminated clouds whenever it passed between the observer and the illuminated area. Airplane visible and located by the shadow cast on the clouds whenever it passed through the searchlight beam.

Flight Test No. 3.- Clear, unlimited ceiling, no moon, finish, intense black. No visibility at 8,000 feet or higher when the airplane passed through the searchlight beam. Slight visibility at 7,000 feet on the descent and at each lower altitude.

7. Discussion of Results

It was shown that the visibility decreased as the color approached black. The finish in intense black gave a relative reflection value of 3-1/2 percent and the dark gray gave a reflection value of 6.0 percent. When compared with the reflection value of black velvet the blackest material readily obtainable, and which has a reflection value of 1.0 percent, it can be seen that the intense black used very nearly approached the limit.

The elevation of 45 to 50 degrees and an altitude of 8,000 feet gives a range of visibility for an observation airplane in the light of a 300,000,000 beam candle power searchlight of about 3800 yards.

Description of Sample: REFLECTION CHARACTERISTICS OF CAMOUFLAGE FINISHES

Test No. M 2291 [redacted]

Date 2-20-32

Observer G. P. Y. - W. R. K.

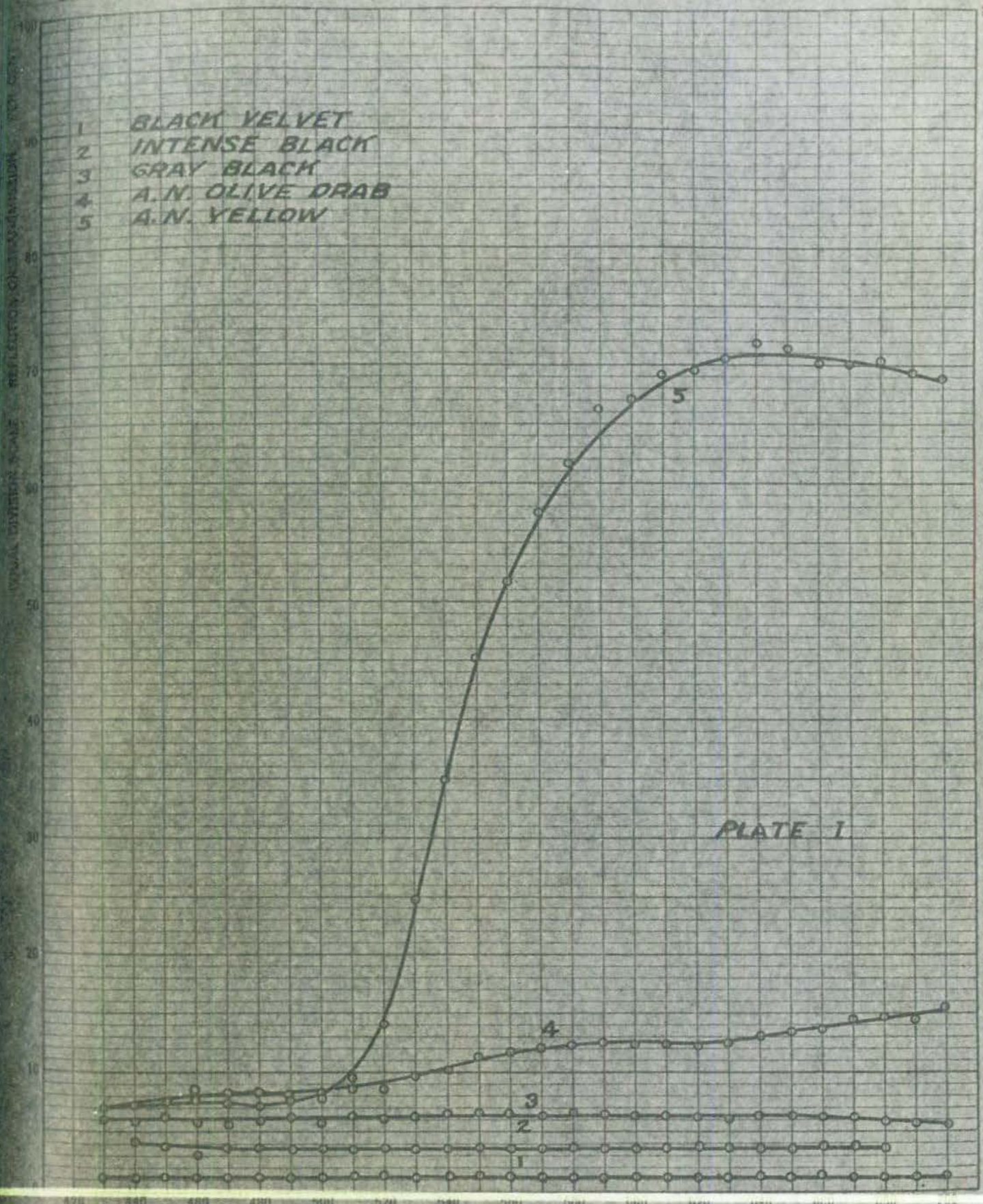


PLATE 1

Description of Sample
REFLECTION CHARACTERISTICS OF CAMOUFLAGE FINISHES

Test No. M2291 [redacted]
Date 2-20-32
Observer G.P.Y. - W.R.K.

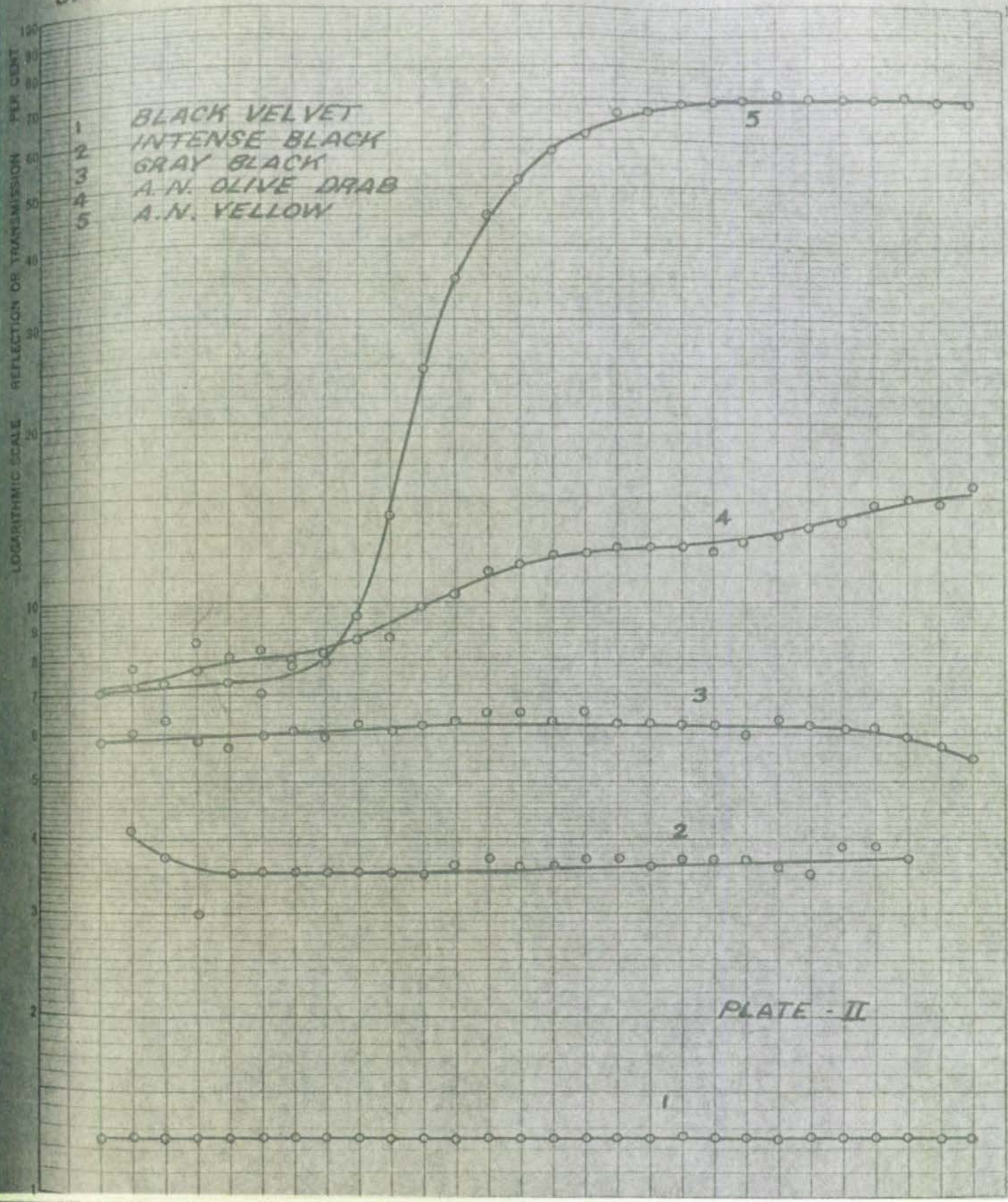
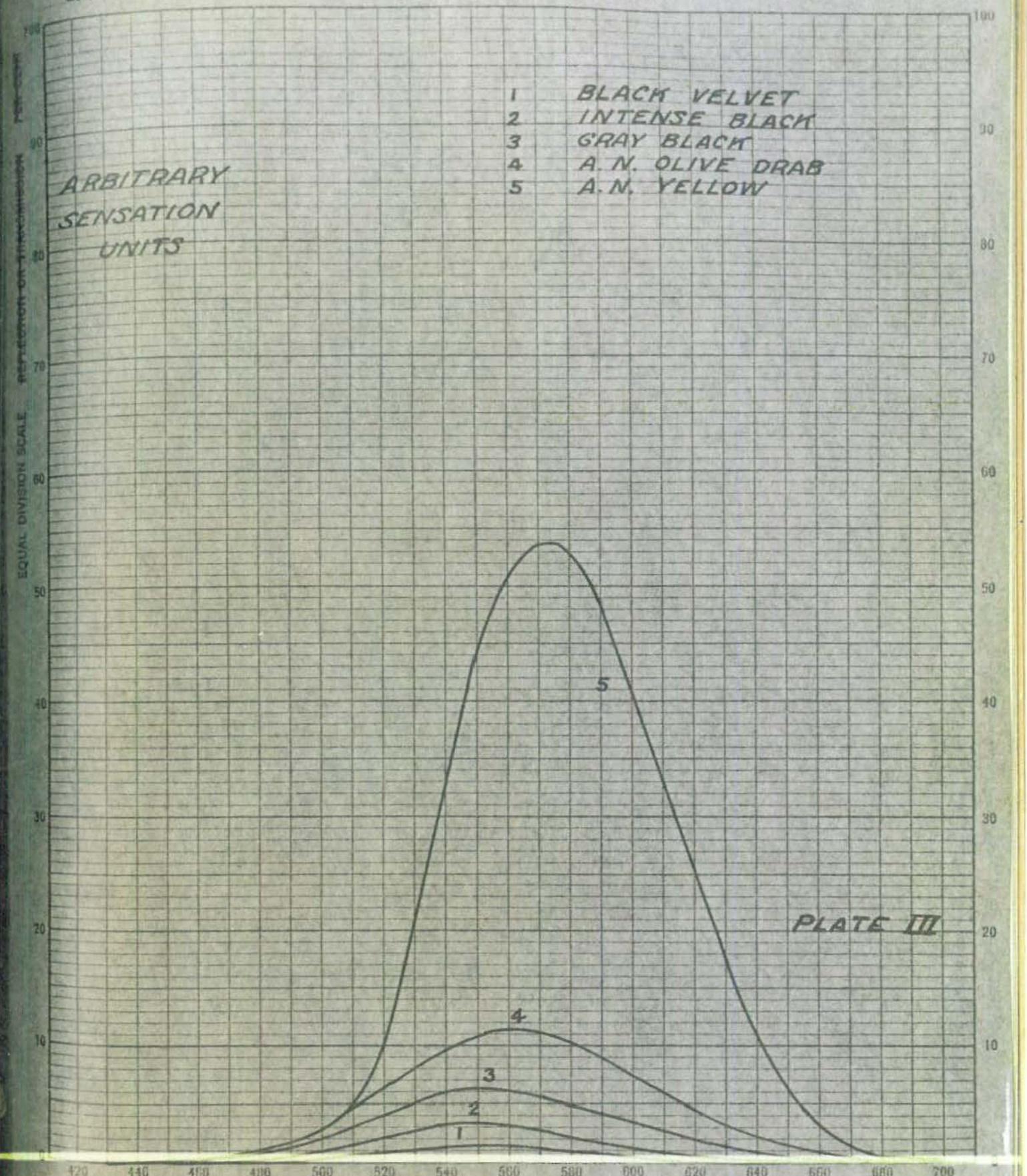


PLATE - II

WAVE LENGTH IN MILLIMICRONS

Description of Sample
RELATIVE LUMINOSITY OF CAMOUFLAGE FINISHES

Test No. M 2291 [redacted]
Date 3-15-32
Observer W. R. K.



KEUFFEL & ESSER CO. N. Y. NO. N 355-10R

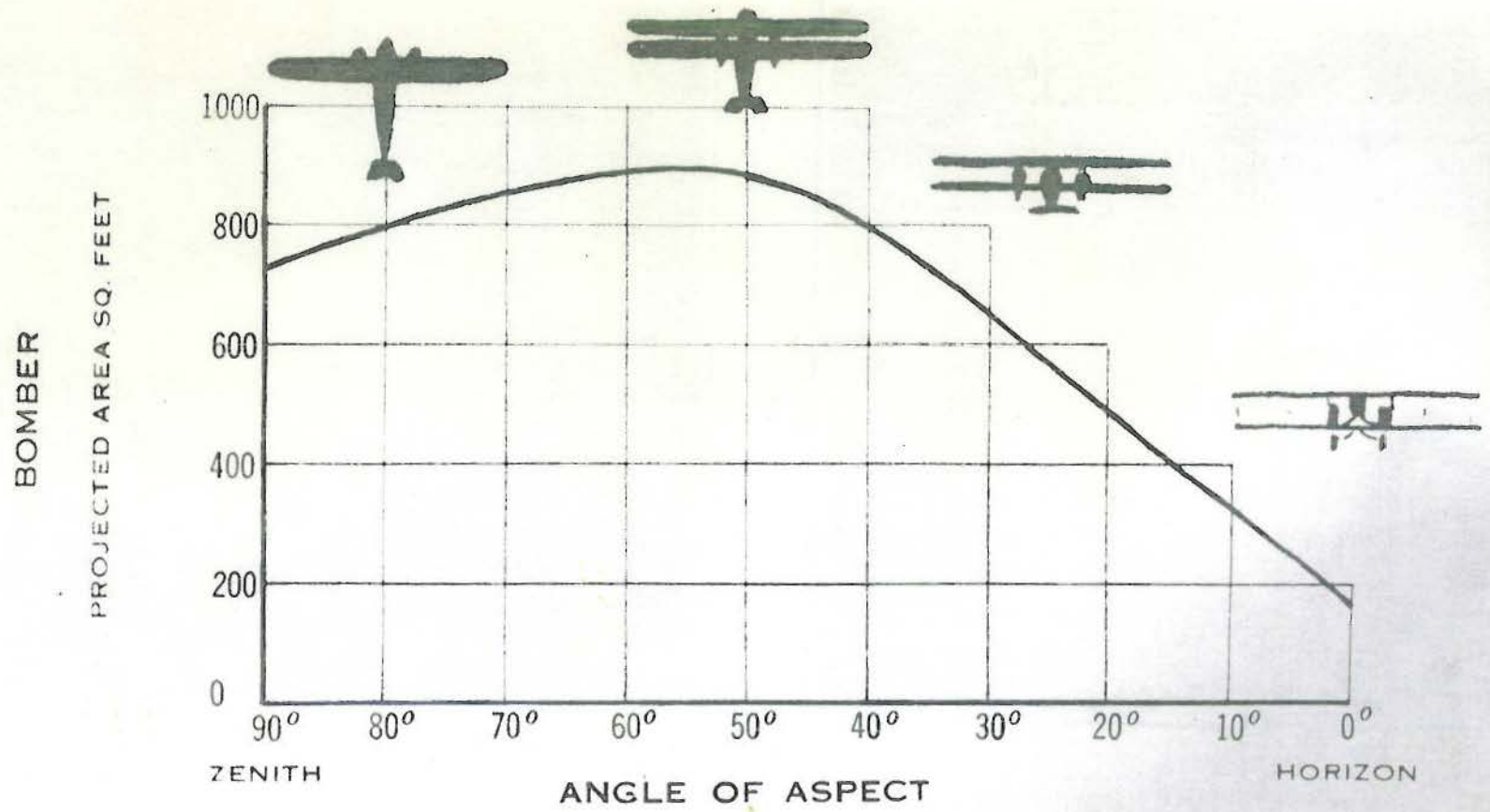
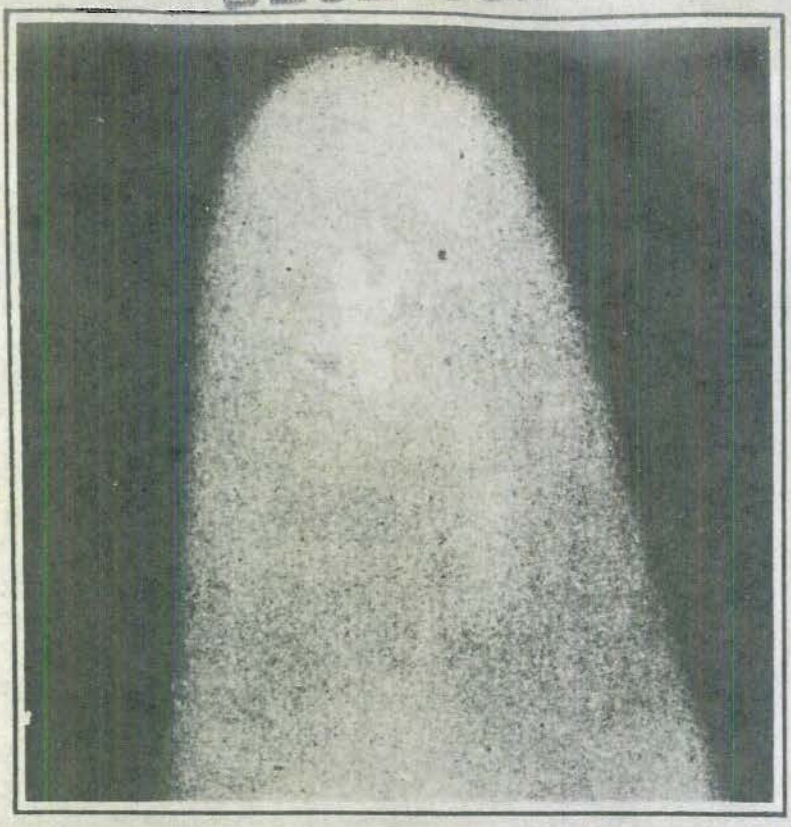


PLATE IV



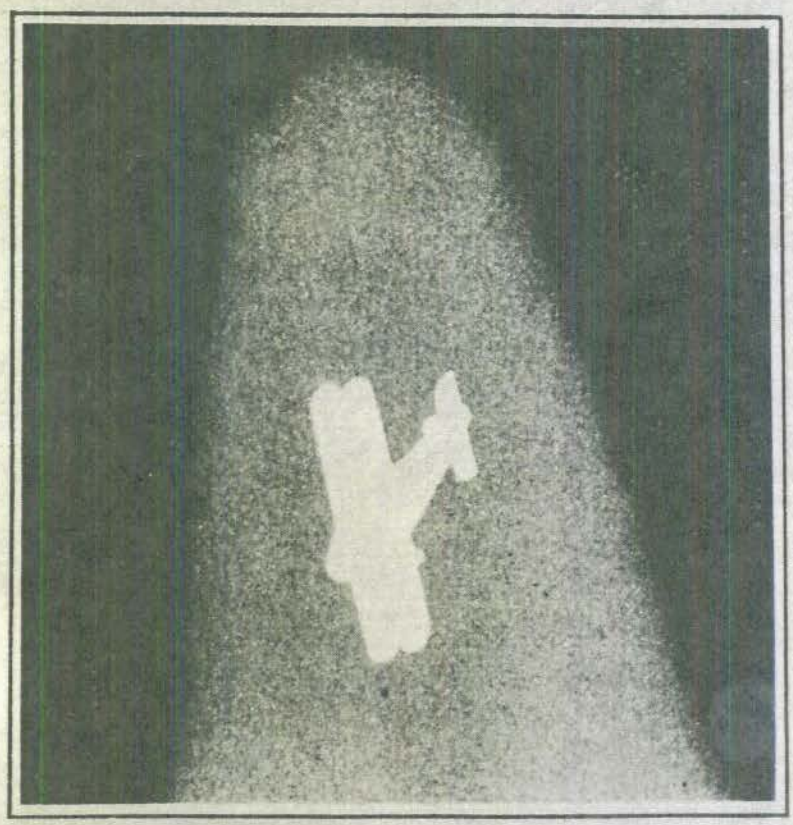


PLATE V

APPENDIX--C

U. S. ARMY
SPECIFICATION

No. 14037
April 8, 1931

WATER COLOR

I. GENERAL SPECIFICATIONS

1. The current issues of the following specifications in effect on date of issuance of proposals form part of this specification:

3-1 Sup. - Color Card
23-54 - Boxes and Crates for Shipment
100-2 - Standard Specifications for Marking Shipments.

II. GRADE

1. This specification covers one grade only, of water color for use in finishing dope fabric surfaces of aircraft.

III. MATERIAL AND WORKMANSHIP

1. The water color shall be a dry mixture of pigments and adhesive, free from lumps and extraneous material.

IV. GENERAL REQUIREMENTS

1. There are no general requirements applicable to this specification.

V. DETAIL REQUIREMENTS

1. Shade.- The shade shall be as specified in the purchase order or contract and shall conform to the shades specified in the color card, Supplement to 3-1.

2. Fineness.- The dry mixture shall all pass through a 100-mesh sieve and at least 80 per cent through a 200- mesh sieve.

3. Water Soluble Material.- The pigments shall be insoluble in water. The filtrate from a water mixture shall contain only such soluble adhesive as may be present.

4. Adhesion.- The dry paint shall not brush off when applied to a clean, smooth, doped fabric surface, but shall be capable of being washed from the surface using cold water and light rubbing.

VI. METHOD OF INSPECTION AND TESTS

1. The water color shall be subject to inspection by authorized Government Inspectors who shall be given all necessary facilities to determine compliance with these specifications.

2. Acceptance or approval of material in course of manufacture shall in no case be construed as a guarantee of the acceptance of the finished product.

3. Water soluble material shall be determined by mixing 10-grams of the dry powder in 100 cc. distilled water. The filtrate from this mixture shall be clear and only a slight amber color. The presence of a water soluble dye will be cause for rejection.

VII. PACKING AND MARKING

1. This material shall be furnished in strong, cardboard cartons containing ten pounds of the materials

2. Domestic Shipment.- The cartons shall be packed in strong boxes which will insure arrival at destination in an undamaged condition.

3. Overseas Shipment.- Material shall be packed in water- proof, paper-lined wooden boxes in accordance with Specification No. 83-54.

4. Shipments shall be marked in accordance with Specification No. 100-E.

VIII. NOTES:

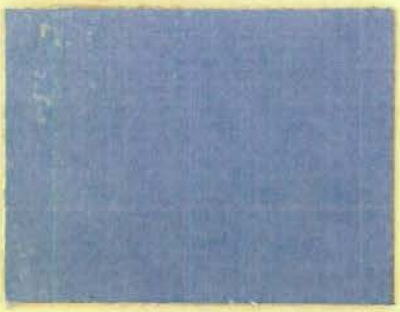
1. Water colors are intended for use as a temporary finish for decreasing the visibility of aircraft.

2. NOTICE: When drawings, specifications, or other data belonging to the War Department or the military establishment are furnished to manufacturers, or others, for any purpose, the United States thereby incurs no responsibility nor any obligation whatsoever, and the furnishing of the said drawings, specifications, or other data by the Government, is not to be regarded, by implication or otherwise, as in any manner licensing the holder or any other person or corporation or conveying any rights or permission to manufacture, use or sell any patented invention that may in any way be related thereto.

3. The use of this specification for the material covered herein is made mandatory on all procuring agencies of the Army.

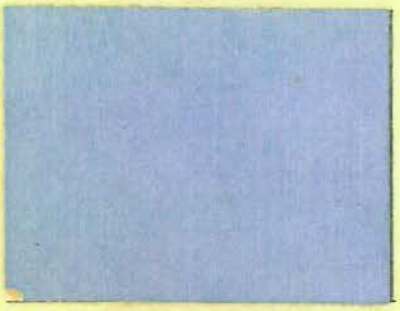
(Copies of this specification may be obtained from the Chief, Materiel Division, Air Corps, Wright Field, Dayton, Ohio).

HB/



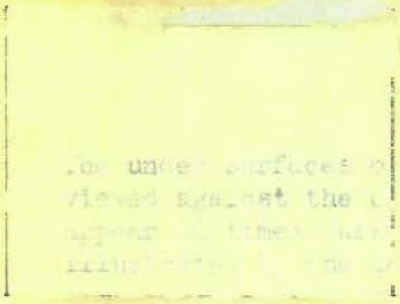
a

Dark gray blue for horizontal upper surfaces.
r = 0.20
Munsell PB 5/4



b

Light gray blue for underneath horizontal surfaces.
r = 0.40
Munsell PB 7/4



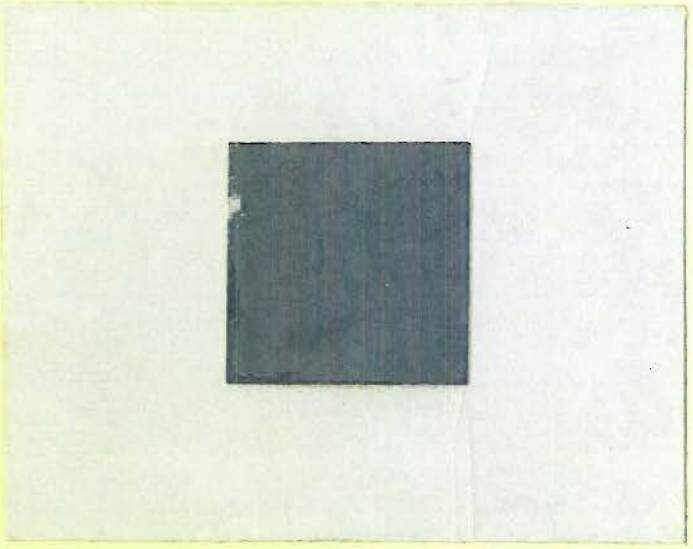
c

Battleship gray.
r = 0.40
Munsell PB 7/2

d

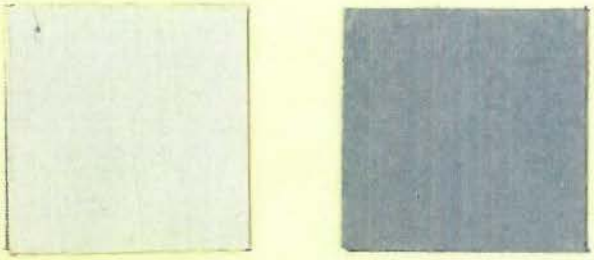
Army color for underneath horizontal surfaces.
r = 0.40
Munsell B 7/4

PLATE 1



The under surfaces of a plane painted pure white viewed against the clouds on a cloudy day will appear 10 times darker than the clouds. This is illustrated by the dark gray square which is 10 times darker than the large light gray square. For the two squares r is 0.06 and 0.60, respectively, and the Munsell values are N3 and N8.

PLATE 2

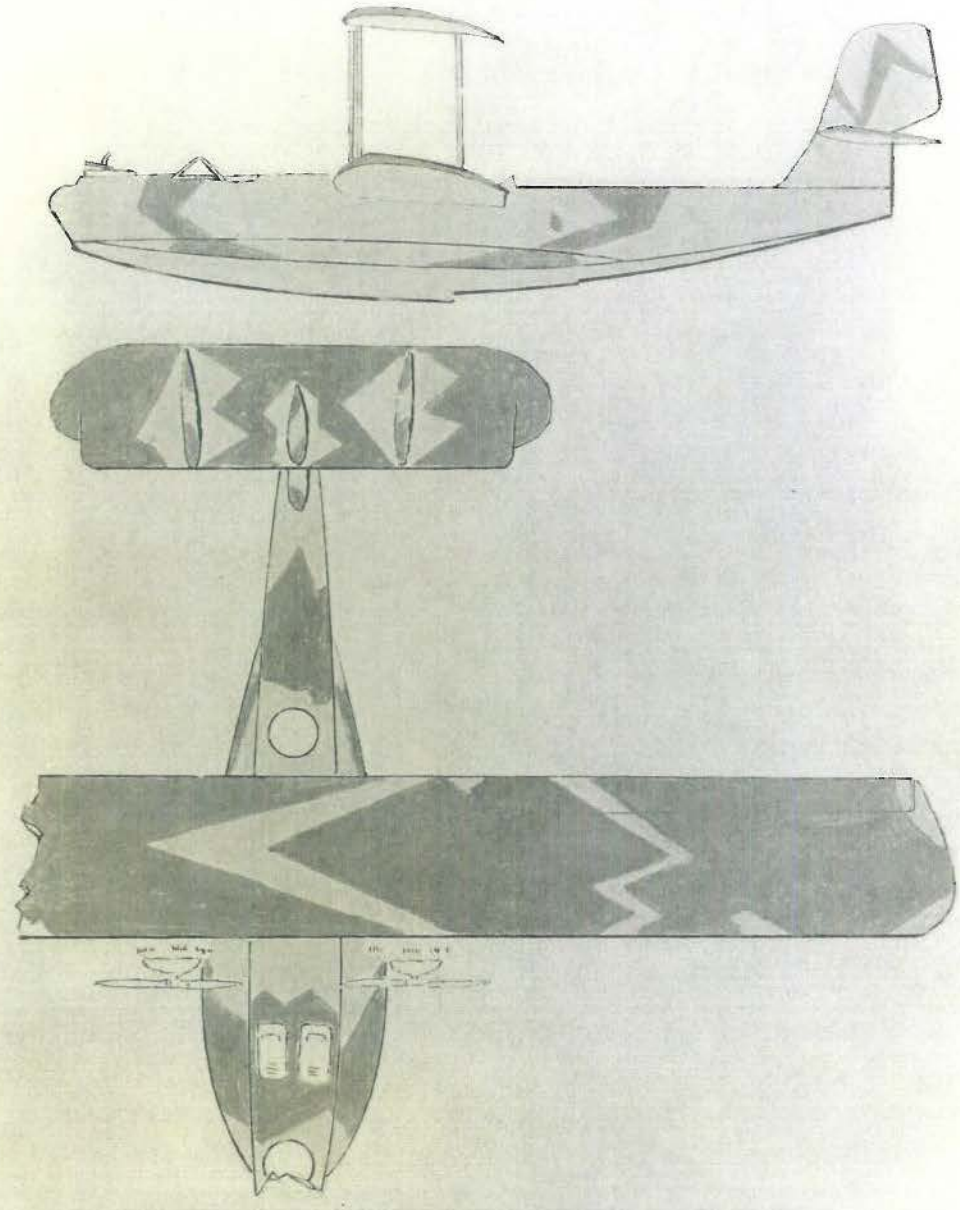


In sunny weather a surface in the sunshine is 4 to 5 times as bright as in the shadow. This is illustrated by the two squares, the light one being about 4 times as bright as the dark one. For the squares r is 0.60 and 0.17 and the Munsell values are about N3 and N5, respectively.

PLATE 3

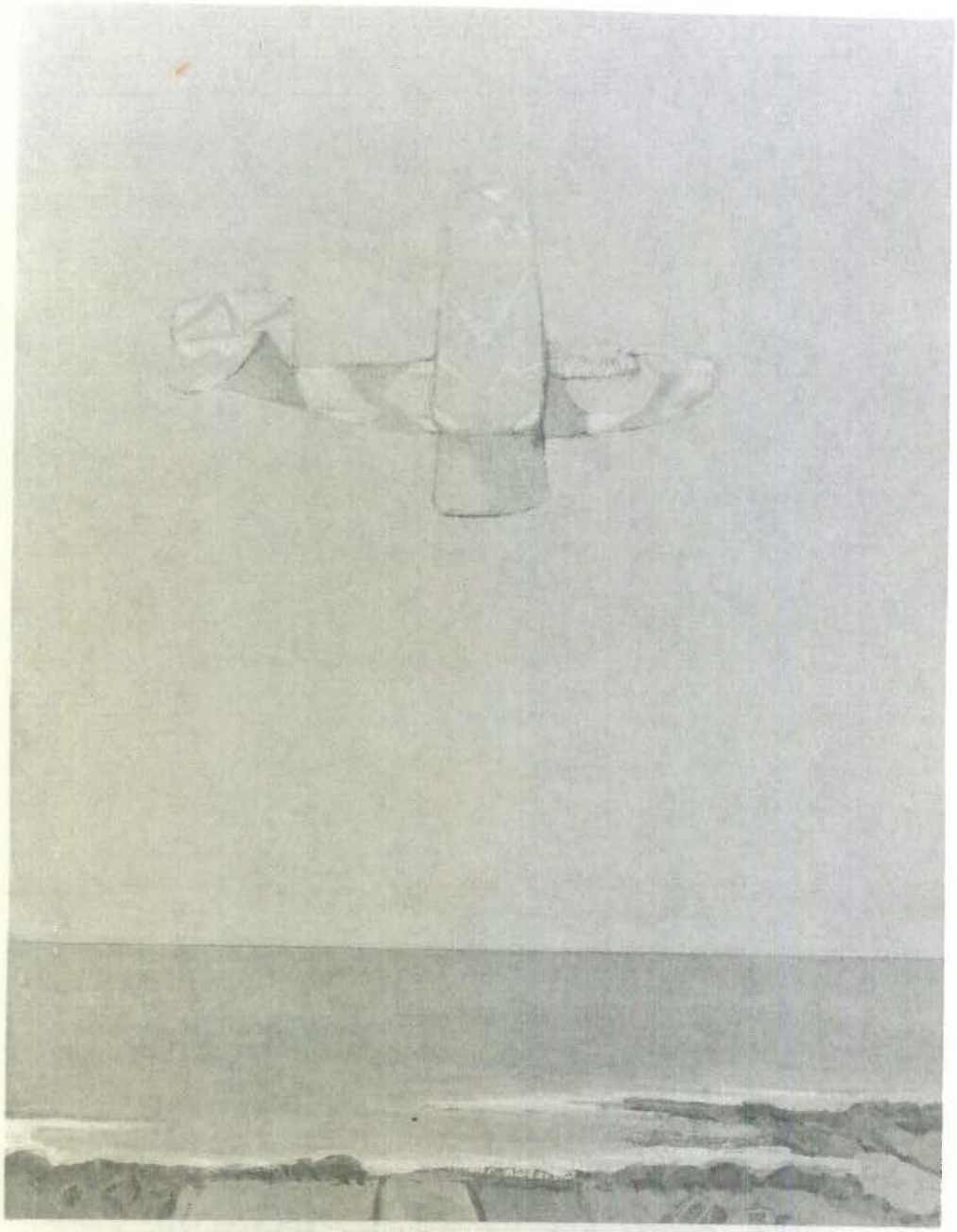
Aluminum painted plane with a stripe of the dark gray blue color of Plate 1a on the fuselage.

PLATE 4



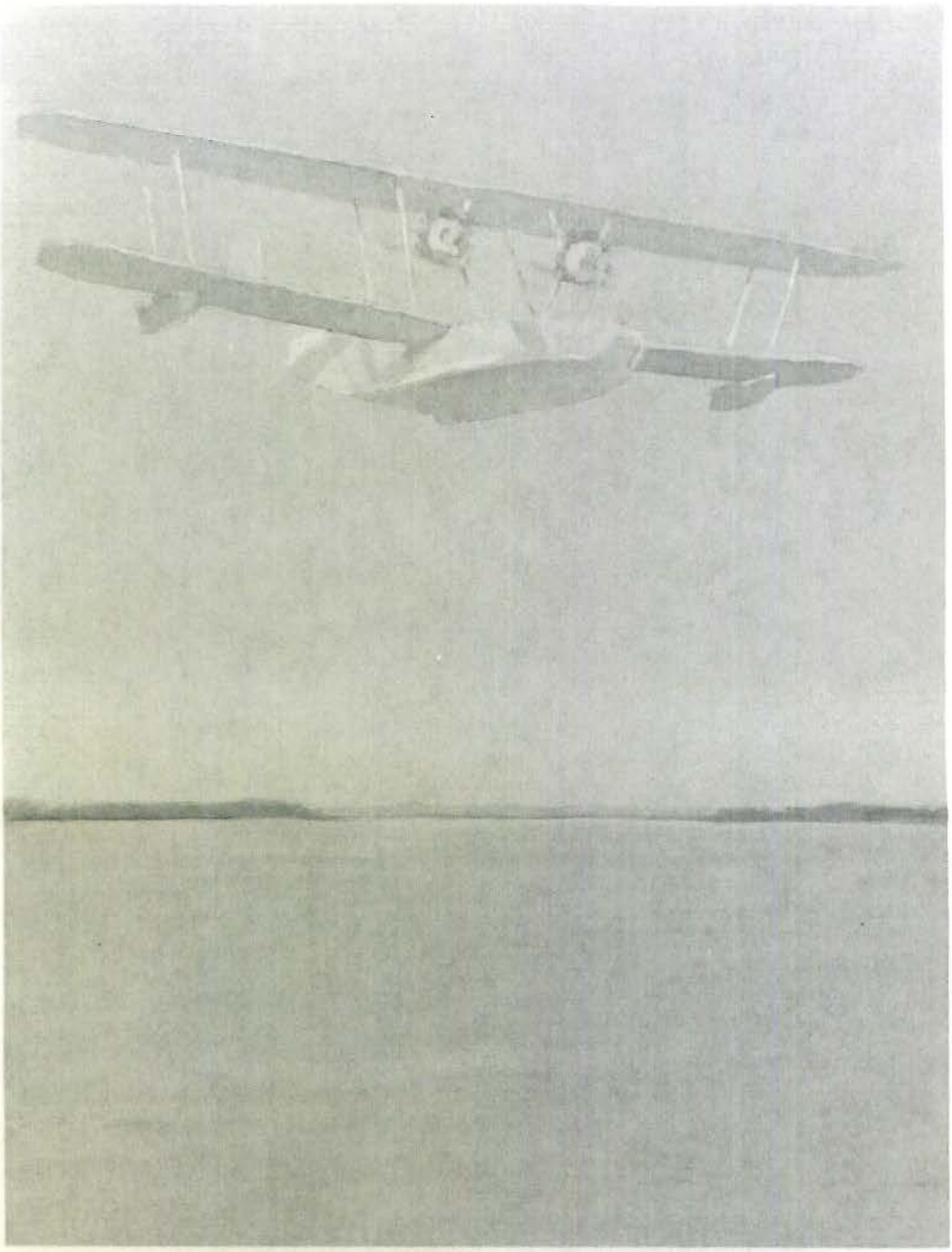
Photographs of paintings of side and top views of plane in accord with the rules of Section 3, Chapter III, and with pattern.

PLATE 5



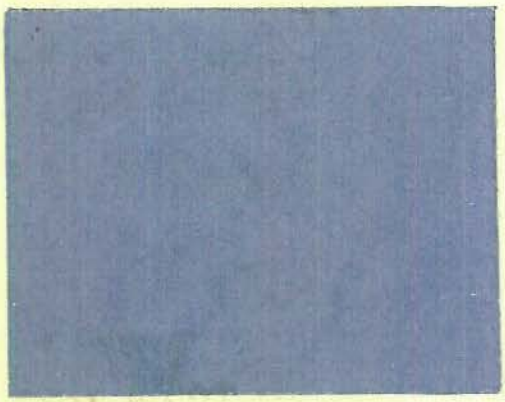
Photograph of a painting of the camouflaged plane of Plate 5 in sunny weather, view from above. The painting was from imagination, not from life.

PLATE 6



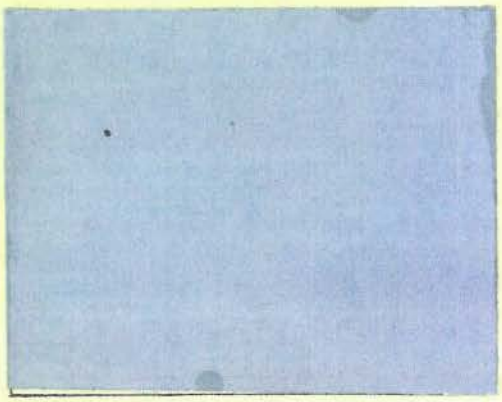
Photograph of a painting of the camouflaged plane of Plate 5 in sunny weather, view from below. The painting was from imagination, not from life.

PLATE 7



a

Dark gray blue
Munsell PB 5/4

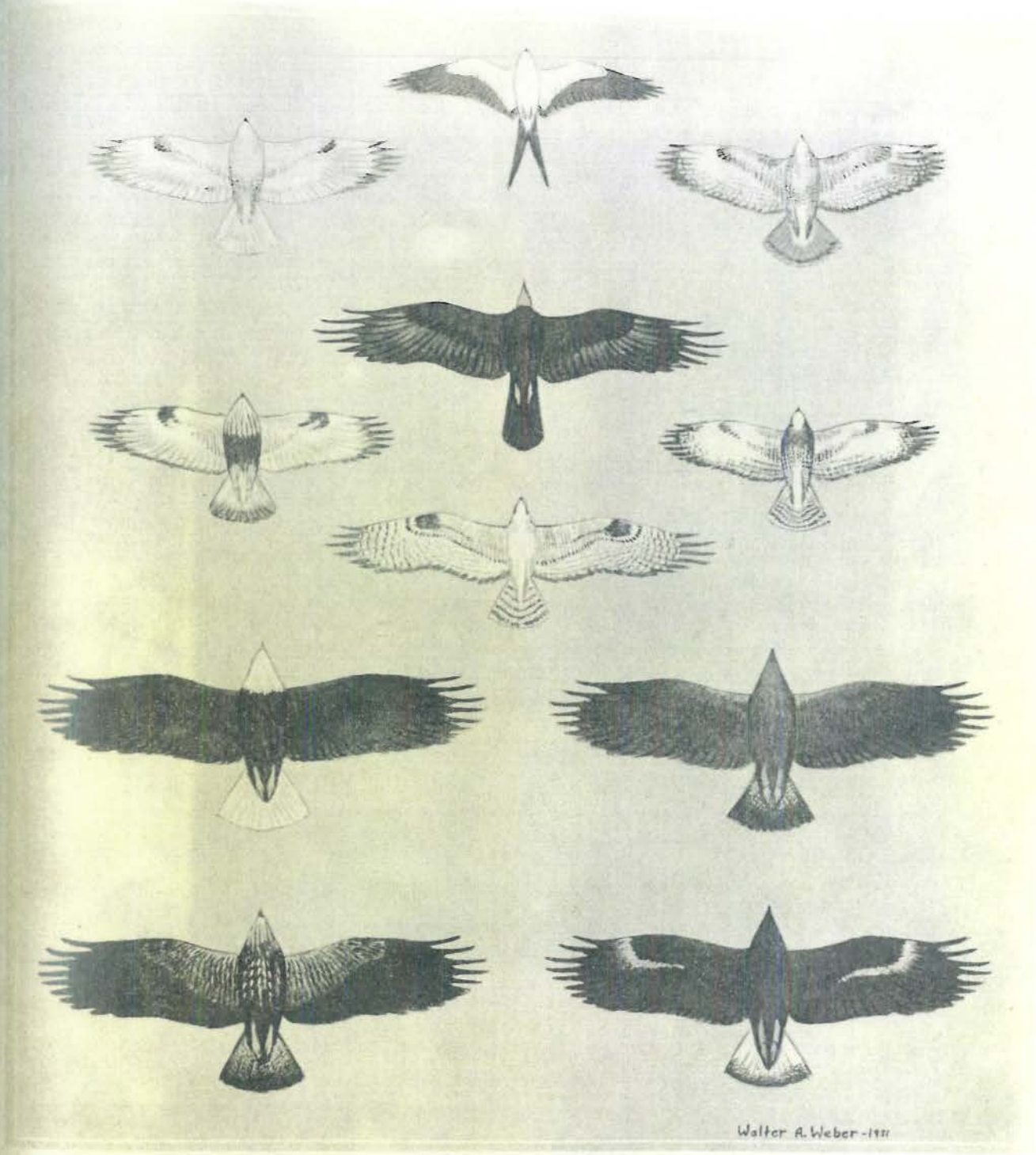


b

Light gray blue
Munsell PB 7/4

Water color paint.

PLATE 8



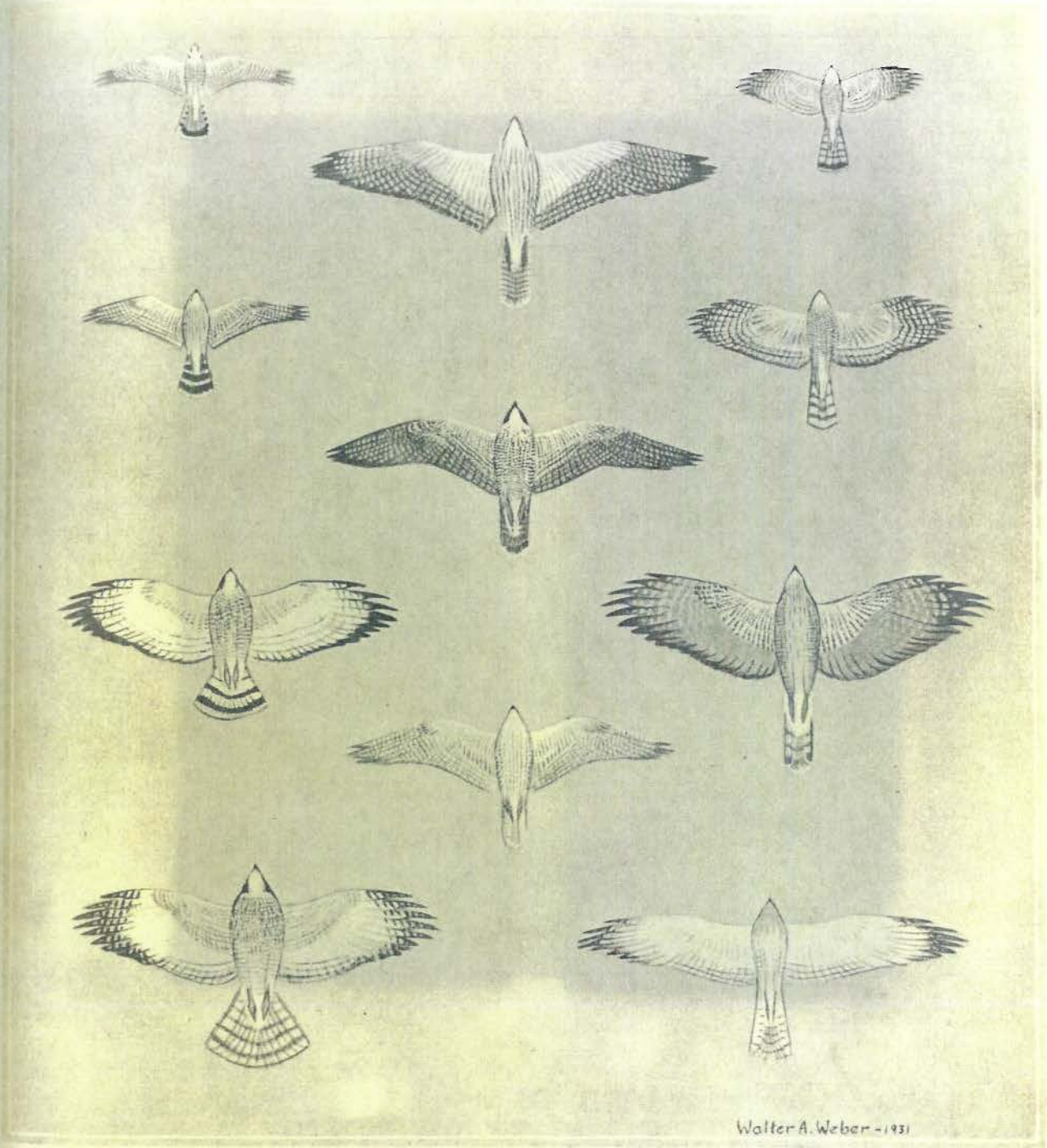
(About 1/24 actual size)

FIG. 113. Outlines and under-surface markings of Minnesota Birds of Prey. The birds in each plate are drawn to the same scale, but the scale differs in the two plates, being greater in the right-hand one. The birds in each plate can therefore be compared with each other as to relative size but not the birds in one plate with those in the other.

Reading from above downward:

FERRUGINOUS ROUGH-LEGGED HAWK, ♂ *ad.*
AMERICAN ROUGH-LEGGED HAWK, ♂ *ad.*
BALD EAGLE, ADULT, ♂ *ad.*
BALD EAGLE, ♂ *im.*
SWALLOW-TAILED KITE, ♂ *ad.*
TURKEY VULTURE, ♂ *ad.*
OSPREY, ♂ *ad.*
RED-TAILED HAWK, ♂ *ad.*
SWAINSON'S HAWK, ♂ *ad.*
GOLDEN EAGLE, ADULT, ♂ *ad.*
GOLDEN EAGLE, ♂ *im.*

PLATE 9

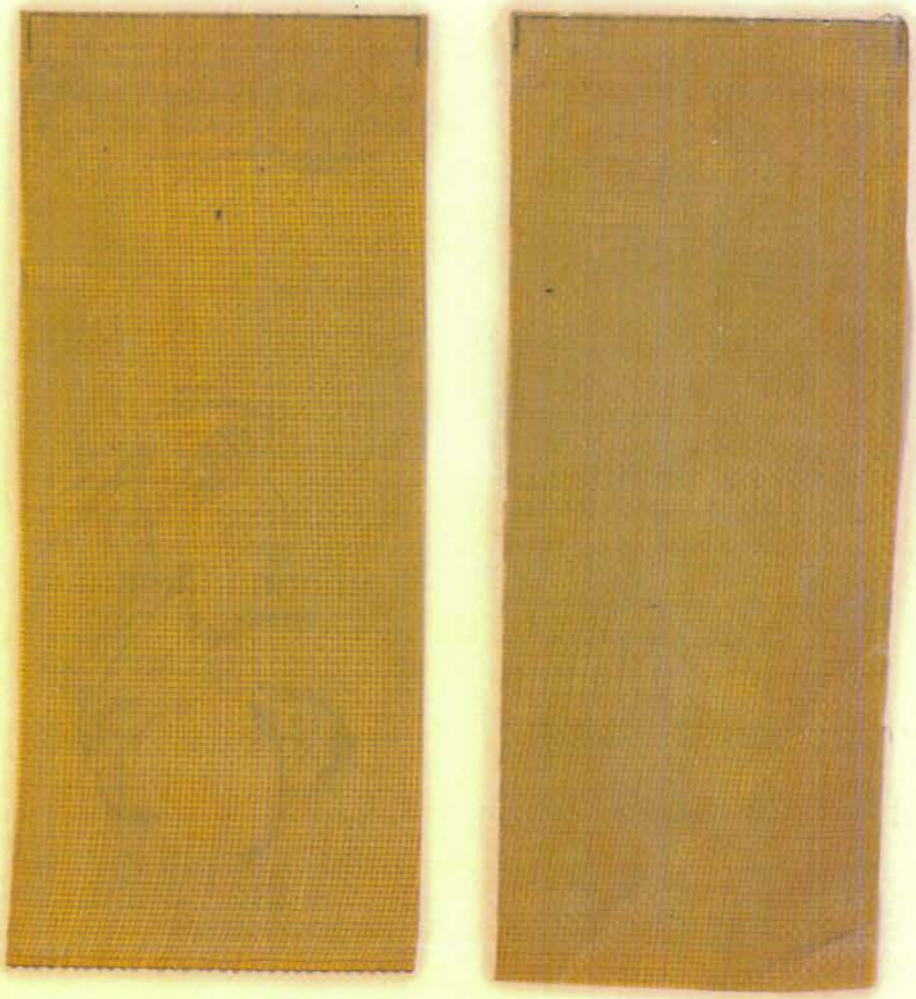


(About 1/15 actual size)

Reading from above downward:

SPARROW HAWK, ♂ *ad.*
PIGEON HAWK, ♂ *ad.*
BROAD-WINGED HAWK, ♂ *ad.*
RED-SHOULDERED HAWK, ♂ *ad.*
GYRFALCON, ♂ *ad.*
DUCK HAWK, ♂ *ad.*
PRAIRIE FALCON, ♂ *ad.*
SHARP-SHINNED HAWK, ♂ *ad.*
COOPER'S HAWK, ♂ *ad.*
GOSHAWK, ♂ *ad.*
MARSH HAWK, ♂ *ad.*

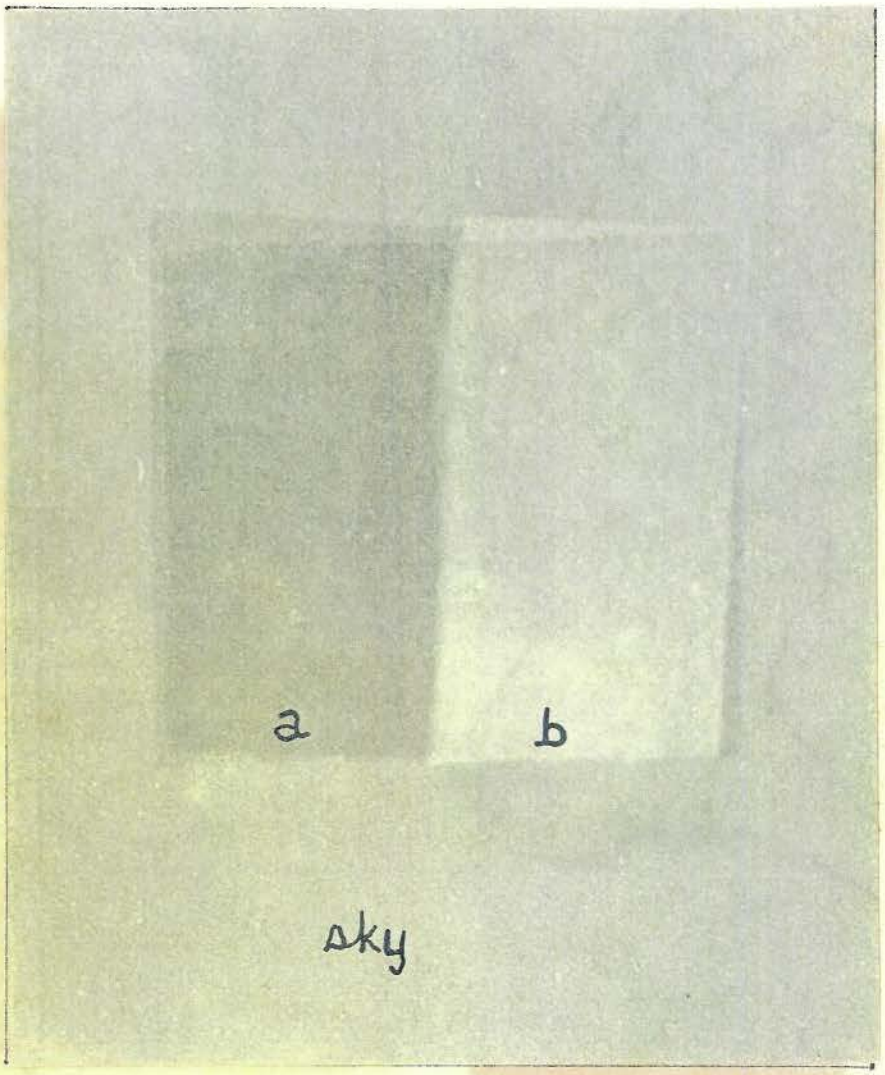
 PLATE 10



a b

Doped wire mesh fabric, Naval Aircraft Factory.
a original fabric
b fabric made translucent by sandpapering one side.
Turn samples up from the page and hold to the light; keep clean.

PLATE 11



Photograph of wire mesh fabric in sunlight against the blue sky.

a two layers of transparent fabric.
b one layer of transparent and one layer of translucent fabric.

PLATE 12