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Low Visibility Camouflage

of Ships

by

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Preliminary Report

on

Low Visibility Camouflage of Ships

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ABSTRACT

Measurements were made of the color of the sea and sky, and from an analysis of these low visibility ship camouflage is worked out which amounts to (a) painting the entire ship a fairly dark color for clear weather and aerial observers, and (b) painting the ship the present Navy gray for hazy, overcast, and thick weather.

Experiments are under way at this Laboratory to determine the effectiveness of dyes in reducing the visibility of the periscope feather.

An experiment is suggested with phosphorescent paint as a means of reducing night visibility

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Chapter I

Introduction

AUTHORIZATION

1. The problem was authorized by Bureau of Construction and Repair letter L1/NP14(F)N/C of 25 June 1935. Other references pertinent to the report are listed below.

References: (a) "The Development of Marine Camouflage and Tests Relating Thereto", by Harold Van Buskirk, Lieut. (CC) U.S.N.R.F., Vols.1 and 2, BuC&R file 14258-A14, enclosures (A) and (B) with Vol.4.

(b) "Tests Conducted at the Research Station, Eastman Kodak Laboratories", by Loyd A. Jones, Lieut.(CC) U.S.N.R.F., BuC&R file 14258-A14, enclosure (C) with Vol.4.

(c) NRL Report No. H-1097 of 22 Nov.1934 - "Preliminary Report on Sky Camouflage of Naval Airplanes".

(d) "Handbook of Instructions for Naval Airplane Camouflage" - 15 March 1935, by the Naval Research Laboratory.

(e) NRL Report No. H-1036 of 7 March 1934, "The Problem of Visibility".

(f) NRL let.C-F39-5 of 12 April 1935 to BuC&R with 1st to 6th endorsements thereto.

(g) NRL let.C-F39-5:C-S19-7 of 18 July 1935 to CNO.

2. The investigation of camouflage of ships was directed, see reference (f), with attention to three items: (1) low visibility of surfact craft, excepting submarines; (2) breaking up of straight lines by paint; and (3) the use of dyes to conceal the feather of the periscope of a submerged submarine.

3. Definitions.

"Low Visibility Camouflage" of a ship means painting the ship with suitable colors and patterns to make it as invisible as possible.

"Dazzle Camouflage" means painting a ship in such a way as to produce deception or distortion, as, for example, to make the ship look like some other sort of ship, or to make judgment of its course diffi-

cult. This aspect of camouflage received much attention during the World War. We are not concerned with it here except in so far as the breaking up of straight lines by paint may be regarded as a type of dazzle camouflage.

4. Scope of Present Report. In the following report various references have been consulted and a number of measurements of sea and sky brightness and color have been made under various weather conditions. From these and the physics of the problem the coloration of the ship has been worked out to effect as low visibility as possible under a number of conditions. Detailed recommendations are given for painting a destroyer to achieve as low visibility as possible. The destroyer was selected for first experimentation on the idea that if an improved low visibility camouflage were developed, the same type of painting could with little modification be tried on other classes of ships.

Detailed recommendations are offered for painting certain areas of the destroyer to break up straight vertical lines in order to decrease the precision of the coincidence range finder.

5. Recording color. In various places throughout this report the color and brightness of paints, sea, sky, 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 graded 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.

6. Reflectivity. The reflectivity, denoted by r, of an area, such as a painted surface, or the sea surface, is the fraction of incident light reflected by the area. The brightness of an area depends directly on r. Thus a gray area for which r = 0.4 is twice as bright as one for which r = 0.2, provided the two areas are equally illuminated. For white paper and white paint r = 0.7 to 0.8. Mixing colors with the paint reduces r so that a light blue paint usually does not have a reflectivity greater than 0.5 or 0.6. For the present Navy Gray r is about 0.4.

Chapter II

History and References

7. Historical. For a number of years before 1908 the ships of the United States Navy were painted white for reasons which were probably not guided by considerations of low visibility. About 1908 a gray color was adopted for war conditions which was somewhat darker than the present Navy Gray. Samples of the dark gray and the present Navy gray are shown in Plate 1, a and b, respectively. Their respective reflectivities r are about 0.3 and 0.4. Unquestionably the dark gray was adopted because it had a lower visibility than the previously used white color, but no information is available as to the considerations, or experiments, or conditions, which led to the choice of this particular shade.

During 1915 the Bureau of Construction and Repair initiated experiments which resulted in a lighter color, the present Navy Gray, being adopted in the early part of 1917. (Reference (a), Vol.2, page 182.) The considerations which dictated the selection of the color were:

(1) That the ship be as invisible as possible to an observer on a surface ship and on a submarine.

(2) That the weather be mostly overcast, or hazy, or foggy, as in the North Sea area.

(3) That the present Navy Gray was the best solution under the foregoing conditions.

It was recognized that at night the present light gray was less visible than the dark gray, but was more visible in clear weather, sunlight, and under searchlight illumination. (Reference (a), Vol.2, pages 191 - 192.)

It is to be emphasized that conditions (1) and (2) are not all-inclusive, because situations may often exist in which these conditions are not fulfilled. This may be the explanation of the opinion expressed November 14, 1916, by the Commander, Destroyer Force, Atlantic Fleet (reference (a), Vol.2, page 242) who stated: "Light gray is the least desirable color for general adoption. In certain angles of light and in certain conditions of atmosphere vessels painted light gray stand out with sharp distinction. The visibility is increased by the black water line, of which there seems to be no need. Dark gray for destroyers is recommended." It seems probable that the originator of this statement had experimented with, or was thinking of, conditions differing from (1) and (2), and hence reached, correctly, a conclusion opposed to (3).

A type of camouflage referred to as the "German Method" (reference (a), Vol.2, page 220) deserves mention. In this method the lower portions of the ship near the water were painted a dark gray, which was graded successively lighter on the higher portions up to a very light gray or white on the masts. The scheme attempted to match the sea brightness on those areas of the ship usually viewed against a sea background,

and to match the sky brightness on those areas usually viewed against a sky background. The U.S.S. OHIO was painted in this way, but time did not permit sufficient observation for a final conclusion. However, the Commanding Officer, U.S.S. OHIO, stated in a report of January 24, 1919 (reference (a), Vol.2, page 230): "That the design and colors are very effective when the paint is new. The masts particularly are less visible than the masts of other vessels not painted with this design."

During the World War low visibility was attempted by painting ships with a wide variety of colors and patterns, as stripes, spots, splotches, with no outstanding success. In fact, no evidence is presented to contradict the conclusion that a pattern of colors, when viewed at a distance sufficiently great so that the pattern was unresolved, was no different, neither better nor worse, than a single smooth color equivalent to the average of the component colors of the pattern. (Reference (a), Vol. 1, Chapter C, page 58.)

7. References. The four references cited below include about all the information on camouflage which has been available to this Laboratory. All four have the same designation as those on page 1 of this report. Following each reference is a brief remark or comment on the contents. Actually, reference (a), Vol.2, is by far the most important in the present connection and is frequently referred to.

Reference:(a) Bureau of Construction and Repair files, "The Development of Marine Camouflage and Tests Relating Thereto" by Lieut.Harold Van Buskirk, Construction Corps, U.S. N.R.F., May 1, 1919, in two volumes, Vol.1 and 2.

Volume 1 deals with "dazzle camouflage" and "low visibility camouflage" mostly on models and merchant ships. It is mainly of historical interest, but has some points of value in case "dazzle camouflage" were to be reinvestigated.

Volume 1, Chapter C, pages 1 to 54, "Report of the Submarine Defense Association" by Bates, must be read with caution for occasionally the statements are more optimistic or enthusiastic than the more sober paragraphs would appear to justify. Pages 55 to 138 by Jones give an excellent summary of theoretical ideas underlying low visibility.

Volume 1, Chapter D, gives miscellaneous ideas and suggestions about achieving low visibility received during the World War. Any one having such ideas, no matter how fantastic, would do well to consult this chapter to see whether his notions were already there.

Volume 2, Chapter H, pages 182 to 267, summarizes tests at sea of low visibility painting of Navy ships by the United States Navy during 1916 and 1917. The experiments and conclusions are of importance here.

Volume 2, Chapters I and J, deal with "dazzle camouflage".

[redacted]

Reference:(b) Bureau of Construction and Repair files, "Tests Conducted at the Research Station, Eastman Kodak Laboratories" by Lieutenant Loyd A. Jones, Construction Corps, U.S.N.R.F., May 1, 1919.

Chapter 1 gives measurements of the resolving power of the eye for various patterns and colors. Of no direct interest here, Chapter 2 describes a theater for investigating dazzle camouflage of ship models.

Reference:(c) and (d) Naval Research Laboratory Report No.H-1097 by E. O. Hulburt and C. Bittinger, "Preliminary Report on Sky Camouflage of Naval Airplanes", 22 November 1934, and "Handbook of Instructions for Naval Airplane Camouflage" prepared by the Naval Research Laboratory, dated 15 March 1935.

These contain one fact of interest here; namely, to paint a plane for low visibility when viewed from above against the sea, the horizontal surfaces should be a dark blue, Munsell BGB 2/4. For a large plane an irregular, large pattern of the dark blue, BGB 2/4, and of dark green, GYG 2/4, was used.

Reference:(e) Naval Research Laboratory Report No. H-1036, "The Problem of Visibility" by E. O. Hulburt, 7 March 1934.

Deals mainly with attempts to measure and to improve visibility. Gives measurements of the relative brightness of the sea and sky near the horizon for various conditions of haze. Otherwise of no particular interest here.

[redacted]

Chapter III

Low Visibility Camouflage of Ships

8. General principles of low visibility camouflage of ships. The general principle of low visibility camouflage is that the ship be painted to be the same color and brightness as the background. The principle is simple enough but is practically impossible to carry out under all conditions, for the brightness of the ship varies with the position of the sun and the background may be either the sea or the sky, or both, depending upon the position of the observer.

In 1916 the Bureau of Construction and Repair noted (reference (a), Vol.2, page 183) "That it is not practicable to adopt a single color which will satisfy all conditions of light, atmosphere, and sea conditions generally; and that the question is primarily one of determining the most probable weather conditions that will obtain." It is believed that this remark is as true today as it was in 1916.

With the airplane a new element has entered into the requirements of low visibility camouflage; the ship must be painted to be of low visibility to the observer in an airplane. This calls for a different type of camouflage than in the case of the observer on the surface.

No single type of camouflage will satisfy all the requirements. Therefore, in the later sections of this chapter are discussed types of camouflage for low visibility to the aerial and maritime observer in clear and overcase or hazy weather.

9. Measurements of the color of the sea and sky. Measurements were made by means of the Munsell Book of Color of the color of the sea and sky in the North Atlantic Ocean. The color of the sea and sky within about 5° of the horizon is shown in Plate 2, which refers to clear, cloudless, breezy weather conditions viewed from altitudes below 100 feet in directions not too near the bearing of the sun. The color of the open sea in clear, cloudless weather, with moderate breeze, as seen by an aviator at 5,000 feet altitude, is shown in Plate 3. Underneath the aviator the color is a dark gray blue, nearly black, Munsell PB 2/2, $r = 0.04$, and becomes lighter toward the horizon, being about Munsell PB 5/2 to 6/2, $r = 0.2$ to 0.3 near the horizon. The color of the sea near the horizon should theoretically be the same for all altitudes of observer if there were no haze; i.e. perfect visibility. However, there is always some haze, so that the sea near the horizon usually becomes lighter in color as the altitude of the observer is increased.

Clouds, of course, make the entire sea surface grayer and haze renders the scene grayer and lighter. For a mirror calm sea, which rarely occurs, the sea near the horizon is the same color and brightness as the sky near the horizon.

10. Low visibility camouflage against airplane observers. To achieve low visibility camouflage against airplane observers, paint the ship:

[redacted]

(a) Horizontal surfaces a very dark gray blue, Munsell PB 2/2, r = 0.04

(b) Vertical surfaces a moderate gray blue, Munsell PB 5/2 r = 0.2

All paint should be mat, not glossy. The two colors are shown in Plate 4, and drawings of a destroyer painted with them are given in Plate 5. The reasons for the selection of the two colors are discussed in the following paragraphs.

In Plates 6 and 7 are shown drawings of a ship at various distances as viewed from altitudes of 1,000 and 5,000 feet. The drawings are accurate to the scale of a battleship. They show that the aviator practically always sees the entire ship against the sea as a background, except in the rare case that the visibility is greater than 30 miles and the altitude of the aviator is below 1,000 feet; in this case the aviator may see the upper portions of the ship against the sky.

In Plate 8 are shown photographs of a model of a destroyer broadside and bow-on from angles to the horizontal of 10°, 20°, 30° and 45°. These illustrate the fact that, roughly speaking, the horizontal surfaces do not come into prominent view until the horizontal angle is greater than 20°. Below 20° it is mainly the vertical surfaces which are seen. An aviator at an altitude of 5,000 feet looking down at an angle of 20° to the horizontal sees a ship at about 3 miles away. Referring to Plate 3, it is seen that at this distance the sea is pretty dark.

The foregoing calculation illustrates the general conclusion that whenever the ship is near enough to the observer for the horizontal surfaces to be seen, then the sea background is dark, as the central area of Plate 3. Therefore, the horizontal surfaces should be the very dark gray blue of Plate 4a.

The deck paint F #20 now used on destroyers is a dark gray blue, or a dark gray, Munsell PB 3/2, r = 0.08, approximately. This is slightly lighter than the dark gray blue of Plate 4a. It may be that the F #20 paint is dark enough, and that the somewhat darker shade of Plate 4a is unnecessary.

The moderate gray blue of Plate 4b was chosen for the vertical surfaces, for in sunlight this matches the average color of the sea in clear breezy weather viewed at angles to the horizontal less than 20°. In shadow the vertical surfaces will be too dark. In this case to match the color of the sea they should be much lighter, even lighter than the present Navy Gray, which, of course, would be too bright in sunlight. It is thought more advantageous to match the sunlit surfaces against the sea, even though the surfaces in shadow will be too dark, rather than to match the shadowed surfaces against the sea and have the sunlit surfaces too bright. At a distance through haze the sea appears a lighter gray than if there were no haze, but the ship will also appear a lighter gray. Therefore, the match of the ship against the sea should still obtain in haze. Similarly, for cloudy weather. In a mirror calm the ship viewed

at horizontal angles less than 20° will probably be too dark, but at angles greater than 20° it should be approximately of the same brightness as the sea background.

At night under natural illumination a ship camouflaged as in Plate 5 will probably be more visible than if it were painted the present Navy gray; under searchlight illumination it will be less visible.

A ship viewed in a direction close to that of the sun will be dark against the sea no matter what color it is painted. In this case low visibility camouflage is impossible.

A ship camouflaged as in Plate 5 will always be too dark against the sky. Therefore, in order to have the best chance of seeing the ship, the aviator should fly fairly low choosing his altitude such that the true horizon is at the limit of visibility. In this way he will pick up the ship against a sky background.

If low visibility to the airplane observer were accomplished, there remain other features of importance such as smoke, bow wave and wake to be considered. Smoke may be avoided. A recent opinion of experienced aviators of the Bureau of Aeronautics was that the wake was often the first thing seen of the ship, and that the bow wave was of lesser importance. This would mean that no matter how effective the camouflage might be the wake may still be a very visible feature, especially in the case of vessels at high speed.

11. Low visibility camouflage for conditions of haze, mist, fog, and overcast weather. Under these conditions the present Navy gray appears to yield the lowest visibility against a sky background, as demonstrated by the Navy experiments during 1915 and 1916 (reference (a), Vol.2, Chapter H). However, to an aviator overhead the Navy gray ship would be light against the sea and consequently a darker color would be less visible. If it is assumed that aviators do not usually operate in thick and overcast weather, then the present Navy gray is the best for such conditions.

12. Low visibility camouflage in clear weather against observers on the surface. A ship observed from another ship in clear weather is probably the most frequent situation which occurs. Low visibility in such a case is very important. It seems certain, however, that it is not possible to provide a camouflage which will be equally effective in the various situations which arise in this case. In Plate 9 are shown drawings to scale of a battleship at various ranges viewed from an altitude of 180 feet which is about the greatest height available on a surface ship. The Plate merely illustrates the fact that the background of the ship is, in general, part sea and part sky, and that the portions of the ship seen against the sea and sky vary with the range. They also vary with the altitude of the observer.

In average clear weather the brightness of the sea and sky near the horizon differs so markedly that a color which matched the one is very visible against the other. The present Navy gray in sunlight matches the clear sky near the horizon to a certain extent but is much lighter than the sea. In shadow it matches the sea approximately, but is much darker than the sky.

A type of camouflage sometimes referred to as the "German Method" (reference (a), Vol.2, page 220) consisted in painting the lower portions of the ship near the water a dark color which was graded successively lighter on the upper portions to a very light gray on the masts. It seems doubtful whether the graded system offers any advantages which would not be offset by an equal or greater number of disadvantages.

If the graded system of camouflage were to be tested, the dark color near the water should be the moderate gray blue of Plate 9b, and the lightest color on the masts equal to or lighter than the present Navy gray. The system is shown in Plate 10, with the horizontal surfaces the very dark gray blue of Plate 9a for low visibility to airplane observers. The system may fail in practice because in the superstructure and deck gear of a ship there are so many dark shadows that even though the upper portions were painted a very light color, their general appearance at a distance may always be too dark.

13. An attempted combination of the various systems of camouflage into a single system. It has been seen that low visibility camouflage in clear weather against aviators calls for very dark horizontal surfaces and fairly dark vertical surfaces, and in thick weather against all observers, aerial and maritime, for a light gray, the present Navy gray. The dark colors and the light gray differ so markedly in brightness that there seems to be no entirely satisfactory way in which to combine them into a single system which would achieve low visibility in both clear and thick weather.

An attempt in this direction would appear to be a system in which the horizontal surfaces be given the very dark color of Plate 4a and the vertical surfaces the present Navy gray. Such a system would be satisfactory in thick weather, but might not be effective against aviators in clear weather, because the vertical surfaces might be so bright as to be conspicuous to the aerial observer.

Chapter IV

Breaking Up Straight Lines by Means of Paint.

14. In general it is believed that it is impossible to break up straight lines by means of paint without at the same time increasing visibility. Further difficulties with this type of deceptive camouflage are outlined in ref.(a), Vol.2, page 216, as a result of experiments in 1918. These are (a) that at short ranges there are innumerable objects aboard ship that can be used for range targets and the breaking up of all their lines is entirely impracticable, and (b) that at longer ranges and against the sun the deceptive pattern is invisible and hence of no value.

15. The principle of breaking up a straight line is to paint a bold irregular pattern in contrasting brightnesses of paint on the areas near the straight line. If a portion of the pattern blends with the background, the observer (for example, the range finder operator) may have difficulty in finding the straight line. An example of such a pattern is given in Plate 11 in which the pattern is put on the stacks, deckhouses and bow. In this case the model of the destroyer was Navy gray and the dark spots were the dark gray of Plate 4b. If the destroyer had been painted the dark gray, the spots should be Navy gray.

16. Another example of bold pattern is shown in Plate 12. The light areas are Munsell PB 6/2, r = 0.27, and the dark areas are Munsell PB 3/2, r = 0.06. The light and dark areas are approximately equal, so that the average reflectivity is r = 0.16 which is fairly near to the vertical surface color of Plate 4b. Therefore, at a distance so great that the pattern can not be resolved the appearance of the ship of Plate 12 will be that of Plate 5. If the pattern areas are 3 feet across the pattern will be unresolved with the unaided eye at distances beyond 3 miles, and with a range finder at distances beyond about 10 miles. For ranges below 10 miles the pattern is visible with the range finder and may disturb observation, in the case of the coincidence range finder, provided the pattern is well illuminated.

Chapter V

Low Visibility at Night with Luminous Paint

17. At night a ship is usually seen against a sky background and is usually darker than the sky background even when painted with as light a color as the present Navy gray. Therefore, if the paint were slightly self luminous a lowered visibility at night might be secured. This suggestion was made by Commander Simons in 1918, ref.(a), Vol.1, page 71, who experimented with phosphorescent calcium sulphide on small models. It would seem that further experimentation with the phosphorescent paint is simple and that conclusions as to its effectiveness would be of value.

18. To this end about ten pounds of phosphorescent calcium sulphide have been ordered and a suitable vehicle is being investigated. The keeping and weathering qualities of the phosphorescent material are not known. The material in its present form is white and in the dark glows feebly with a bluish-white light. A surface painted with it had about the brightness of a white horizontal surface illuminated by full starlight.

Chapter VI

The Use of Dyes to Reduce the Visibility of the Periscope Feather

19. Experiments are underway on the Potomac River at this Laboratory to find out whether the conspicuousness of the periscope feather can be reduced by coloration with a water soluble dye. A motor boat of 9 knots speed is being equipped with an imitation periscope tube pushed through the water in front of the bow. A water solution of a dark dye will be sprayed or squirted out of various holes in the tube. The experiments and their results, positive or negative, will be described in a future report.

Chapter VII

Recommended Experiments

20. Material. The paint necessary in the camouflage experiments consists of various shades of gray or gray blue. It is believed that all the required paint and colors can be readily mixed from standard paint available at any Navy depot. The paint should be mat, not glossy.

21. Experiments on low visibility camouflage against airplane observers. It is recommended that two destroyers be painted as follows:

1st destroyer - Paint according to present Navy practice; i.e., the present Navy gray and dark decks.

2nd destroyer - Painted with the camouflage of Plates 4 and 5; i.e. all horizontal surfaces, as decks, tops of deckhouses, etc., the dark gray blue of Plate 4a, and all vertical surfaces, as sides of ship, sides of deckhouses, stacks, etc., the moderate gray blue of Plate 4b. The painting need not be exact or carried into corners. Small gear, wires, rigging and areas permanently in shadow, as under boats, etc., need not be painted. The pole masts of a destroyer probably need not be painted. All bright and shiny objects, as searchlights, glass, guns, etc., should be painted or put under dark covers.

The two destroyers should remain near to each other and be observed from the surface and the air under a variety of conditions of weather and light, day and night, with and without searchlight illumination.

The results of the experiment will point the way to further tests and will decide whether it is worthwhile to test the graded camouflage of Plate 10 and the camouflage of Chapter III, par.13.

22. Experiments on breaking up straight lines by means of paint. It is recommended that a pattern similar to that of Plate 11 be put on the stacks and deckhouses of a destroyer. If the destroyer is painted Navy gray, the pattern should be the moderate dark gray of Plate 4b, and if the destroyer is the dark gray the pattern should be Navy gray. Observation of the effectiveness of the pattern will point to modification and the desirability of tests with the pattern of Plate 12.

23. Experiments at night with phosphorescent paint. Paint a panel about 1 foot square with the phosphorescent paint and observe it at night against a sky background. If the paint reduces the visibility of the panel, a larger object such as a portion of one of the stacks of a

destroyer may be painted and observed at night from various distances. The paint will be supplied by this Laboratory.

Plates 1 thru 12 of this report are not now available. If and when copies are available, they will be tipped in on these blank pages.