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NAVY DEPARTMENT  
BUREAU OF CONSTRUCTION AND REPAIR

Report on  
Low Visibility Camouflage of Submarines -  
Tests at Sea, of June and July, 1937

NAVAL RESEARCH LABORATORY  
ANACOSTIA STATION  
WASHINGTON, D.C.

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NOTE: Plates 1, 3, 4, 5 and 8, being artist's paintings, are included only in two copies of this report and are omitted from the other copies.

APPENDIX: REPORT OF COMMANDER SUBMARINE SQUADRON FOUR.

## A B S T R A C T

The experiments of Submarine Squadron Four in deep water off Pearl Harbor showed that a dark blue color was the least visible to aircraft observers. Portions of a submarine painted with the color and submerged to slightly below periscope depth were invisible to overhead observers. Further experiments with the dark blue color on submarines in other areas of the sea are recommended.

## INTRODUCTION

1. Authorization. The investigation of the camouflage of submarines to avoid detection by aircraft was authorized by Bureau of Construction and Repair letter SS/S19-7 of 4 March 1937.

2. References: (a) Naval Research Laboratory Report H-1350, 26 March 1937, "Preliminary Report on Camouflage of Submarines to Avoid Detection by Aircraft".  
(b) Report of Commander Submarine Squadron Four, "Submarines--Color Painting of to Avoid Detection by Aircraft", FF4-4/S19(161), August 2, 1937.

3. Scope of the Present Report. Analysis of underwater daylight illumination, Reference (a), indicated that a submerged submarine should be painted a fairly dark color for visibility in water so deep, that the bottom of the sea can not be seen. Two cases were considered, optically pure water and optically impure water, the impurity being caused by small particles which scatter the light. It was concluded that in the case of pure water the color should be very dark of reflectivity about 4 percent, and for impure water the color should be moderately dark of reflectivity above 4 percent but not above about 12 percent. Specific experiments with uniform dark blue, green and gray colors and with patterns of the colors were recommended. As described in Reference (b), experiments were carried out by Submarine Squadron Four in deep water off Pearl Harbor. A dark blue color was found to be the least visible for that area. The present report summarizes the experiments and suggests that further experiments with the blue color in various areas would be desirable.

4. Results of Tests by Submarine Squadron Four in Hawaiian Waters: Experiments on low visibility painting were carried out by Submarine Squadron Four in deep water off Pearl Harbor during June and July, 1937. Their report is given in full in the Appendix and is summarized here briefly. Preliminary observations from the air were made of a black submarine submerged to various depths. A painting of the submarine is shown in Plate 1. The submarine appeared greener and darker than the background. This indicated that the water was very clear and that a dark blue color should be used. Three experiments were then performed.

(a) First Experiment. In the first experiment three submarines were used, S-28 painted a normal black, S-35 a uniform dark blue gray and S-21 a uniform dark purple. The dark blue gray and the dark purple colors are shown in Plate 2, a and b, which were prepared from some of the paint actually used on the submarines. Observations from the air of the three submarines operating at periscope depth showed that the normal black color and the dark gray blue, Plate 2a, appeared darker than the background, and that the dark purple color, Plate 1b, appeared lighter than the background. The appearance of the submarines is shown in Plate 3. When the submarines

(d) Formula for paint, color c, Plate 2.

Ultramarine blue, in oil	4 gallons
Carriage part lake, in oil	1 quart
Inside white	1 gallon
Black enamel	2 gallons
Paint drier	1 gallon
Linseed oil, raw	5 gallons

(e) Colors of paint of Plates 2c and 6. The colors of Plates 2c and 6 must not be used as standards or guides from which to mix paint for they may fade or otherwise change with time. In order to insure reproducibility of the colors at some future time it is necessary to specify them in terms of some standard. In the case of Plate 6 this is a simple matter; it matches the Munsell color PB 3/8, "Munsell Book of Color, Abridged Edition, Munsell Color Company, Inc., Baltimore, Maryland", 1929. In the case of Plate 2c the specification is not simple, for none of the available color charts contains an exact match of the color. For example, Plate Xm, Dark Aniline Blue of "Color Standards and Nomenclature, Ridgeway, published by the author, Washington, D.C., 1912", is a fairly close match to Plate 1c, but is slightly too light and too purple. Again, Plate 1c is somewhere between Munsell PB-P 2/6 and PB 2/6. The spectrophotometric curve of Plate 2c determined by the United States National Bureau of Standards is given in Plate 7. In theory this curve is a satisfactory permanent record of the color. For, in order to reproduce the color all that is necessary to do is by trial to make a paint whose spectrophotometric curve is that of Plate 7. In practice this might require several trials. The reflectivity for daylight of the color of Plate 2c is about 4 percent and of Plate 6 is about 8 percent.

6. Recommendations. It is recommended:

- (a) That additional tests be carried out with the dark blue color, Plate 2c, on submarines in areas where the water is clear. The recommendation may be superfluous, for as seen in paragraph 17 of the Appendix, further tests were contemplated.
- (b) That tests be carried out with the dark blue color, Plate 2c, on submarines in areas where the water is not clear.
- (c) That, if the tests of (b) show that the color is too dark, the paint be made lighter by adding a small amount of white and the tests continued until the correct color is found. A correct color may be somewhere between the very dark blue of Plate 2c and the moderately dark blue of Plate 6.

7. It can not be emphasized too strongly that any bright objects left unpainted, marine growth on the underbody, bubbles due to leaks, etc., may be readily visible and may overshadow effects of the low visibility painting. Such imperfections may not seem important at first, but the more closely the paint approaches the background in color, the more apparent will the imperfections become.

8. Further remarks. The term "impure" water, or water which is not optically clear, is necessarily vague and indefinite, for the optical clearness of water may vary within wide limits, and each degree of optical clarity, or lack of such clarity, may require a different shade of paint for lowest visibility. Thus it may turn out that there is no single shade which is equally satisfactory for all degrees of clarity. The selection of the most suitable shade would then be a compromise to be determined by experiment and the probable areas of operation.

9. Conceivably, it is possible that scattering particles, as small plant or animal life, might occur in layers and might give rise to unusual light or color effects on a submarine moving through or near the particles. Such circumstances would be regarded as abnormal or rare.

10. In this connection, mention may be made of halo effects which are sometimes observed. A painting of such an effect is given in Plate 8, which shows a light area around a black submarine. Whether such effects are due to marine growth on the underbody, to bubbles exuded from the hull, or to some other cause, can not be said. Whether such effects are evanescent, frequent or unfrequent is uncertain. Whether such effects occur at all on a properly painted, clean, non-leaking submarine is undetermined.

11. It is scarcely necessary to remark that certain effects may occur which are beyond the province of low visibility painting. For example, a submarine moving under and near to the surface may modify or disturb the surface waves and thus cause a sort of wake which may betray its presence. Oil from the submarine may leave a visible slick.

12. It is interesting to note that the dark blue color Plate 2c is of the same brightness as the color found best for horizontal surfaces of surface ships for low visibility. <sup>1</sup>

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1 Naval Research Laboratory Report H-1239, February 21, 1936, "Camouflage of Naval Ships - Tests at Sea of November and December, 1935."  
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Therefore, the color Plate 2c can be used as a low visibility color both for submarines and for the horizontal surfaces of all ships.

13. Owing to the limited time assigned to the experiments at Pearl Harbor, it was impossible to test the visibility of a S/M painted a given color on both a clear sunny day and an overcast grey day. This should be done. As a matter of theory, the state of the sky would have little effect upon the visibility of the submerged S/M, that is, a color which is of low sub-surface visibility for a clear sky will also be of low visibility for a cloudy sky. The reason is that the color of the light reflected from the surface of the water, and the color of this light, whether blue or gray, has an entirely negligible effect on the contrast of the submerged submarine with its underwater background.

APPENDIX

SUBMARINE SQUADRON FOUR  
U.S.S. ARGONAUT, SQUADRON LEADER  
SUBMARINE BASE, PEARL HARBOR, HAWAII, U.S.A.

FF4-4/S19  
(161)

August 2, 1937

From: Commander Submarine Squadron Four.  
To: The Chief of the Bureau of Construction & Repair.  
Via: Commander Submarine Force, U. S. FLEET.

Subject: Submarines - Color Painting of to Avoid Detection by Aircraft.

Reference: (a) Bucon. CONFIDENTIAL letter to Comsubfor SS/S19-7(RP) of 5 March 1937.  
(b) Naval Research Laboratory Report No. H-1350 dated 3/26/37 - "Preliminary Report on Camouflage of Submarines to Avoid Detection by Aircraft".  
(c) Bucon. CONFIDENTIAL ltr to Comsubfor SS/S19-7(DF) of 30 March 1937.  
(d) Comsubfor CONFIDENTIAL letter to Comsubron-4 file FF4/S19 Serial C207 of 26 April 1937.  
(e) Comsubfor CONFIDENTIAL letter to Bucon. file FF4/S19 Serial C 208 of 26 April 1937.

Enclosures: (Under Separate Cover):  
(A) Test of 24 June 1937 - USS S-22.  
(B) Test of 28 June 1937 - USS S-21, S-28, S-35.  
(C) Test of 2 July 1937 - USS S-21, S-35.  
(D) Roll of Kodachrome Movie Film.  
(E) Roll of Kodachrome still pictures.  
(F) Photograph of sea surface 24 June 1937 from 800 ft. altitude, wind force 2.  
(G) Photograph of sea surface 24 June 1937, 1000 ft., force 2.  
(H) Photograph of sea surface 24 June 1937, 1200 ft., force 2.  
(I) USS S-21 Photographed - submerged 6/28/37, from 900 ft. altitude.  
(J) Photograph USS S-28 - submerged 6/28/37, from 900 ft. altitude.  
(K) Photograph USS S-35 - submerged 6/28/37, from 900 ft. altitude.  
(L) Photograph USS S-21 - submerged 6/28/37, from 900 ft. altitude.  
(M) Photograph USS S-28 - submerged 6/28/37, from 900 ft. altitude.  
(N) Photograph USS S-35 - submerged 6/28/37, from 900 ft. altitude.  
(O) Photograph of USS S-22 submerged, turning, 7/8/37 - from 2000 ft. altitude.  
(P) Photograph of USS S-22, submerged, 7/8/37, from 2000 ft. altitude.

Enclosures: (Continued)

- (Q) Photograph of USS S-22, submerged, 7/8/37, from 1500 ft. altitude.
- (R) Photograph of USS S-22, submerged, 7/8/37, from 1000 ft. altitude.
- (S) Photograph of USS S-22, submerged, 7/8/37, from 1000 ft. altitude.
- (T) Photograph of USS S-22, submerged, 7/8/37, from 1000 ft. altitude.
- (U) Photograph of USS S-22, submerged, 7/8/37, from 1000 ft. altitude.
- (V) Photograph of USS S-22, submerged, 7/8/37, from 900 ft. altitude.
- (W) Photograph of USS S-22, submerged, 7/8/37, from 700 ft. altitude.
- (X) Sample of Sea water - 50 ft. level.
- (Y) Sample of sea water - 75 ft. level.
- (Z) Sample of sea water - 100 ft. level.
- (AA) Formula for paint (PB 50% PBP 50%)  $\frac{2.2}{10}$  Munsell.
- (BB) Sample of paint (Munsell PBP 2.4/5.)
- (CC) Sample of paint - Munsell (75% PB 25% PBP)  $\frac{2.5}{4}$
- (DD) Sample of paint - Munsell (50% PB 50% PBP)  $\frac{2.2}{10}$ .

(Note by Naval Research Laboratory - Enclosures A to E and X to DD are omitted.)

1. In accordance with instructions received the services of Mr. Bittinger were arranged for and tests were scheduled in connection with camouflage of submarines against aircraft.

2. On 24 June 1937, a preliminary flight was made over the Pearl Harbor Area to acquaint Mr. Bittinger with local color and visibility conditions. From this flight it was apparent that the colors tentatively prescribed by reference (b) in plates 5 and 6 were not ideal for Hawaiian waters. Modifications were accordingly arranged in the colors chosen and the tests proceeded as outlined. (See Enclosure "A").

3. On 28 June 1937, a test with four submarines was conducted. Due to the failure of the paint from Mare Island to arrive on time, paints for this test and subsequent tests reported in this letter were mixed at the Submarine Base paint shop, Pearl Harbor, under the supervision of Mr. Bittinger.

4. The U.S.S. S-21, S-28, and S-35 were used as submerged vessels, with the U.S.S. S-25 as liaison by the plane for submerged vessels. This was a grey day, overcast, wind N.E. -1, knot, and sea N.E. -1. No difficulty was experienced in controlling the movements of the submerged vessels from the planes. The U.S.S. S-21 was painted a solid color described in the Munsell Scale as PBP 2-4/5. The U.S.S. S-28 was painted a normal black, Munsell Scale N2. The U.S.S. S-35 was painted a solid color described in Munsell Scale as (75% PB, 25% PBP) 2.5/4. Still pictures in black and white, still pictures in color, and moving pictures in color were taken on this day's operations. (See Enclosure "B").

5. At periscope depth, the U.S.S. S-21 painted a solid color, Munsell Scale PBP 2.4/5, appeared lighter than the surrounding sea (Enclosure "B"). At periscope depth the U.S.S. S-28 painted solid black, Munsell Scale No. N2, appeared darker than the surrounding sea. At periscope depth the U.S.S. S-35, painted Munsell Scale (75% PB, 25% PBP) 2.5/4, appeared darker than the surrounding sea. It was evident from this, that the first day's operations had straddled the proper color for Hawaiian waters. (See Enclosures "B", "I", "J", "K", "L", "M", and "N").

6. On the next run with the three submarines operating at seventy five feet there was no trace of the U.S.S. S-21 and the U.S.S. S-35 visible. The U.S.S. S-28, solid black, Munsell Scale N2 was barely discernable.

7. On the next run, the three submarines operating at one hundred feet, there was no trace of the vessels to be picked up. The vessels were then ordered to fire water slugs at two-minute intervals. Despite the slugs arriving on the surface, no trace could be picked up of the submarines. At that time the observer was at an altitude of approximately one thousand feet which was deemed to be ideal for observation. A relative appearance of the ocean color and the submarines at periscope depth is shown on Enclosure "B".

8. On 2 July, the second test was conducted. The U.S.S. S-21 and the U.S.S. S-35 each had colors as shown in Enclosure "C" in order to test color combinations and patterns. The day was bright and sunny with a very slight haze, wind 14 knots, sea 2. The U.S.S. S-25 was used as reference vessel and was placed midway on the surface between the U.S.S. S-21 and the U.S.S. S-35. The U.S.S. S-21 was painted black, Munsell Scale N2 for about 50% of its area and purple-blue, Munsell Scale PBP 2.4/5 as shown in Enclosure "C" for the remaining 50% of its area. The U.S.S. S-35 was painted 10% of its area black, Munsell Scale N2, 30% of its area purple-blue, Munsell Scale PBP 2.4/5, and the remaining 60% of its area, Munsell Scale (75% PB, 25% PBP) 2.5/4 as shown in Enclosure "C". Observations made at the time indicated that four or five days aging of paints had caused the colors to bleach somewhat, but that even this slight bleaching had marked effect, seemingly increasing the chance of detection as a result of having increased the percentage of reflection. This would seem to indicate that colors finally adopted should be nearly a fixed color with little or no tendency to bleach. To provide maximum protection for a period of time it might be advisable to paint with a slightly darker shade at the beginning. With the observer seeking the best view of the submarines, operating at an altitude varying from 800 to 1500 feet, the U.S.S. S-25 and the U.S.S. S-28 were not visible at 75 foot depths despite the fact that the water slugs were fired every minute. Following this the U.S.S. S-25 was operated submerged and operated at periscope depth at all speeds for short periods of time. This particular procedure was used with special observation of "turbulence". Throughout all the experiments every opportunity was taken to observe "turbulence" but the observer was unable at any time to detect any green which he could not definitely attribute to various lighter colored portions of the submarine, such as instruments, insulators, side light screens, JK heads, green grass, exposed red anti-corrosive paint, white seagrowths, etc. Areas not entirely wetted appear green at first. Any air, either from leaks, water slugs, or air entrapped at diving seems to coat the decks with green until the air is detached and arrives on the surface. Camera failure this date resulted in no black and white photographs. Observations of "turbulence" will continue.

9. On 8 July 1937 observations of the U.S.S. S-22 were made. The U.S.S. S-22 was engaged in an actual torpedo practice and the observations continued up until surface time. The U.S.S. S-22 was painted normal black, Munsell Scale (PB 50%, PBP 50%) 2.2/10. From the air the entire vessel was relatively hard to distinguish, the BLACK PORTIONS ONLY BEING DISCERNABLE. The blue used, (PB 50% PBP 50%) 2.2/10 appeared to be ideal for deep Hawaiian waters in bright sunshine and the very smooth sea encountered that day. The observers were able to locate the vessel principally by the periscope feather and those portions of the hull left painted black. The portions painted blue blended perfectly into the surrounding sea. From the air the submarine appeared to be a series of irregularly shaped black sections separated by sea. The results of this day were particularly gratifying because it was felt that proper shade of blue for Hawaiian waters had been attained. It is believed that the ideal would be two colors in large patterns, colors being approximately of the shade indicated by Enclosure "AA", put on a submarine in a generally irregular pattern but so arranged to break up any large straight lines, such as conning tower, decks, etc., with the approximate distance between patterns equal to the distance between wave crests. "See Enclosures "O", "P", "Q", "R", "S", "T", "U", "V" and "W". Enclosure "R" gives the best possible view of the day's operations.

10. The green halo generally found as a frame around the submarine hull is due to:

- (a) Grass at the water line or rust on hull.
- (b) Red anti-corrosive paint showing through black anti-fouling paint.
- (c) White or whitish sea growths, annelids, etc.
- (d) Any lighter than dark blue objects, such as peloruses, JK devices, bridge instruments, insulators, etc.

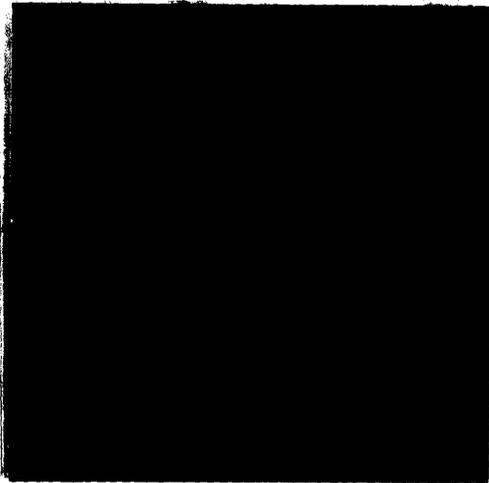
11. Model experiments conducted in Pearl Harbor on a rack towed alongside a motor launch showed no turbulence effect when the model was submerged to a depth of two feet and towed at a speed of seven knots. When the models were towed very close to the surface at a depth of about four inches, cavitation bubbles would form and adhere to the models masts with surprising tenacity. However, on deeper submergence the bubbles disappeared. No greenish color was visible.

12. The question of turbulence can not be dismissed lightly for, among other things, we have been able with QC4 equipment to take the range on the disturbed wake of a vessel as long as one half hour after the vessel was known to have created a wake. Two observers on 8 July 1937 firing runs were unable to see any turbulence effect on color. Mr. Bittinger saw it on one occasion.

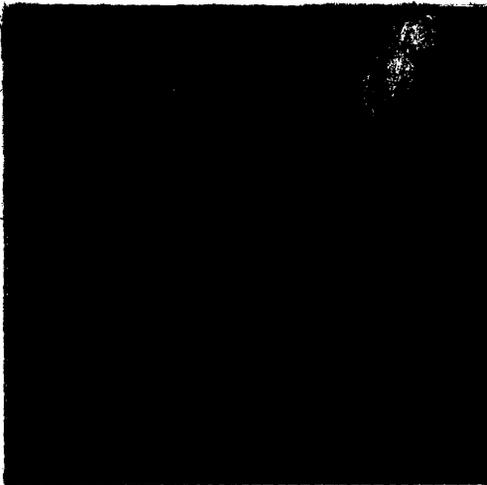
13. Having arrived at what is considered an excellent color on the U.S.S. S-22 on 8 July, the Squadron Commander feels that the principle object of the experiment has been attained. However, the green halo so visible on every submarine constitutes far more of a menace to invisible operations than the present black color of the submarines.

14. Any effort to remove water line grass or sea annelids results in

a Dark gray-blue  
too dark for deep  
Hawaiian waters



b Dark purple  
too light for deep  
Hawaiian waters



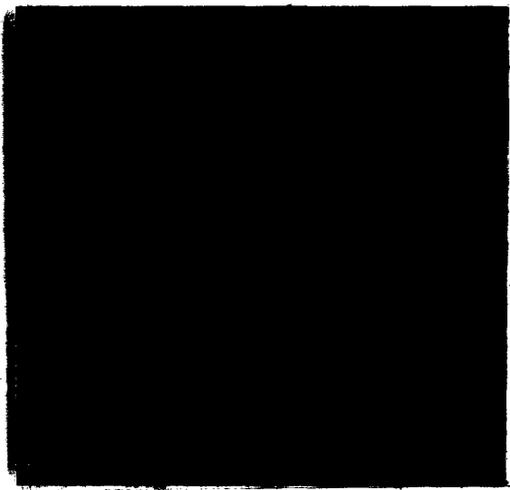
c Dark blue  
correct for deep  
Hawaiian waters

*7.5 PB 2/6 printed  
really about 1.5/6*

Low Visibility Colors

*(no copies of plates 1, 3, 4, 5, 7 & 8 available)*

Plate 2



Moderately dark blue  
suggested for water  
which is not optically  
clear.

5PB 3/8

Low Visibility Color