UNITED STATES

EXPERIMENTAL MODEL BASIN

NAVY YARD, WASHINGTON, D.C.

FOULING OF SHIPS' BOTTOMS

EFFECT OF PHYSICAL CHARACTER OF SURFACE

BY
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BUREAU OF
CONSTRUCTION AND REPAIR
NAVY DEPARTMENT

APRIL, 1935 REPORT NO. 398

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INTRODUCTION

Whereas there are many factors incident to the growth and propogation of marine life that determine the amount and degree of fouling, it is believed that the attachment of marine life is dependent, amongst other things, on the physical character of the submerged surface. The great bulk of research and experiment has been directed toward the prevention of marine life attachment by impregnating the surface with toxic substances. In no known case, however, has the physical character of the surface been evaluated in relation to the amount of fouling acquired in the many tests and observations made.

Outside of an identification of the type of marine life, fouling character has been the subject of an arbitrary scale. Hence the possibilities and the use of stereoscopic photographs were to be investigated to supplement the usual visual observations.

OBJECTIVES OF TEST

The broad objectives of this investigation were

(a) To determine the relative degrees of fouling as influenced by the character of the surface.

(b) To investigate the possibilities of stereoscopic photographic observations.

(c) To define the degree of fouling by

(1) The rate of growth.

(2) The volume of growth per unit area.

GENERAL PROCEDURE

For purposes of this investigation, a panel of CRS-1 steel plate 24" x 24" x 1/4" was to be suspended at a depth of 12 feet in sea water for a period of 28 weeks. One surface of the test panel was to be given a mirror finish while in the opposite surface, one half was to be untouched thus representing normal mill finish, and the other half to be coated with two coats of anti-corrosive and one coat of anti-fouling Navy Standard Shipbottom paint.

Once every four weeks the test panel was to be removed for observation and photographing. The photographs were to be stereoscopic for both surfaces.

DETAILS OF TEST

In view of the fact that no 1/4 inch thick CRS-1 grade material was readily available the test panel was made of 1/8 inch stock. To provide means for support during photographing, "ears" were provided at each end and at the mid point of each side of the test panel as shown in Fig. 1. This arrangement provided a clear area of 24 inches by 24 inches for observation.

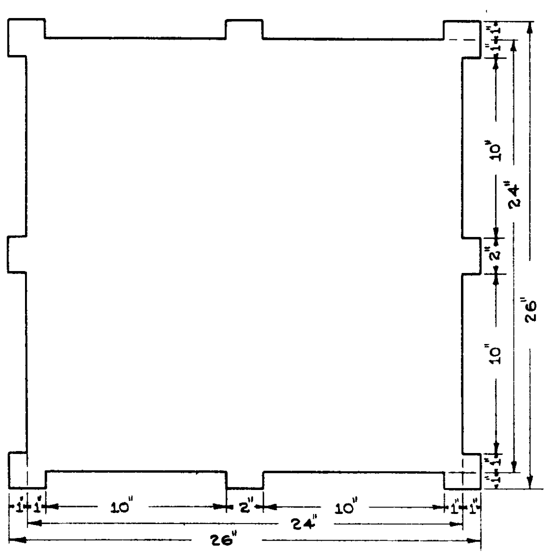


FIG. 1

For maintaining the panel face flat while being photographed, a frame support 26½ inches by 26½ inches, made of 1 inch by 1 inch by 1/8 inch angle was constructed. At the mid point of each side and at right angles thereto a 1 inch by 1 inch angle strut 8 inches long was welded so as to project 4 inches beyond the heel of the angle frame support. These struts were required for attaching the grid screen on the face side, along the 4 inch projection, and for securing the test panel at the rear side along the 3 inch projection. At about 1 3/4 inches from the end of the 3 inch projection, a small lug was welded. Inserting a wood batten, inside the lug, permitted wedging the test panel to the frame support. The dimensions of the "ears" were such as to permit fitting the test panel neatly within the frame, at the same time holding the 24 inch area clear of the frame. Any fouling that would gather on the "ears" could be removed without disturbing conditions on the remainder of the panel, thus assuring means of securing the test panel in the same relative position for each group of photographs.

A screen grid was constructed having a frame of 26½ inches by 26½ inches made of 1/2 inch by 1 inch by 1/8 inch angle. To the 1/2 inch leg horizontal and vertical wires were secured spaced approximately 8½ inches apart. These wires were of No. 26 Standard Wire Gage. In securing the wires, one end was anchored, the opposite end being secured with a small helical spring to the frame. This method permitted a definite tension to be maintained in the wire.

For attaching the grid screen, the angle strut welded to the frame support was drilled along the 4 inch projection with 1/4 inch hole spaced on 1/2 inch centers. Grid was to be located so that at least 1/2 inch should be maintained between grid and the nearest point of fouling.

It is the customary practice at the Norfolk Navy Yard to suspend test panels, in connection with fouling experiments, at a rack located at the submarine basin, Naval Operating Base. This location is some distance from the Navy Yard. Because of the facilities required in connection with the stereoscopic photographs, it was considered more advisable to suspend the test specimen in the Elizabeth River adjacent to the Navy Yard.

The test specimen was suspended with ropes in an approximate east-west direction to assure equal intensity of light on both surfaces.

A 5 inch by 7 inch Graflex camera, focal length of lens $8\frac{1}{2}$ inches, was used. The camera was set with the 7 inch dimension of the plate horizontal.

Stereoscopic photographs were made as follows.

(a) At a convenient position, determined solely by conditions of uniform lighting, an area of approximately 27 inches by 48 inches, the 48 inch dimension being horizontal, was marked off in a vertical wall – the place selected being a brick wall inside a store house (Building No. 29). The wall was painted a flat white. Above this area, two supports, spaced 20 inches apart, 14 inches from each end, were provided for hanging the frame and panel.

(b) The camera was set with the axis of the lens at right angles to the center of the above area. The distance between the photographic plate and the test panel was 80 inches. With the frame and test panel hung from one support, an exposure was made. At the conclusion of this, without moving the camera, the panel was transferred to the other support and another exposure made. The panel was then reversed in the frame and the above procedure repeated.

(c) For purposes of identification, a letter R was attached to the right support and a letter L to the left support. In addition a sign was carried at the bottom of the frame marked "Polished Surface" on one face and "Painted Surface" on the other face. The numbers attached to the sign identified the "group" to which the exposure applied. Photographs made just prior to submergence were numbered 1. Subsequent groups were numbered serially.

(d) For the surface of panel, half of which was painted as given above, the painted portion was located to the right hand when facing the frame.

(e) Two 200 watt lamps, with 24 inch reflectors were used to give uniformity to the illumination. This illumination was in addition to daylight.

OBSERVED DATA

Figs. 2, 3, 4 and 5 show the test panel just prior to initial submergency. Figs. 2 and 3 are the stereoscopic photographs for the polished finish face, and Figs. 4 and 5 for the painted face.

The panel was submerged June 6, 1934.

Figs. 6, 7, 8 and 9 were made on 5 July 1934 and show the test panel after 1 month's submergence. The observations made by the Norfolk Navy Yard at this period were:

Polished side: There were a few small barnacles but no rust in this side. A light slime covered the surface.

Painted side: No shell fouling or rust on painted section and the film was in excellent condition. On the unpainted section there were a few small barnacles but no rust. There was a light slime over the entire panel.

Figs. 10, 11, 12 and 13 show the result after two months' submergence and were made on 1 Aug. 1934.

The observations submitted by the Norfolk Navy Yard for this period were:-

Polished side: There were sixteen barnacles ranging in diameter from 1/4 inch to 1/2 inch, six about 1/8 inch diameter, and a few smaller. Fouling grade 90.

There was a light slime over the panel. The only corrosion was that from the medium steel sister hooks used to suspend the panel under water.

Painted side: The painted section was covered with slime but there was no shell fouling. Fouling grade 98. The paint film is cracked (vertically). On and near the edges there are bare spots due to abrasions when fitting panel in frame at previous inspections. The unpainted half had thirty barnacles ranging in diameter from 1/8 inch to 1/4 inch, twelve ranging in diameter from 1/4 inch to 1/2 inch, and a light spray of smaller barnacles. Fouling grade 75.

Coincident with the submergence of the test panel in Elizabeth River adjacent to the Navy Yard, there was submerged a similarly prepared panel at Hampton Roads on June 7, 1934. The following report covered an inspection of this panel.

On August 1, 1934, this panel was practically covered with heavy ascidians on unpainted sections. There was no difference between polished and unpolished surfaces with respect to fouling. It has been the experience here that ascidians attach spasmodically and in dispersed localities. Entire fouling seasons may pass at the test rack without an attack of ascidians. Ascidians grow rapidly and usually fall off (become detached) within two months after attachment. They are not regarded as an important factor in fouling prevention since they are too soft to withstand normal erosion of the water when vessel is underway.

Continuing its report, the yard added, "The most significant development in this test is the rapid galvanic action of the medium steel sister hooks holding the panel. The original 5/8 inch wire has been reduced fifty per cent. The hooks will be renewed at the next inspection, August 22, 1934."

Figs. 14, 15, 16, and 17 show the results after three months' submergence. These photographs were made on August 31, 1934. The report of the yard's observation follows:

Polished side: There were 13 Balanus barnacles about 1/2 inch in diameter, 12 about 1/16 inch in diameter, and a light layer of silt. The fouling grade was 80.

Painted side: The painted section had no fouling on it except light silt and was graded 98 as to fouling. There was no corrosion except "run downs" from steel hook holding panel in water. The paint film showed a few abrasions from handling and was thin,eroded. The grade assigned for film conditions was 85. The unpainted section had 28 Balanus barnacles 1/2 to 3/4 inch in diameter, 21 about 1/4 inch in diameter and numerous smaller (embryo) barnacles, a few 1/2 inch long hydroids and a light layer of silt. The fouling grade was 60. There was no corrosion from the panel.

Figs. 18, 19, 20 and 21 show the results after four months' submergence. These photographs were made on Sept. 26, 1934. The report of the yard's observation follows:

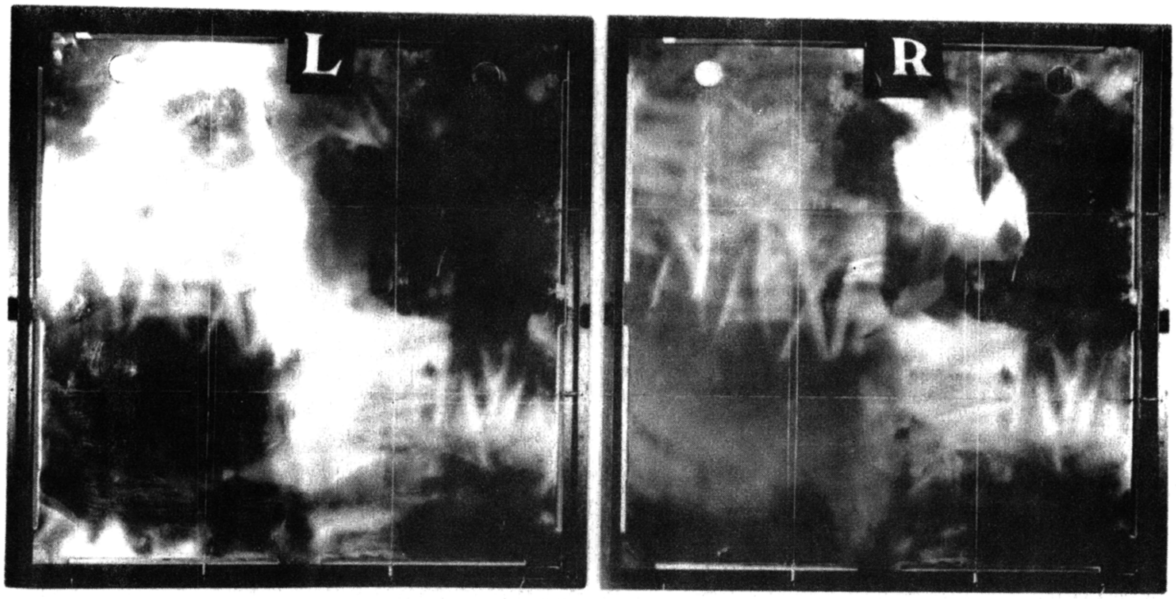
Polished side: There were 18 Balanus barnacles 1/4 inch to 3/4 inch in diameter and many (21 counted) smaller ones. A grade of 75 was assigned for fouling. There was no corrosion on the panel.

Painted side: The painted section had no fouling except a light layer of silt and was graded 98 for fouling. There was no corrosion except "run downs" from hooks. The paint film was scarred near edges and was thin. It was graded 80. The unpainted section had 39 Balanus 1/4 inch to 3/4 inch in diameter and numerous (22 counted) smaller ones. A grade of 60 for fouling was assigned. There was no corrosion of the panel.

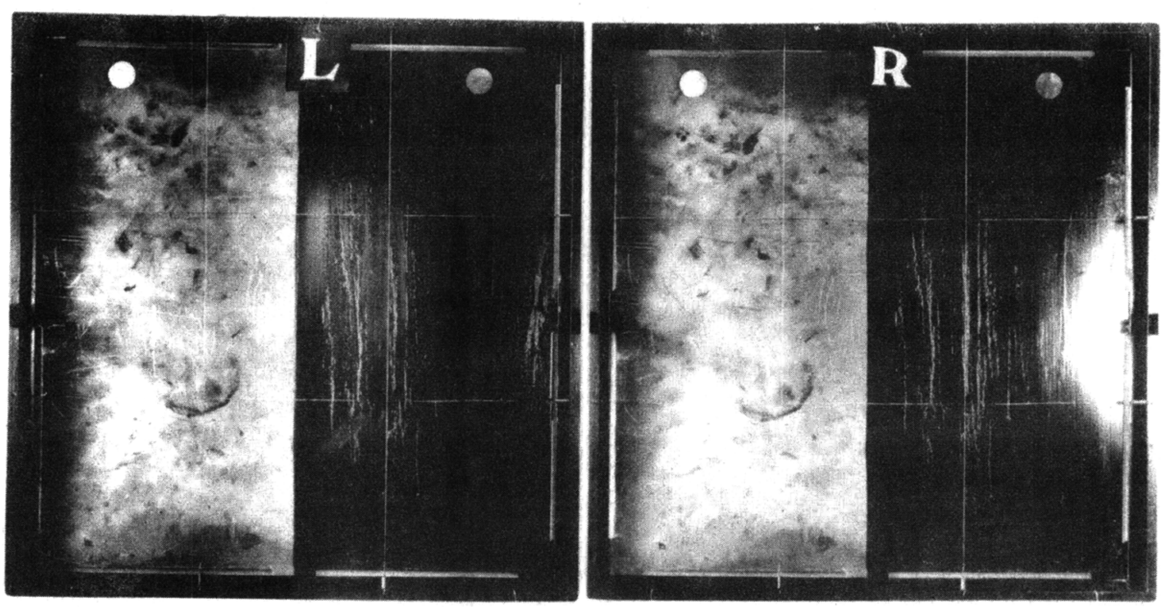
Figs. 22, 23, 24 and 25 represent conditions at the end of the fifth month of submergence. These photographs were made Oct. 24, 1934. The yard's observations for this period follow.

Polished side: There were 36 Balanus barnacles 1/4 inch and larger in diameter and 75 to 100 smaller ones. A grade of 70 was assigned. There was no corrosion from the panel.

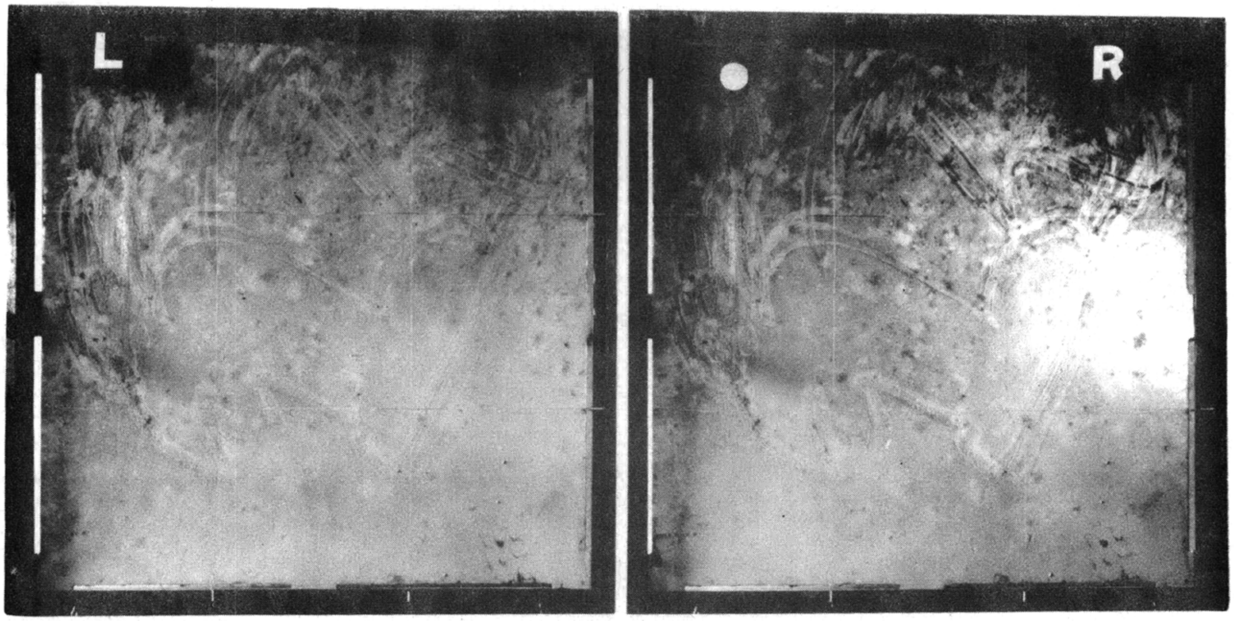
Painted side: The painted half had no fouling except silt. Grade 95 for fouling was assigned. There was no corrosion from the panel. The paint film was off around edges (scars from handling) and was quite thin. The film showed "silking" – numerous, short, vertical "checks". A merit grade of 80 for the film was assigned. On the unpainted half there were 40 Balanus barnacles 1/4 inch and larger in diameter and about 100 smaller ones. A grade of 50 was assigned for fouling. There was no corrosion from the film.



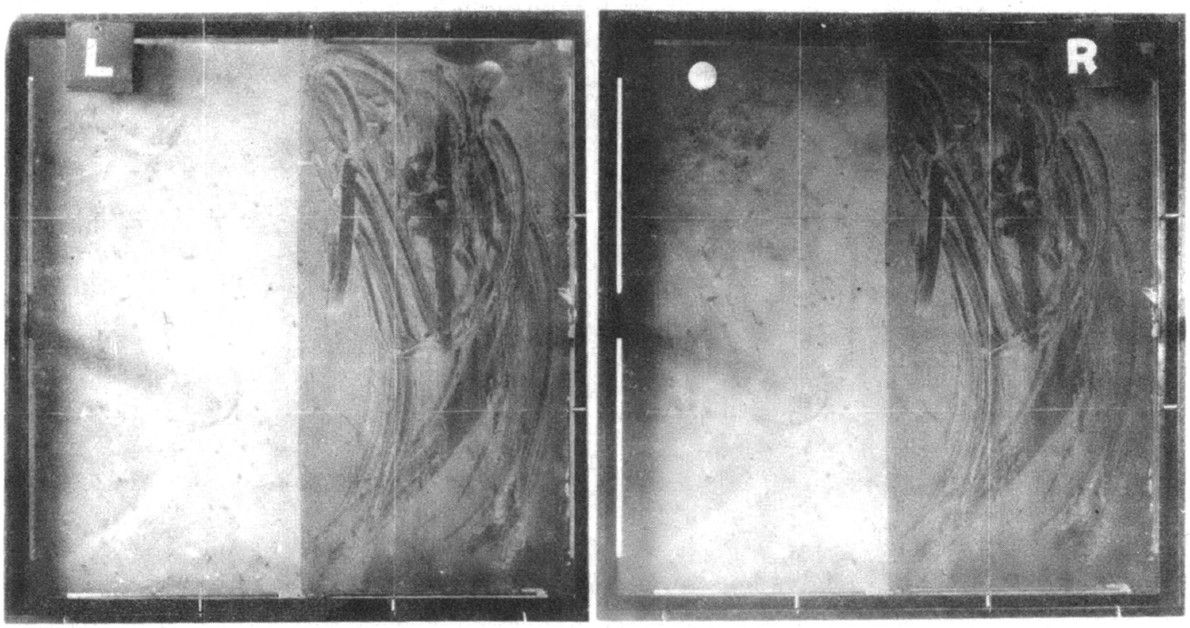
FIGS. 2 and 3. STEREO VIEWS OF POLISHED SURFACE PRIOR TO SUBMERGENCE.
6 June, 1934.



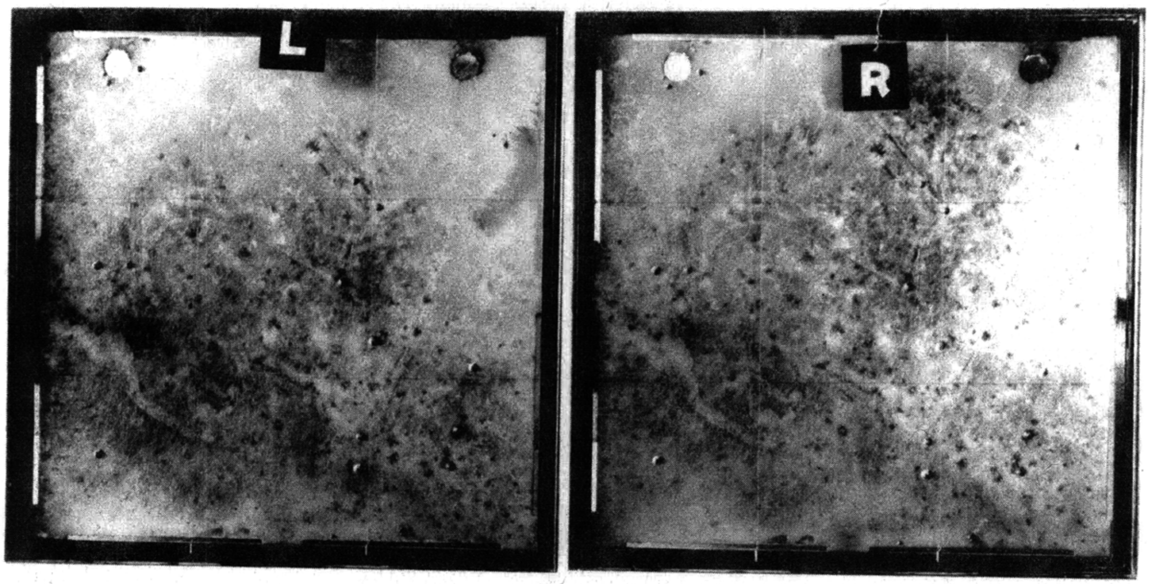
FIGS. 4 and 5. STEREO VIEWS OF UNPOLISHED SURFACE PRIOR TO SUBMERGENCE.
6 June, 1934. The right halves show the painted portion.



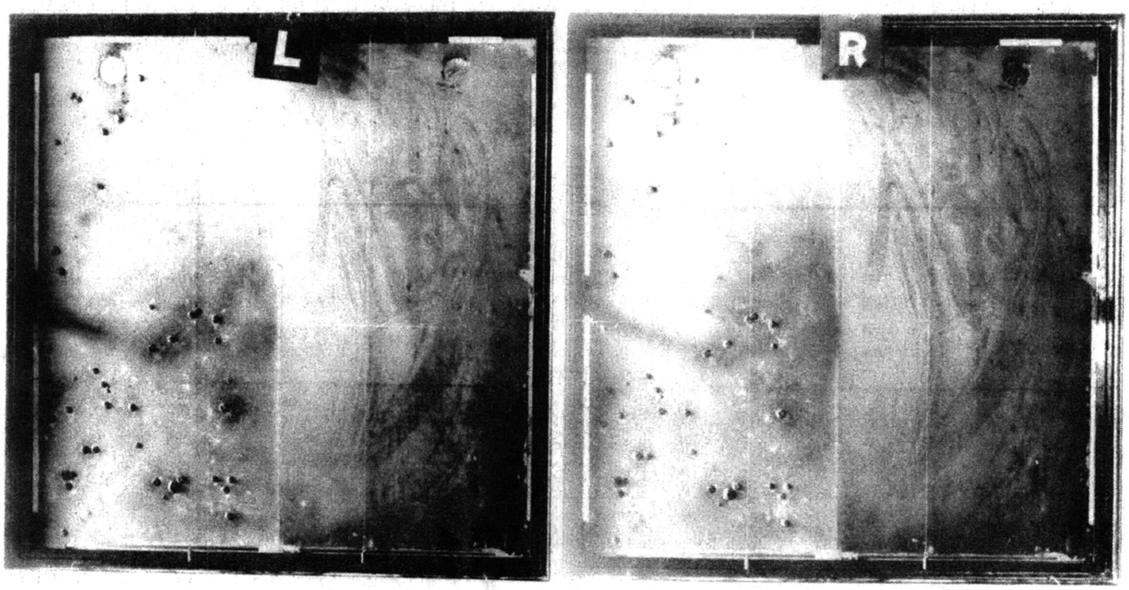
FIGS. 6 and 7. STEREO VIEWS OF POLISHED SURFACE AT THE END OF ONE MONTH'S SUBMERGENCE. 5 July, 1934.



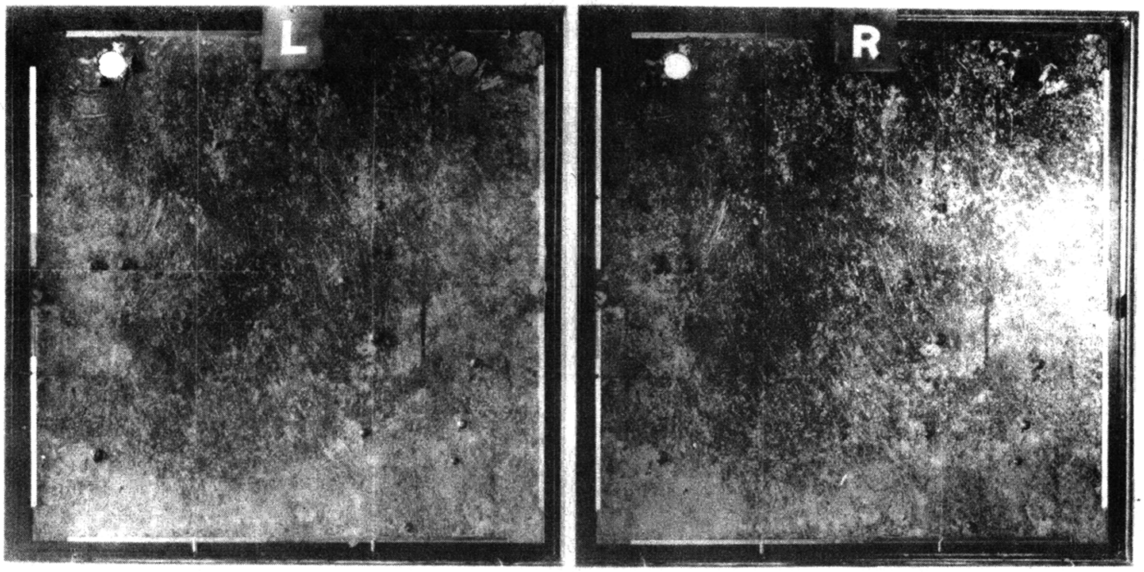
FIGS. 8 and 9. STEREO VIEWS OF UNPOLISHED SURFACE AT THE END OF ONE MONTH'S SUBMERGENCE. 5 July, 1934. The right halves show the painted portion.



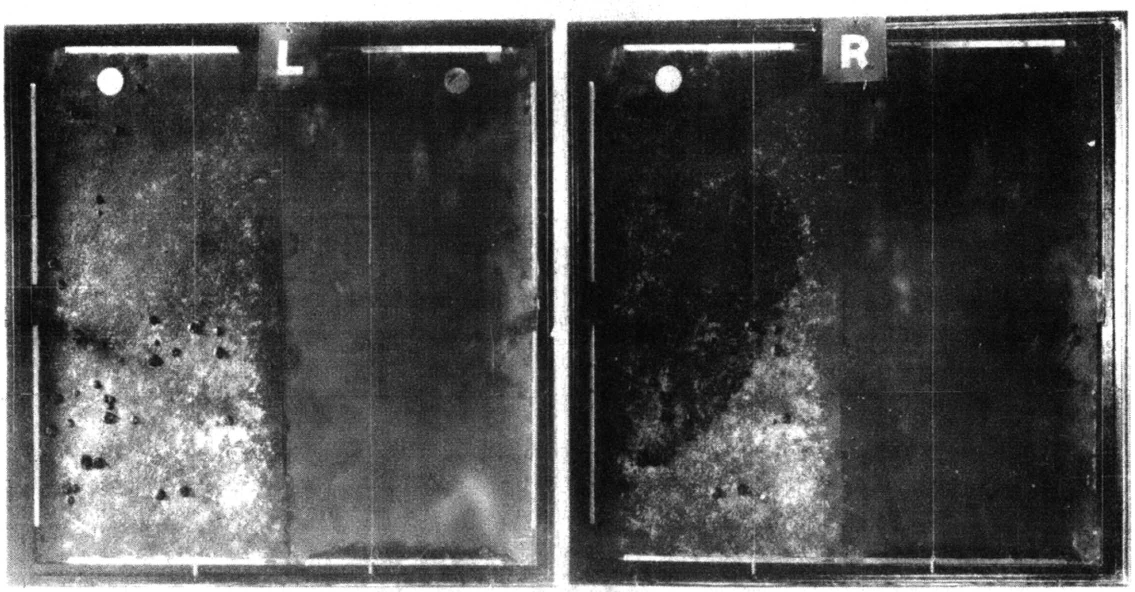
FIGS. 10 and 11. STEREO VIEWS OF POLISHED SURFACE AT THE END OF TWO MONTHS' SUBMERGENCE. 1 August, 1934.



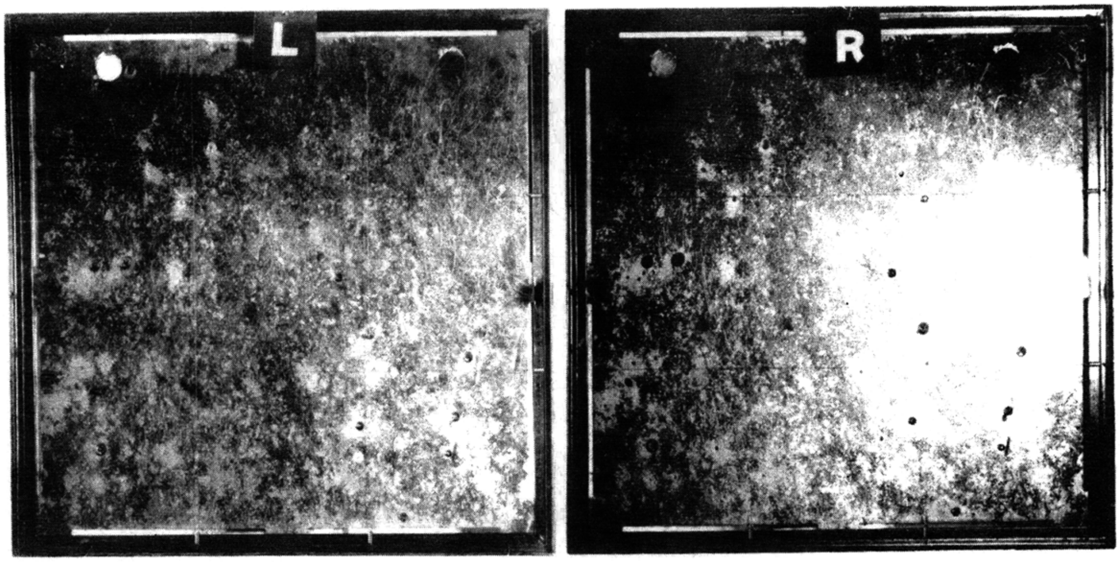
FIGS. 12 and 13. STEREO VIEWS OF UNPOLISHED SURFACE AT THE END OF TWO MONTHS' SUBMERGENCE. 1 August, 1934. The right halves show the painted portion.



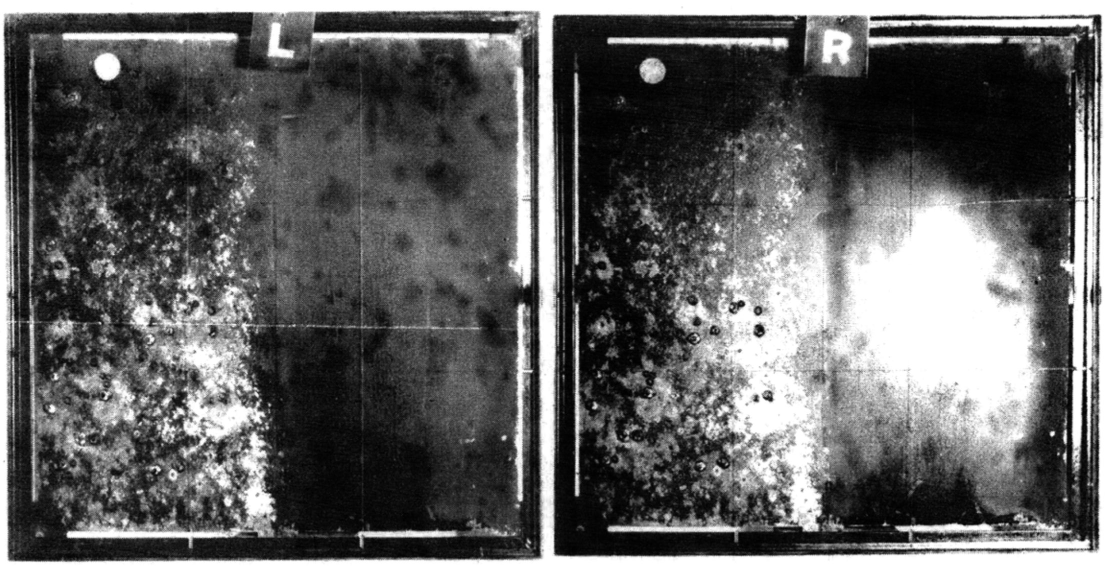
FIGS. 14 and 15. STEREO VIEWS OF POLISHED SURFACE AT THE END OF THREE MONTHS' SUBMERGENCE. 31 August, 1934.



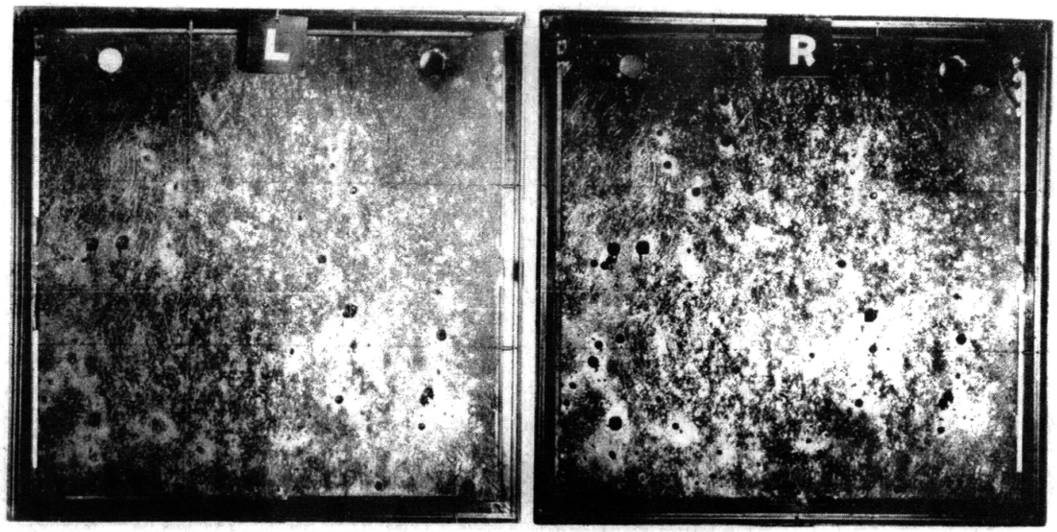
FIGS. 16 and 17. STEREO VIEWS OF UNPOLISHED SURFACE AT THE END OF THREE MONTHS' SUBMERGENCE. 31 August, 1934. The right halves show the painted portion.



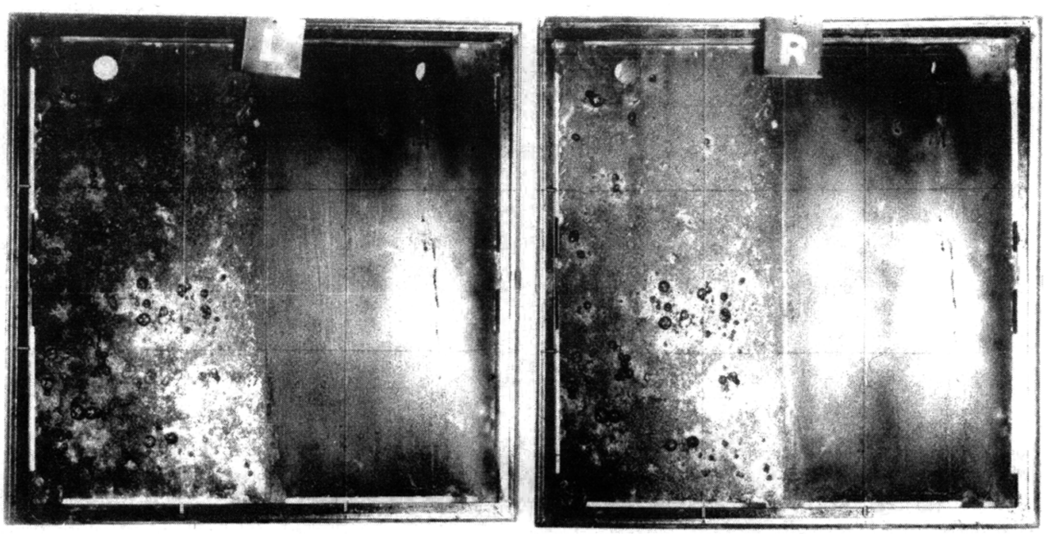
FIGS. 18 and 19. STEREO VIEWS OF POLISHED SURFACE AT THE END OF FOUR MONTHS' SUBMERGENCE. 26 September, 1934.



FIGS. 20 and 21. STEREO VIEWS OF UNPOLISHED SURFACE AT THE END OF FOUR MONTHS' SUBMERGENCE. 26 September, 1934. The right halves show the painted portion.



FIGS. 22 and 23. STEREO VIEWS OF POLISHED SURFACE AT THE END OF FIVE MONTHS' SUBMERGENCE. 24 October, 1934.



FIGS. 24 and 25. STEREO VIEWS OF UNPOLISHED SURFACE AT THE END OF FIVE MONTHS' SUBMERGENCE. 24 October, 1934. The right halves show the painted portion.

Upon recommendation of the Navy Yard that from the indications noted above coupled with the conclusion of the fouling season no further data seemed necessary, the investigation was terminated.

ANALYSIS OF DATA

Prior to a discussion of the methods employed in analyzing the data, it is considered advisable to consider certain aspects of stereoscopic photography.

THEORY OF STEREOSCOPIC MEASUREMENTS

As in normal vision with two eyes, the stereo effect is obtained by viewing the subject simultaneously from two separate points of view. Other things being constant, the length of an object in the line of sight is a function of the parallax produced between the nearer and farther points of the object by the separation of the two points of view.

In making stereo views photographically, it is evident that a single lens camera may be used, provided, of course, that the objects in the field of view do not move relative to each other. This is accomplished by taking successive pictures from the two points of view. The stereo effect is produced when these photographs are properly mounted and viewed in a stereoscope.

To obtain an expression for the relation between depth in the line of sight and parallax consider Fig. 26. P and Q are the end points of the object whose length h is to be determined. LAB is the camera, L the lens, and AB a line in the focal plane of the camera. f is the perpendicular distance from lens to photographic plate. Let P'Q' represent the object PQ when in its second position relative to the camera, t being the displacement normal to the optical axis of the camera. Obviously it is immaterial whether the object with its background or whether the camera is moved to obtain the two required points of view.

The case is general but for the purpose of simplifying the geometry of the derivation, for view No. 1, the right view point, let P be directly in front of Q. Then on the photographic plate the displacement of the image P from that of Q will be zero. For view No. 2, left view point, the displacement between the images is (s), the end points P' and Q' appearing at p' and q'. D is the distance from object to the lens of the camera. Then from Fig. 26

$$\frac{h}{S} = \frac{D}{t - S} \quad \ldots\ldots\ldots\ldots \quad (1)$$

In the application to this problem, S is small compared with t. At most, S is about 0.005 t and hence may be neglected in the term (t – S). Equation (1) thence reduces to

$$h = \frac{SD}{t} \quad \ldots\ldots\ldots\ldots \quad (2)$$

Also, $\frac{S}{D} = \frac{s}{f}$. Therefore substituting for S in equation (2)

$$h = \frac{D^2 s}{f\,t} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

In Fig. 27, where D and f denote the same dimensions as in Fig. 26, let MN represent the actual length of some known object at right angles to the camera's optical axis. Let M'N' be the length of the object's image on the photographic plate. Then, from similar triangles

$$\frac{f}{D} = \frac{l'}{l} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Substituting for f in equation (3)

$$h = \frac{Dl}{l't}\, s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

$$= K\, s \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

For a given set of plates, the quantity $\frac{Dl}{l't}$ is a constant and is determined from direct measurement of the indicated factors.

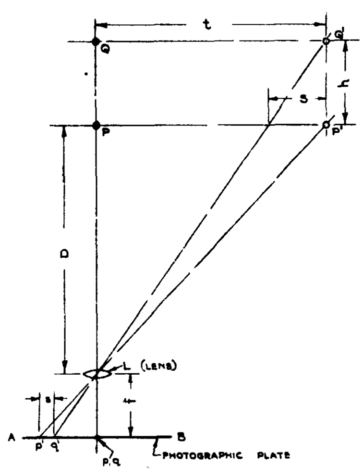


FIG. 26

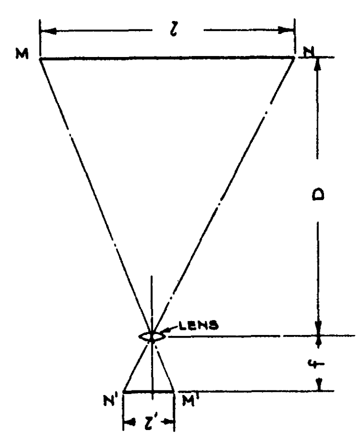


FIG. 27

APPLICATION OF THEORY

The parallax (s) is determined by measuring the displacement of a moving point in the stereoscope. Having mounted the photographs in correct relation, a fixed point is initially located at any desired position over one of the stereo views. The movable point is then placed at the corresponding position over the other stereo view. A stereo or space view causes the fixed and movable points to appear as one point in space and at the same distance from the observer as is the reference point selected in the field. Transverse motion of the movable point to right or left makes the space point appear to move towards or away from the observer. The amount of transverse motion required to make the space point appear to move from the forward to the rear end of the objective or selected subject is the parallax due to the depth in the field of view of the subject.

In practice this parallax is readily measured by securing the movable point to a calibrated micrometer screw and noting the motion, s. This value of s used in equation (5) or (6) gives the value for h of the particular objective observed.

In the arrangements actually employed for Figs. 2 to 25 inclusive, D was equal to 71.2 inches, l, 24 inches, and t, 20 inches. l' is the length of the image of the 24 inch plate on the enlargements made from the original negatives. The amount by which the negatives were enlarged was not identical for each set of pictures. The values of l' for the enlargements for the different groups of negatives are given in table 1.

TABLE 1

Value of l' for enlargement
of each group of plates

l' = length of 24 inch plate on enlarged print
R = scale ratio; i.e. 24 divided by l'
K = constant for the height, equation (6)

GROUP	TIME	l'	R	$K = \frac{DR}{t}$
1	0			
2	1	6.85	3.50	12.5
3	2	6.94	3.46	12.3
4	3	6.37	3.77	13.4
5	4	6.22	3.86	13.7
6	5	5.92	4.06	14.4

In the analysis of the growths observed, only the barnacle growth is treated quantitatively; the number of barnacles, their base diameter, and their height being considered. The remainder of the growth only admits of a qualitative description as detailed above for each observation.

RESULTS OF TEST

Table 2 gives a summary of the average observed measurements. The volume of the barnacles has been computed on the assumptions as outlined in Appendix 1.

Fig. 28 has been prepared from data given in table 2.

TABLE 2

RATE OF BARNACLE GROWTH ON CR STEEL SURFACE

Barnacles of base diameter less than 0.10 inches are omitted in this Summary.

NO. OF BARNACLES	NO. PER SQ. FT.	AGE OF GROWTH IN MOS.	AVE. DIAM. IN INCHES	AVE. HEIGHT IN INCHES	VOL. OF GROWTH IN CU. INCHES PER SQ. FT.
		FOR UNPAINTED MILL FINISH			
0	0	0	0	0	0
		1			
43	21.5	2	0.358	0.190	0.2056
37	18.5	3	0.447	0.183	0.3874
45	22.5	4	0.410	0.204	0.4063
70	35	5	0.401	0.151	0.4834
		FOR SURFACE POLISHED TO MIRROR FINISH			
0	0	0	0	0	0
		1			
19	4.75	2	0.331	0.181	0.0434
16	4.0	3	0.447	0.243	0.0865
25	6.25	4	0.411	0.196	0.1124
45	11.25	5	0.436	0.212	0.2240

DISCUSSION OF RESULTS

The selection of a polished surface, a mill finish surface, and a painted surface was taken as representative, qualitatively, of a smooth, medium, and moderately rough surface. Since no barnacle growth has been observed on the surface painted with Navy Standard Shipbottom paints, it would appear that the physical character of surface was subordinated to the toxicity of the substances applied to the surface. On the other hand, as between the bare surfaces, there is definitely less per unit fouling on the polished surface than on the mill surface.

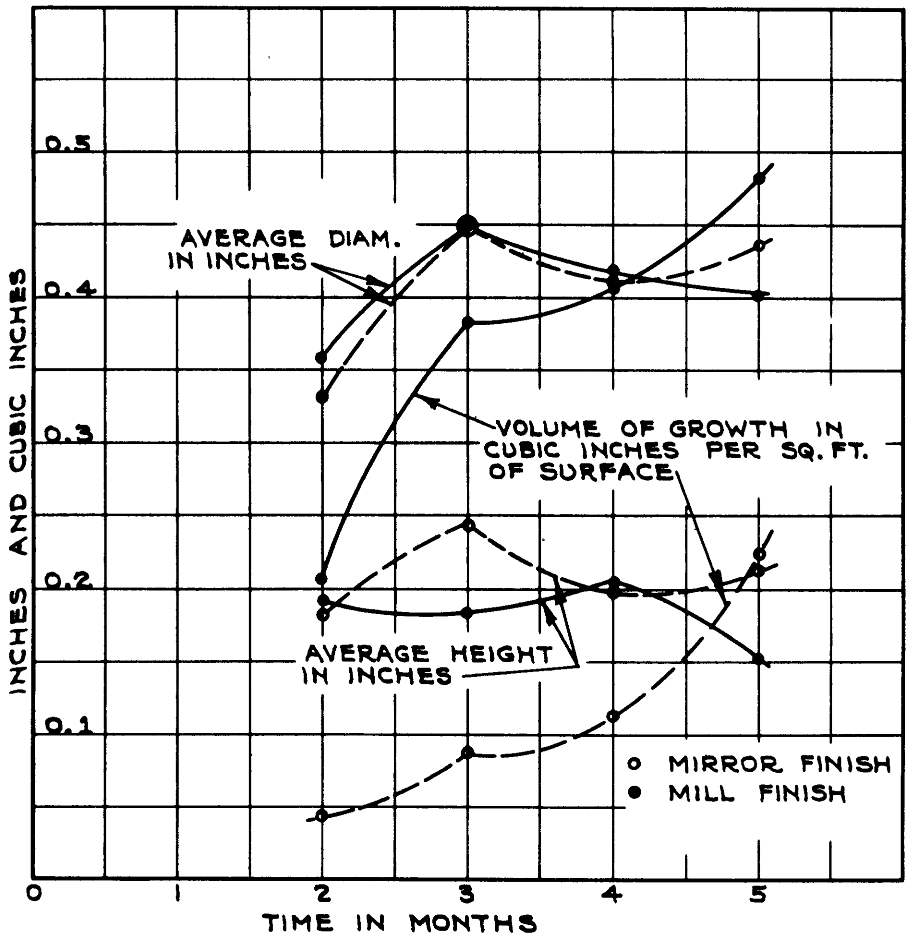


FIG. 28 VARIATION OF AVERAGE HEIGHT, DIAMETER, AND VOLUME OF GROWTH OF BARNACLES WITH AGE

With reference to Fig. 28, it should be observed that the curves, as drawn, are not exact. That is to say, all points on each curve have been connected primarily for purposes of identification. No doubt some experimental errors may be included which will account for apparent changes in direction of the curve. However, disregarding these variations, the spots do indicate, in general, the trend of the curve. The curve giving the average diameter of the barnacles is fairly representative of actual conditions. On the other hand, the average height curve is subjected to some error. It was not possible to measure the height of barnacles with any consistent degree of accuracy because of the presence of silt and slime on the surfaces. The utilization of the cross wires or grid as a base plane for reference of all measurement normal to the surface did not prove entirely satisfactory because of the great area of exposed portions between the grids, and the impossibility of maintaining exactly the space picture of an objective for transference to the grid. Furthermore, the problem was complicated by the buckling of the plate following successive inspections and resubmergence.

Despite these limitations, the curves given in Fig. 28 are indicative of fouling characteristics. The fouling growth on the unpainted or mill finish surface is, as shown, fairly close to a straight line. This is indicative of a constant accelerated rate of growth. The polished surface, however, indicates a slow initial growth followed, apparently, by an increasing accelerated growth. As between the two, the rate of growth on the polished surface is approximately one quarter of that experienced on the unpainted or mill finish surface.

Heretofore the question of comparative fouling has resolved itself into a qualitative estimate. With stereoscopic photography it is possible to evaluate conditions quantitatively. In this particular test it has been considered advisable to calculate the volume of excrescences and to express therefrom a rate per unit area. Another possible method of analysis is to calculate the total area occupied by marine life irrespective of the average height or growth normal to the surface. In other words, some rational method of calculation and analysis is possible.

In addition to this distinct advantage, stereoscopic photographs permit a record capable of measurement not only at one period, but at any time thereafter. Measurements made directly from the test specimen can never be duplicated after submergence. Stereoscopic photographs, like all photographs, preserve a measurable record of each observation.

CONCLUSION

It is concluded, therefore, that

(a) Whereas no fouling growth was attached to the painted section of this test panel, it is known that fouling will attach itself to areas coated with Navy Standard Shipbottom paint. What the corresponding experience on the other two surfaces would have been under this condition is a matter of conjecture.

(b) From these tests, the physical character of the surface does have some influence on fouling, though this seems subordinated to the toxicity of substances coated on the surface.

(c) To what extent the polished surface was truly similar to a mirror finish can not be estimated. Had this been possible, then the observed data would have been qualified to the same extent.

(d) Stereoscopic photography furnishes a new avenue for the quantitative study of fouling.

(e) Future observations should be limited to thickness of plating that will not buckle.

APPENDIX 1
THE VOLUME OF A BARNACLE

To simplify and shorten the labor of computing the volumes of the barnacles the assumptions, that the barnacles are truncated cones and that they are geometrically similar regardless of size, were made. The proportionate dimensions adopted were found by averaging results from measurements on numerous barnacles of various sizes. These proportionate dimensions are given in the figure 29.

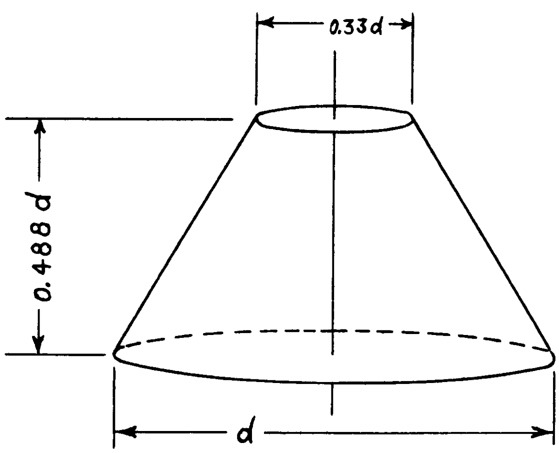


FIG. 29

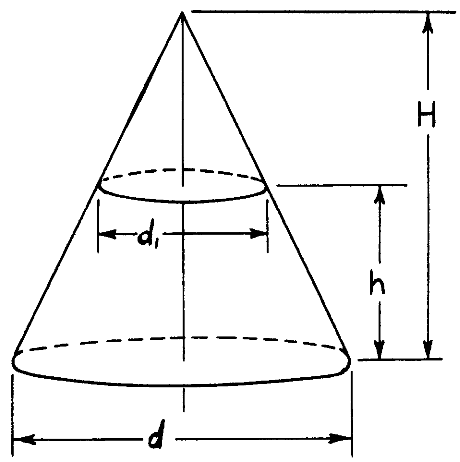


FIG. 30

To derive an expression for the volume of this truncated cone consider Fig. 30. The volume of the large cone is

$$\frac{\pi}{12} d^2 H$$

The volume of the top small cone is

$$\frac{\pi}{12} d_1^2 (H - h)$$

The volume of the truncated cone is the difference of the two above volumes or

$$V_B = \frac{\pi}{12}\left[d^2 H - d_1^2 (H - h)\right] = \frac{\pi}{12}\left[H (d^2 - d_1^2) + d_1^2 h\right] \quad \ldots\ldots\ldots (1)$$

But $\frac{H - h}{d_1} = \frac{H}{d}$

or $H = \frac{hd}{d - d_1}$, $\therefore V_B = \frac{\pi}{12} h \left[d^2 + d_1 d + d_1^2\right]$.

Also from the proportionate dimensions in Fig. **29**

$$h = 0.488\ d \quad \text{and} \quad d_1 = 0.33\ d\ .$$

Substituting these values in equation (1) and reducing gives

$$V_B = 0.184\ d^3\ ,$$

the desired function in terms of the base diameter of the barnacle.