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UNDERWATER STEREO PHOTOGRAPHY FOR HULL INSPECTION.(U)
FEB 80 J MITTLEMAN
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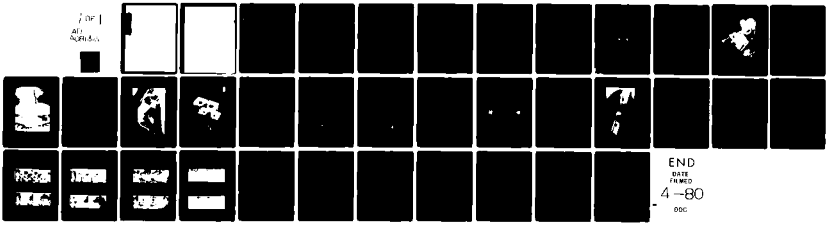

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A low cost system for taking underwater stereo photographs is described and background information covering the basic mathematics of stereophotography is presented. This system allows divers with no prior experience or skill in underwater photography to take high quality stereo photographs of ship's hulls. The photographs, which cover an area of about 2 inches by 3 inches, show such features as corrosion pits, paint blisters, and fouling organisms in great detail. Elevations or pit depths can be measured with an accuracy of about 1/64 over

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of an inch. Several examples of stereophotographs taken with this system are included in the report.

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INTRODUCTION

This report was written in response to numerous requests for a description of an underwater stereoscopic camera apparatus built at NCSC in late 1977. The device described in this report is inexpensive to build, easy to use, and can help the Navy diver produce pictures of consistently high quality. The main disadvantage of the stereo camera assembly described in this report is that the area covered in the photos is very small, approximately 2 in. by 3 in. (51 x 76 mm).

There are many applications where a small field of view is totally unacceptable; however, some of the more important ways in which a ship's hull ages are revealed by small scale phenomena which can be recorded quite adequately by photographing a 2- by 3-in. area. Some of the important signs of age on a ship's hull include:

- Corrosion pitting
- Blistering
- Cracks
- Fouling organisms

By using close-up photography the important but minute details of these phenomena are readily visible in the photograph.

Underwater stereo photographic inspection allows topside personnel to see in three dimensions what is happening on the ships hull underwater. For example, with this capability the tiny blisters which form under a paint layer can be seen before they break (pop) giving adequate warning to the ship's engineer. Similarly, by viewing corrosion pits in three dimensions the ship's engineer is able to assess the seriousness of any corrosion problems which the divers may have found. And, a final thought, if a diver can produce high quality pictures with three dimensional information on them, the credibility of his reports to the ship's engineer or or captain will be greatly enhanced. All of these factors help the topside personnel make the right maintenance decisions at the right time; and is a particularly good reason why the underwater stereo camera apparatus is a valuable tool for many Fleet diving inspections.

THE STEREOSCOPIC EFFECT - THREE DIMENSIONAL PHOTOGRAPHY

The fact that we have depth perception, or can see in three dimensions, is attributable to our two eyes and not one. Each eye sees the foreground in a slightly different relation to the background, and our brain comes up with depth perception by combining these two perspectives. If you hold one thumb up at arms length and first close the right eye, then close the left eye and open the right eye, you will see that your thumb shifts in position relative to the background. Now open both eyes and you'll see your thumb clearly in three dimensions, and if, while keeping your eyes focused on your thumb, you try hard to become aware of the background you'll see that you are seeing double. Now if you could put a camera at each eyeball and take a photograph from each position you would again get two distinctly different perspectives on your thumb with respect to the background, and if you could look at the left picture with your left eye and the right picture with your right eye you would find that a three dimensional effect was produced from the photographs. Figure 1 shows a small circle which is supposed to be in the background and a small "x" which is supposed to be in the foreground. In order to see this little picture in three dimensions, place something like an 8½ x 11 in. sheet of cardboard upright between the circle and the cross on the left and the circle and the cross on the right; then put your nose on the edge of the cardboard so that your left eye can only see the left pair and the right eye can only see the right pair. Give yourself a few minutes until the images fuse, then you'll see the three dimensions.

In order to produce stereo photographs (three dimensional) two cameras must be used to take a picture of the same object, or with one camera take one picture and then move over a couple of inches and take another picture. In designing the stereo camera apparatus to be as inexpensive as possible it was decided to use one camera moved from one position to another instead of two cameras. To ensure that the camera is moved the correct distance in the same plane between subsequent photographs the stereo camera apparatus is designed with a tray that accepts the camera and is moved from left to right by a parallel linkage.

DESIGN FEATURES OF THE STEREO CAMERA APPARATUS

Usually underwater photographs taken by divers without too much photo experience are out of focus and poorly exposed. To complicate these usual shortcomings by asking the diver to take two photographs of the same object from precise locations relative to lateral camera positions and distance from the subject would be a catastrophe without some

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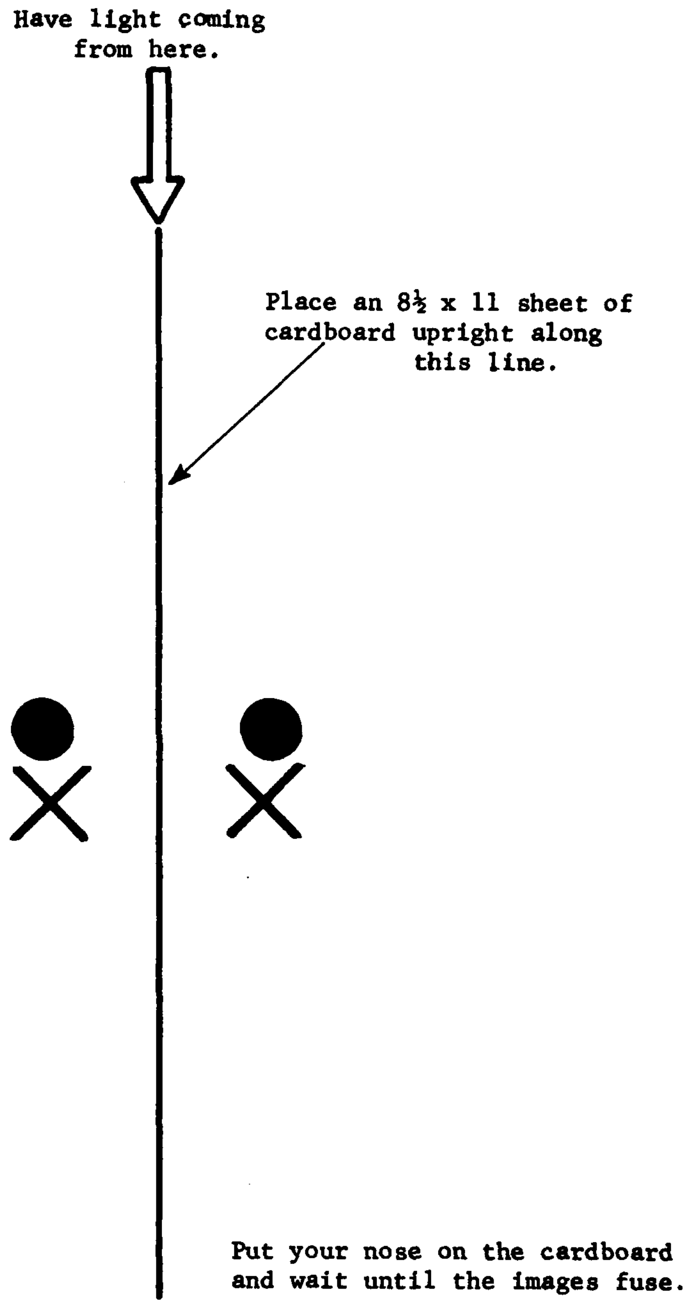

FIGURE 1. STEREO VIEWING DEMONSTRATION

kind of gadget to help him. A fixed distance plexiglas box to hold the camera was provided. Versatility and the area of photographic coverage had to be sacrificed, but the advantages are that with a fixed distance from the hull the focus of the camera can be preset ahead of time and the focus will always be exact for a sharp picture. The aperture, or f-stop, is also fixed beforehand and is always correct as long as the same electronic flash is used at the same distance. In a way, this turns the Nikonos* camera into an Instamatic where it is only required to position the camera and squeeze the shutter release.

By placing a plexiglas box between the camera and the hull and filling the box up with clear water, the problem of underwater visibility can be virtually eliminated because the camera is shooting through clear water at all times. So, in an effort to produce three dimensional photographs from which engineering measurements from hull inspections could be made the problems of focus, lighting, and visibility were solved serendipitously at a small expense of versatility and the image area covered.

HARDWARE FOR UNDERWATER STEREO PICTURES

The elements of the stereo camera apparatus are:

- Nikonos camera
- 3:1 close-up tube
- Electronic "strobe" light
- Clear water box

Figure 2 shows the elements of the stereo camera apparatus separately. The rest of this section describes the design of the clear water box.

STANDOFF DISTANCE

The Nikonos 3:1 close-up tube comes with a set distance wire frame with which the photographer is supposed to frame his subject. This frame is necessary due to the relatively short depth-of-field experienced in close-up photography. The frame was used in the construction of the plexiglas box to determine the proper distance of the camera from the

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*A self-contained underwater 35 mm camera.

(Text Continued on Page 6)

FIGURE 2. STEREO UNDERWATER CAMARA APPARATUS

hull. The dimension of the clear water box from the hull to the camera lens is essentially the same as the distance provided by the wire frame that comes with the 3:1 close-up tube. The front plexiglas face of the clear water box is actually recessed ½ in. by four steel pins which serve as legs at the corners of the clear water box to provide for small marine growth, such as barnacles. These pins hold the front face of the box off of the hull. The camera is mounted behind the clear water box so that the camera lens is in contact with the rear plexiglas face of the box. With the camera set at its shortest focus, 2.75 feet (83.8 cm), and the 3:1 close-up tube inserted between the camera body and the camera lens, the distance from the front of the lens to the subject; i.e., the ship's hull, is 6 7/8 inches (17.5 cm). This is the only critical dimension of the clear water box. The top-to-bottom (short dimension of 35 mm film) and side-to-side (long dimension film) dimensions need only be large enough to cover the field of view of the camera in both the left and right positions. In one of the first models of the clear water box, the dimensions of the front and rear plexiglas faces were 4¼ inches (10.8 cm) from top-to-bottom and 6½ inches (16.5 cm) side-to-side.

CONSTRUCTION MATERIAL FOR THE CLEAR WATER BOX

The front and rear faces of the clear-water box are made of 3/8 inch plexiglas. This material is particularly suitable for use underwater because it is transparent, has a reasonably strong impact strength, and scratches in the plexiglas disappear when the box is underwater. Also the top face of the camera box is clear 3/8 inch plexiglas to allow the electronic flash to project through the box onto the area of the ship's hull being photographed. The two sides and the bottom of the clear water box are formed from a single piece of 1/8 inch aluminum plate.

A parallel linkage between the camera and the frame of the box allows the camera to slide laterally from left to right, in order to take two pictures from different perspective points. In the top plexiglas plate of the clear-water box there are two threaded holes with sealing bolts (Figure 3). These holes are used to fill and drain the plexiglas box of clear water. On the front surface of the clear-water box on the left hand side, as veiwed from behind, several color reference dots may be placed in a small piece of plexiglas to appear on the left border of the left photograph; these color dots allow the color photograph to be compared with known colors. This is particularly important when, as in hull scrubbing operations, the color of the hull's antifouling paint is used to determine the degree to which the cleaning has been a success. Also a small elevation scale in the form of a double staircase with steps separated by 1/16 inch may be placed on the front face. This elevation scale appears in both photographs and, when viewed stereoscopically, can be used to visually estimate the height of fouling or the depth of corrosion pits. finally, around the

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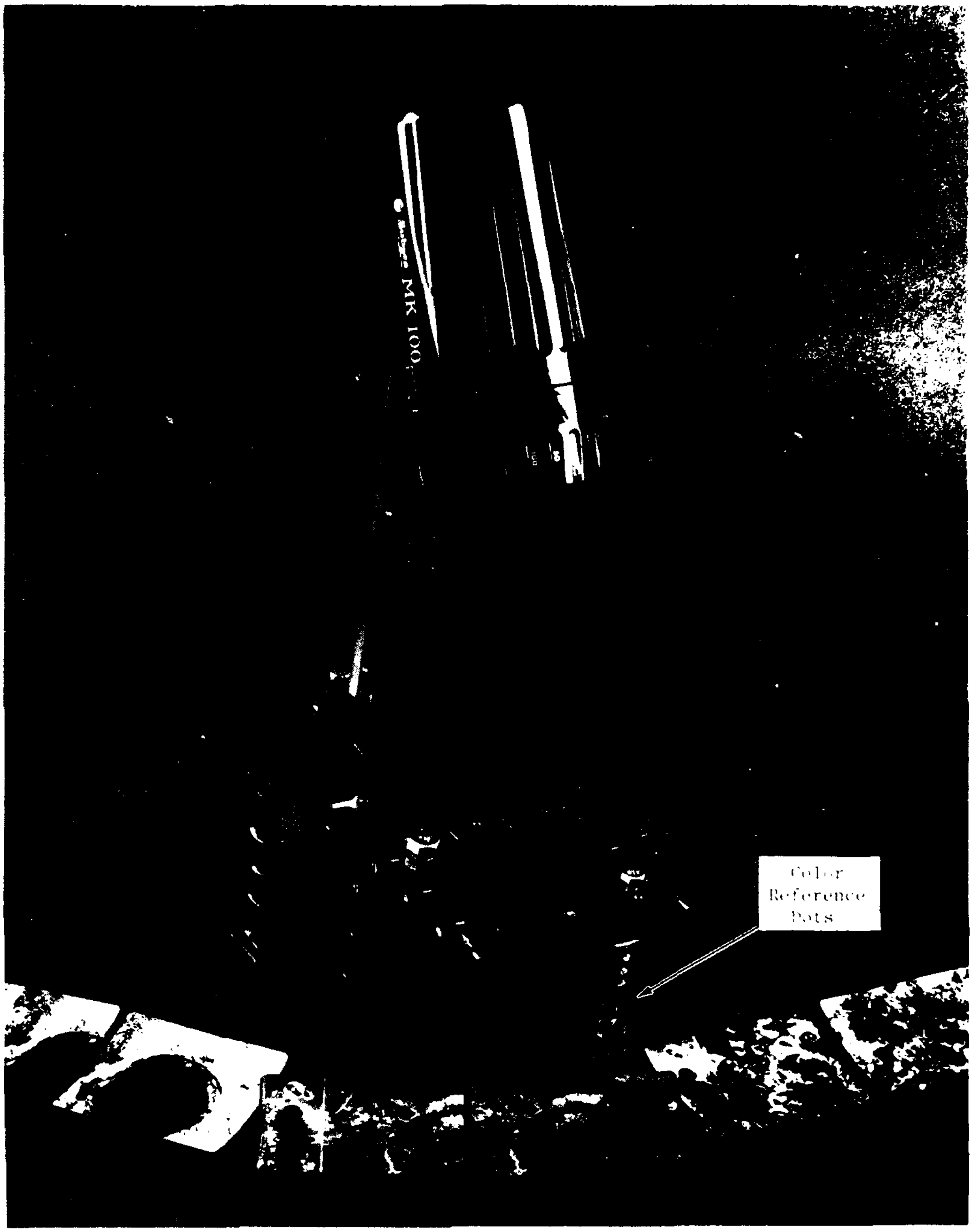

FIGURE 3. ASSEMBLED CAMERA APPARATUS

front face of the clear water box there is a rubber skirt which extends out as far as the stand-off pins and keeps the diver's air bubbles from spreading against the hull into the field of view of the camera.

Detailed engineering drawings can be requested from John Mittleman, Code 715, Naval Coastal Systems Center, Panama City, Florida, 32407.

VIEWING THREE DIMENSIONAL PHOTOGRAPHY

Once the ship's hull has been photographed with the stereo camera apparatus and prints are returned from the processor there is the problem of viewing the left photograph with the left eye and the right photograph with the right eye. This can be accomplished in several ways, depending on the size of the prints. If 8 x 10 in. prints are to be viewed a mirror stereoscope can be used (Figure 4). This device consists of a set of lenses, prisms, and mirrors which allow the large format pictures to be viewed stereoscopically. If 4 x 5 in. or smaller photographs are used, a pocket stereoscope (Figure 5) can be used. This simple device consists of two lenses and legs to hold them at the proper distance from the photographs. The cost of the mirror stereoscope, which is particularly suitable for viewing the large prints and taking engineering measurements of corrosion, pit depth, or fouling size, generally sells for about $200. The pocket stereoscope, which is much more suitable for a qualitative analysis of the ship's hull condition, is extremely portable and sells for under $20. many people who work in air photo interpretation have developed their eye muscles to the point where they can voluntarily look at one photograph with one eye and the other photograph with the other eye in a way similar to the exercise that went with Figure 1. In order to do this the eyes are "walled" slightly while the focus of each eyeball is maintained at close range. This technique is particularly suitable for small format photographs. If larger format photographs are to be viewed without the aid of a stereoscope it often helps to place the left photograph on the right side and the right photograph on the left side and view the two large format prints cross-eyed while maintaining the eyeball's focus at the proper range. There is no cost associated with either of these latter two options, but it takes a few hours to train your eyes to separate the pointing and focusing functions.

MEASURING THE RESULTS

If the reader should decide that it is not necessary to measure elevations in great detail this section can be ignored. After all, the

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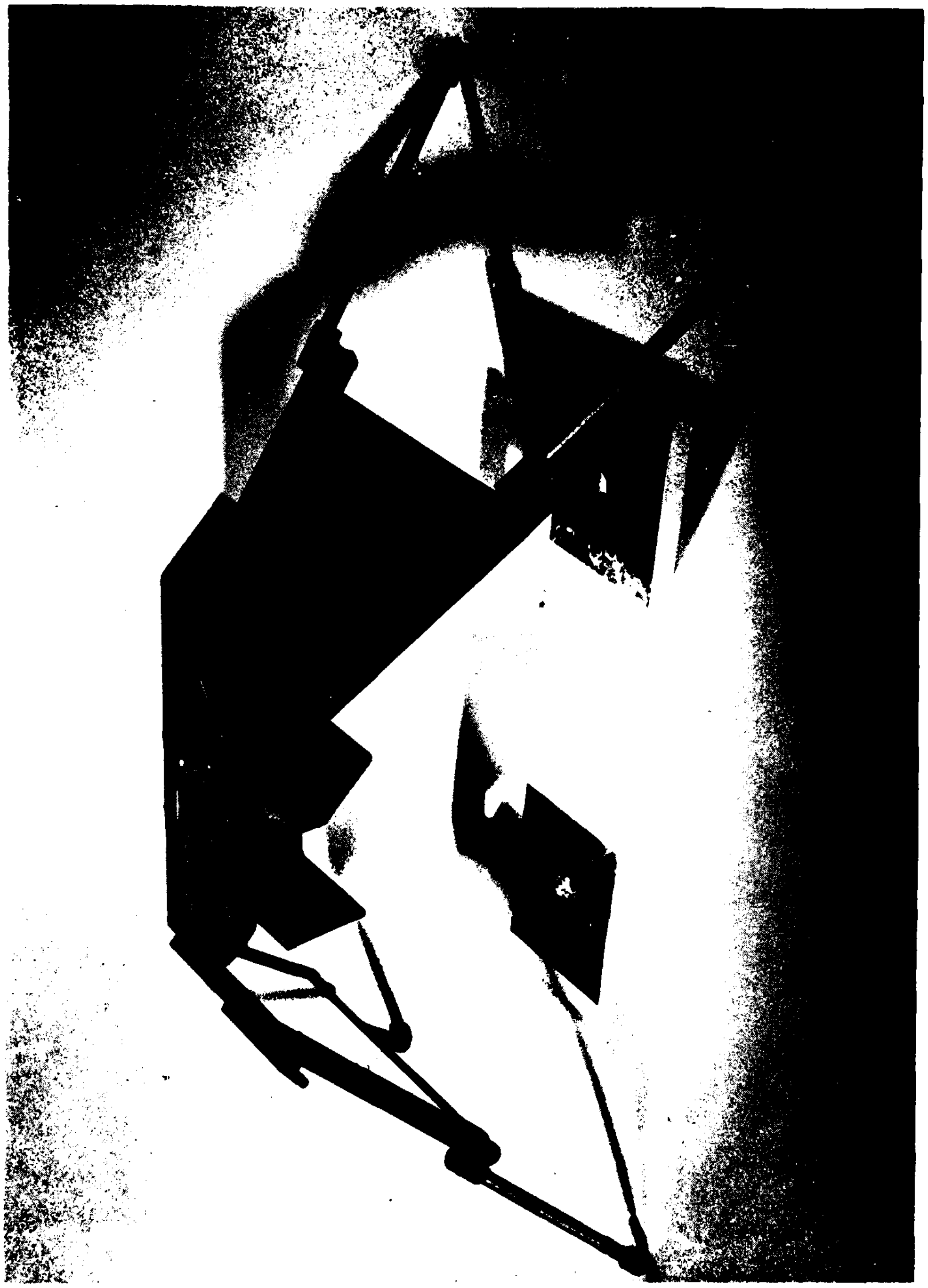

FIGURE 4. MIRROR STEREOSCOPE

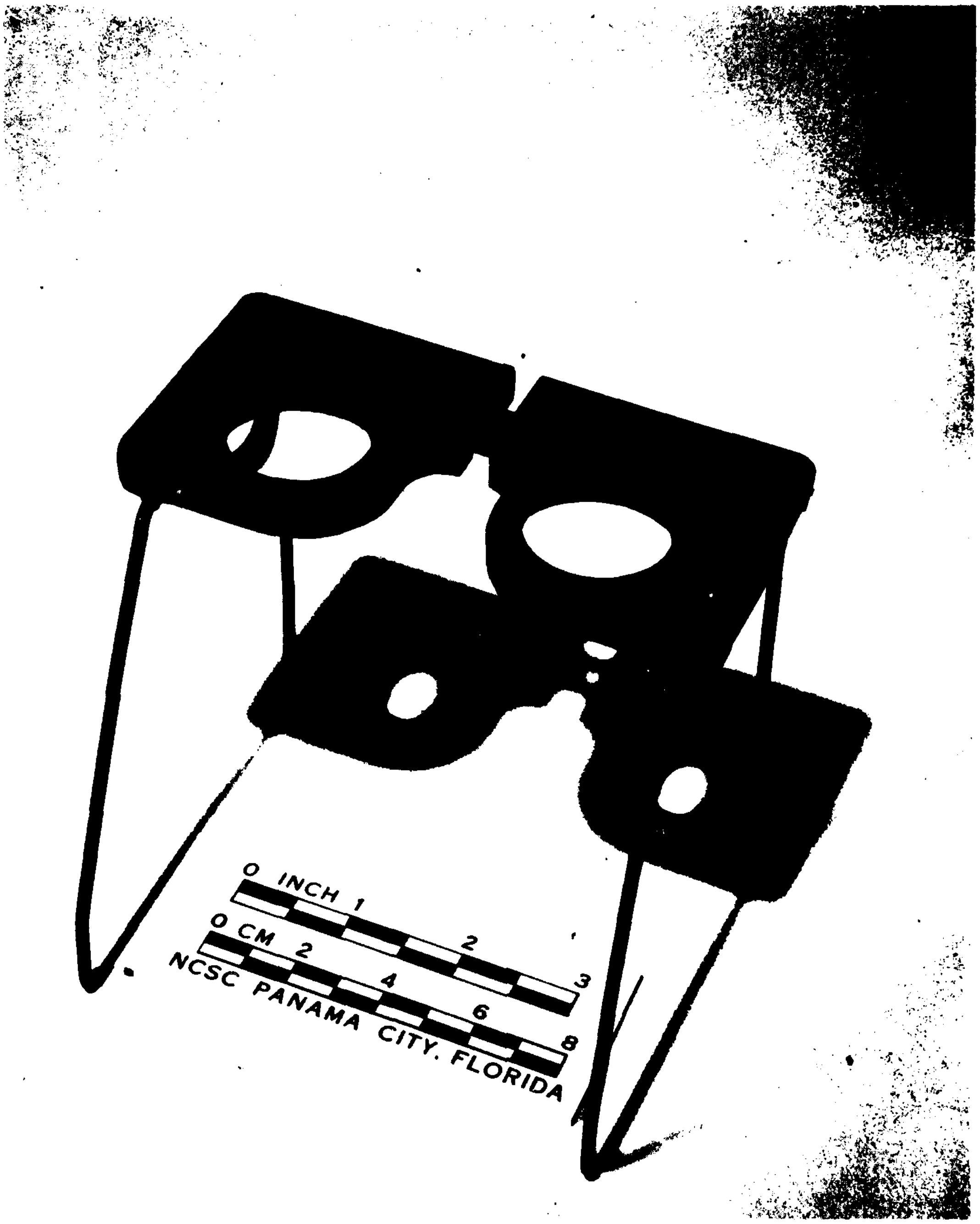

FIGURE 5. POCKET STEREOSCOPE

front face of the clear water box can have a little staircase for comparing heights, or depths, and in most cases, that ought to be good enough. Similarly, plan dimensions can be measured closely enough by comparing the color dot size (1/4 in. diameter) to the pit or subject of interest. But, for those jobs where a little more precision is required, the next few subsections may be useful. Even so, the Nikinos camera is not sufficiently distortion free to justify really elaborate mathematics; so just enough is given to allow the engineer reasonably good calculations.

BASIC MATHEMATICS

A sketch of the basic optical setup is shown in Figure 6, and the symbols used in the equations are defined pictorally. We want some quantity that measures the barnacle's height (h). Two points on the barnacle have been chosen, and the places where their images appear on the film are noted. By looking at similar traingles like the one shown in Figure 7 we can write

$$\frac{i}{H_1} = \frac{d_{11}}{D_{11}}$$

and similarly

$$\frac{i}{H_1} = \frac{d_{21}}{D_{21}}, \frac{i}{H_2} = \frac{d_{12}}{D_{12}} \text{ and } \frac{i}{H_2} = \frac{d_{22}}{D_{22}} .$$

Solving for each d_{ij} and forming the first differences, which are, physically, the spacings between images, we get

$$d_1 = d_{12} - d_{11} = i(\frac{D_{12}}{H_2} - \frac{D_{11}}{H_1})$$

and

$$d_2 = d_{21} - d_{22} = i(\frac{D_{21}}{H_1} - \frac{D_{22}}{H_2}) .$$

Now, forming the second difference gets us close, since the camera spacing (D_T) is equal to both ($D_{11} + D_{21}$) and ($D_{12} + D_{22}$)

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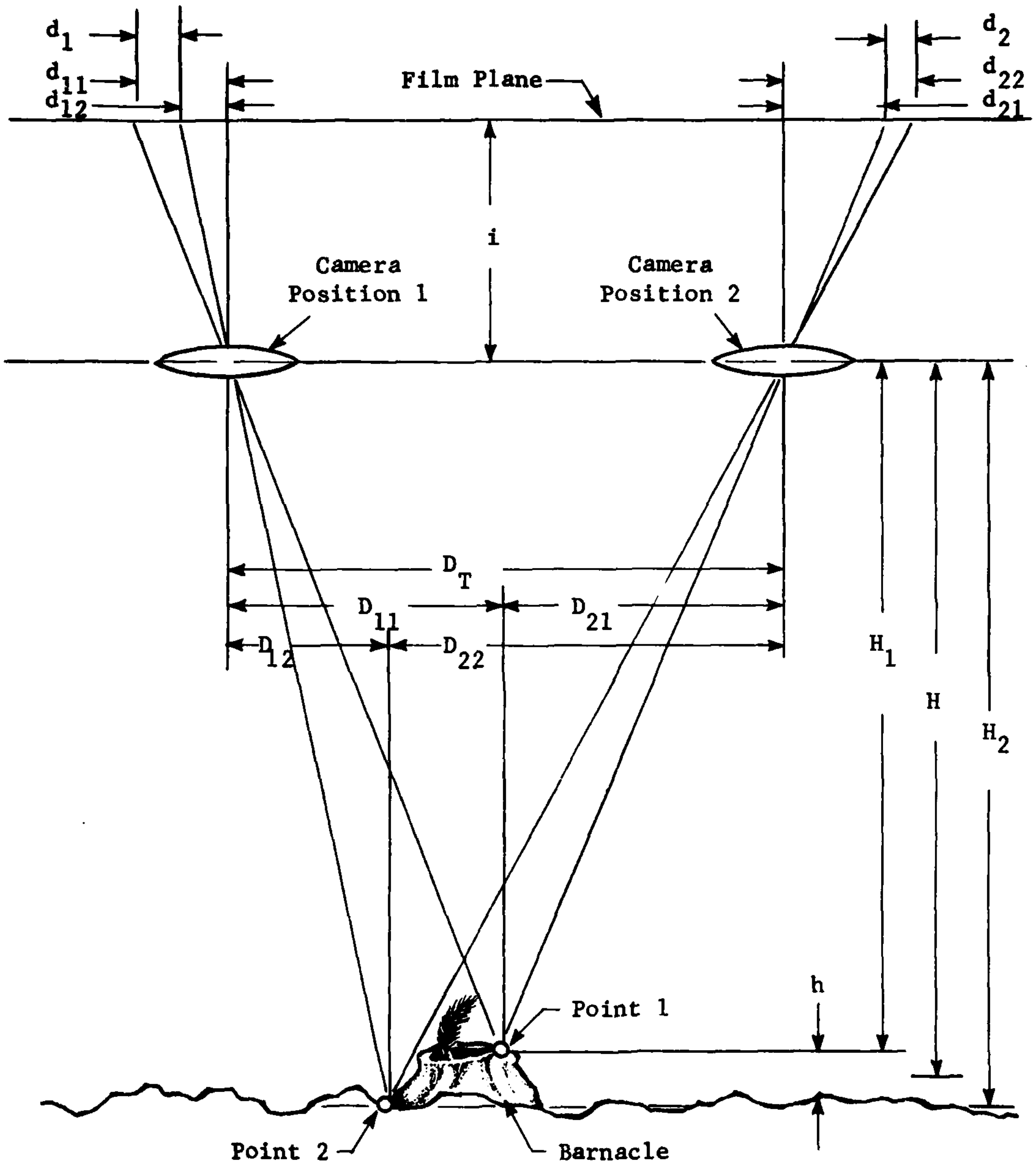

FIGURE 6. OPTICAL STEREO ARRANGEMENT

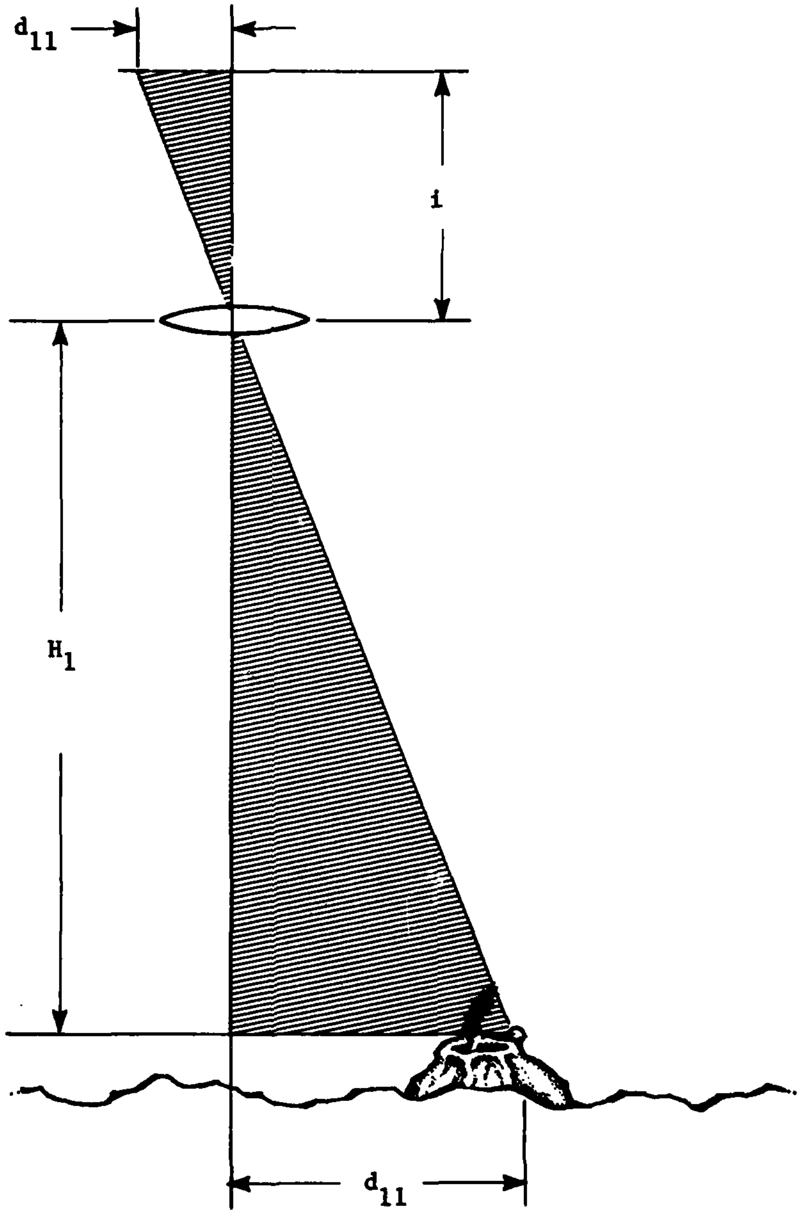

FIGURE 7. A SIMILAR OPTICAL TRIANGLE OF STEREO ARRANGEMENT

$$d_2 - d_1 = i\left(\frac{D_{21}}{H_1} - \frac{D_{22}}{H_2} - \frac{D_{12}}{H_2} + \frac{D_{11}}{H_1}\right)$$

$$= i\ D_T\left(\frac{1}{H_1} - \frac{1}{H_2}\right)$$

$$= i\ D_T\left(\frac{H_2 - H_1}{H_1 H_2}\right)$$

$$= \frac{i\ D_T\ h}{H_1 H_2} \quad .$$

Now it's time for the big approximation, where H_1H_2 is replaced with H^2. In our setup, H_1 may be about 6-5/8 in. and H_2 about 6-7/8 in. Let's take H to be somewhere in between; 6-3/4 in. Then

$$H_1H_2 = 6\text{-}5/8 \times 6\text{-}7/8 = 45.547$$

$$H^2 = 6\text{-}3/4 \times 6\text{-}3/4 = 45.463$$

The difference, 0.016 in., is about 0.03 percent of either figure. So, for all practical purposes,

$$d_2 - d_1 = \frac{i\ D_T\ h}{H^2} \quad .$$

Finally, we've found something that measures (h), since all the other parts of the equation are the same each time a pair of photos is shot. Unfortunately, it is impractical to measure the distance d_1 and d_2 because the two images may be in opposite corners of the photo, and it's only that part of the distance parallel to the camera motion that interests us. There is, however, a neat solution called parallax.

PARALLAX MEASUREMENTS

Go back to the second difference ($d_2 - d_1$). This was actually ($d_{21} - d_{22}$) - ($d_{12} - d_{11}$) and can be rearranged to give ($d_{21} + d_{11}$) - ($d_{22} + d_{12}$). If the two photographs are put on top of each other the image positions would lie as shown in Figure 8 (upper). Each of the quantities ($d_{21} + d_{11}$) and ($d_{22} + d_{12}$) can be measured directly since the images of point #1 on the barnacle are separated by a line which is

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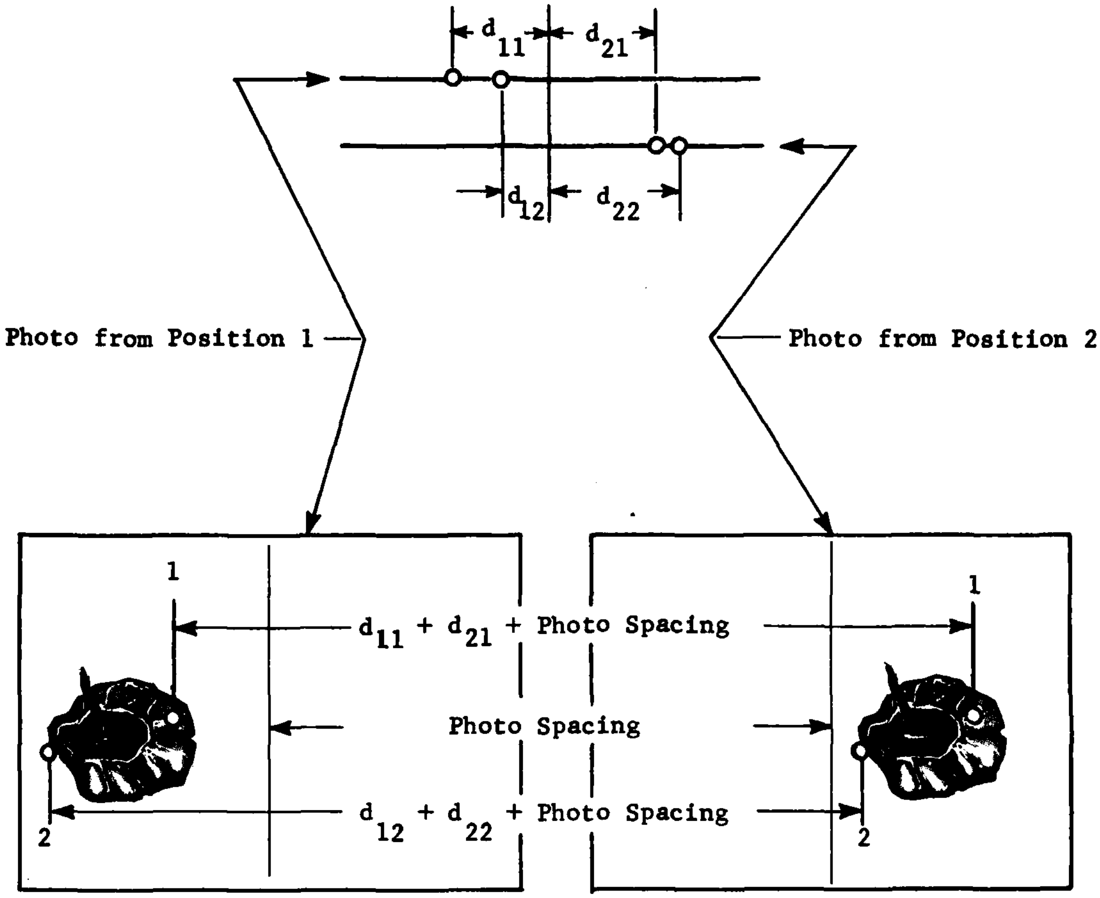

FIGURE 8. ILLUSTRATION OF PARALLAX

parallel to the camera motion line, as are the images of point #2 on the barnacle (Figure 8, lower). The difference between these two distances is called parallax. The instrument used to measure parallax is called a "parallax bar" and is nothing more than a long micrometer which measures parallax very accurately. Some parallax bars even have a pencil holder for drawing contours (Figure 9). Letting $(d_{21} + d_{11})$ equal p_1 and $(d_{22} + d_{12})$ equal p_2, then heights are found from the formula

$$h = \frac{(p_1 - p_2)H^2}{i\ D_T} \quad .$$

CALIBRATION

The first step in calibrating the stereo camera apparatus is to determine the distortion produced by the Nikonos. To do this, a reasonably flat subject with convenient location marks is photographed, and the apparent elevation of each mark is measured. For example, a sheet of graph paper can be sandwiched between plexiglas sheets as shown in Figure 10. When this is photographed and mapped, the apparent elevations of the graph paper lines will vary, and future maps can be corrected by this amount.

The second step in calibration is to measure the multiplier $(H^2/i\ D_t)$ which relates actual height to the parallax difference in the equation

$$h = (p_1 - p_2)\left(\frac{H^2}{i\ D_T}\right) \quad .$$

This is done by photographing objects of known elevation, measuring parallax difference, and figuring backwards to get $(H^2/i\ D_T)$. The actual number may vary from place to place on the photos, but this, too, can be recorded and applied as a correction on subsequent tests.

ALIGNING THE PHOTOGRAPHS

From the preceding on "Parallax Measurements," we know that height is related to parallax, and that parallax, because it is the difference between two measurements, can be measured regardless of the spacing between photos. However, if the photographs are not aligned properly then the spacing between them won't be the same at the top of the photos as it is at the bottom, and the net result will be an error in measurement (Figure 11A). This sort of error will make the top of a flat scene

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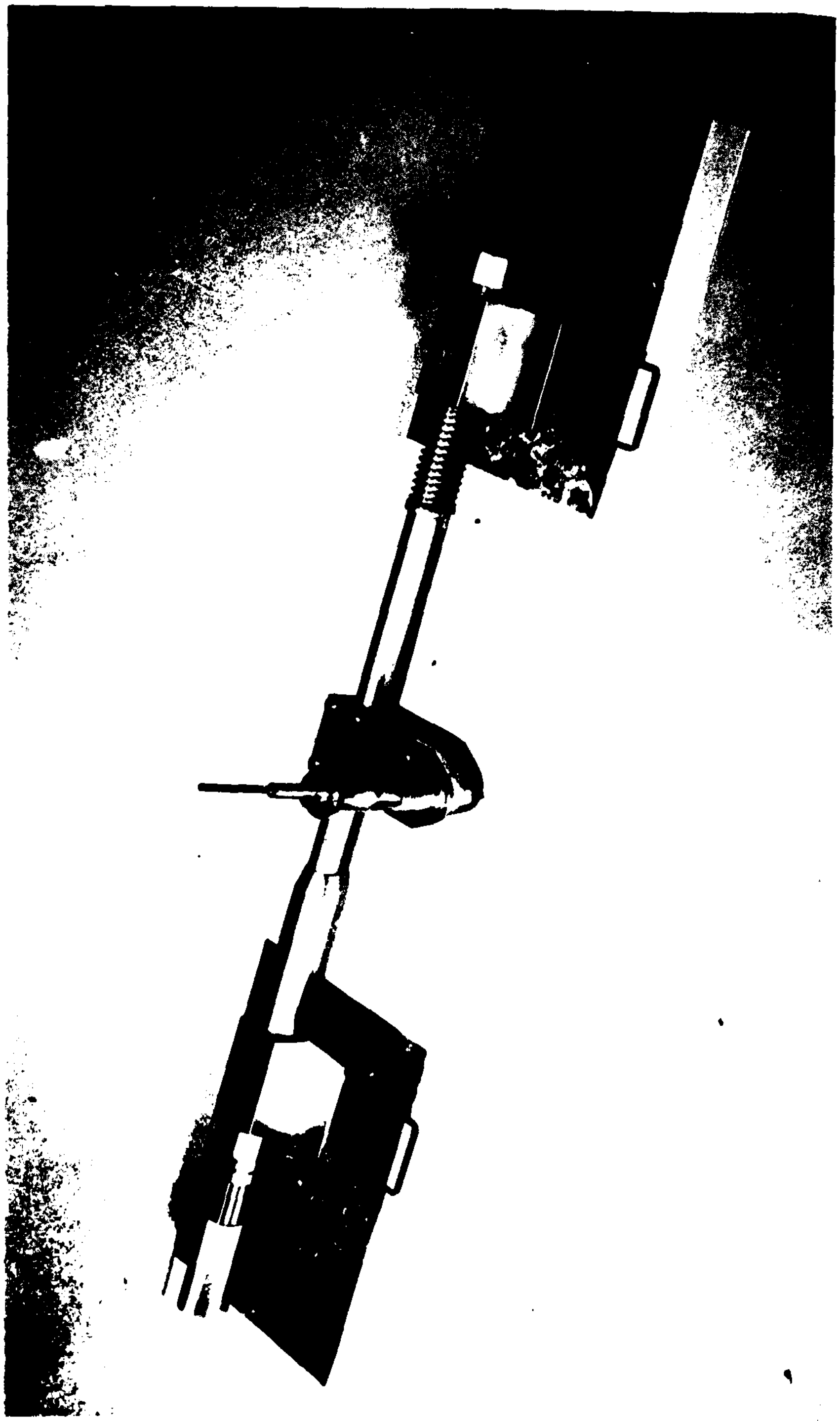


FIGURE 9. PARALLAX BAR

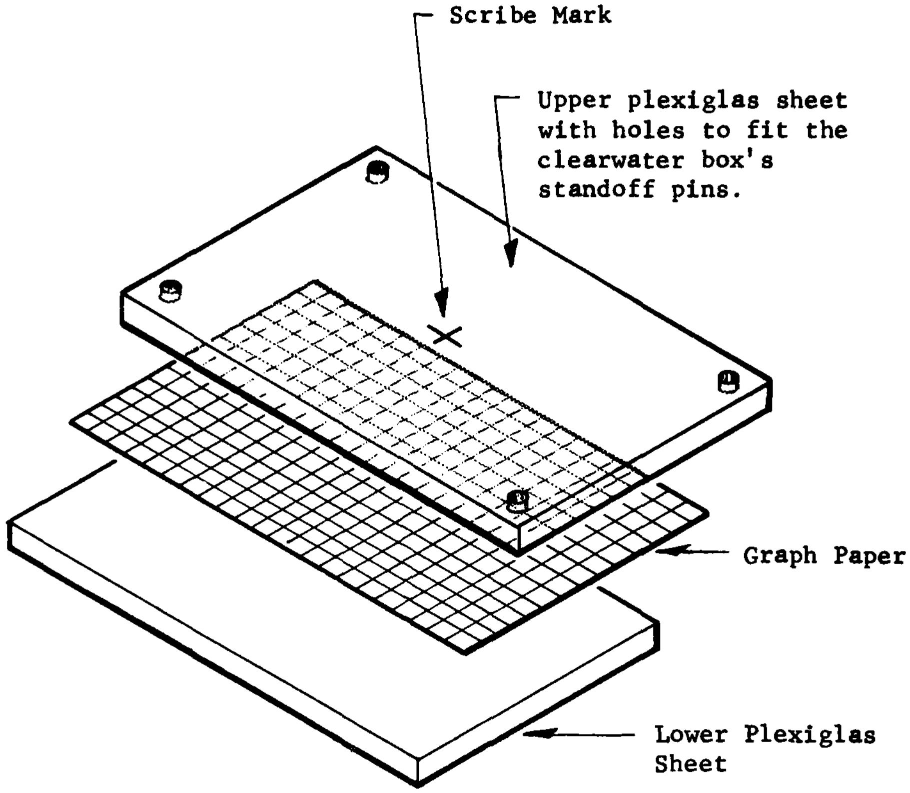
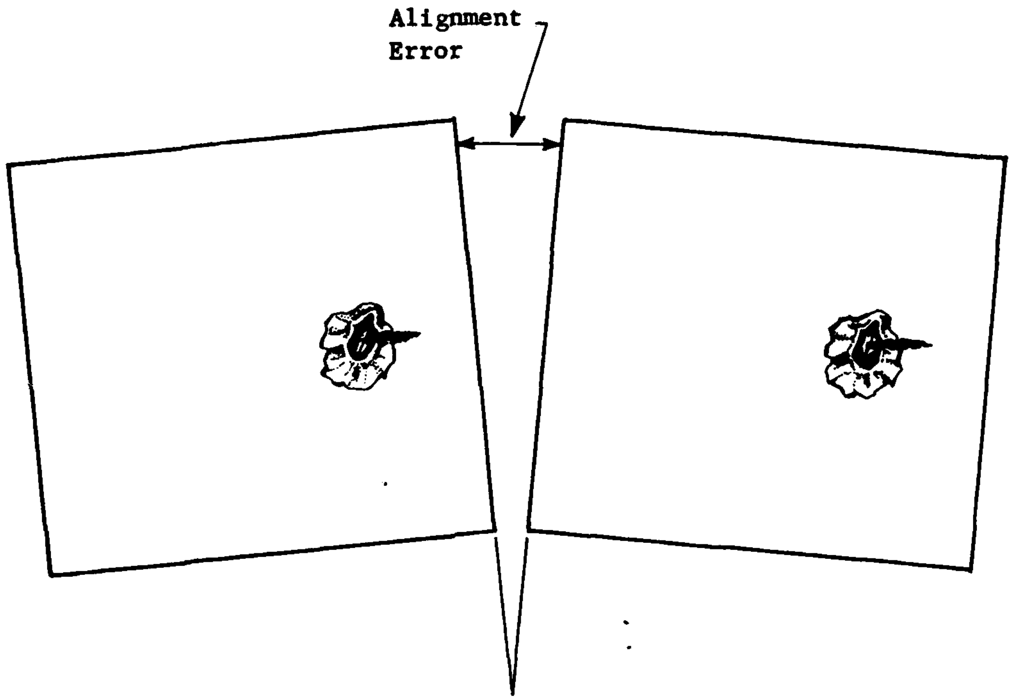
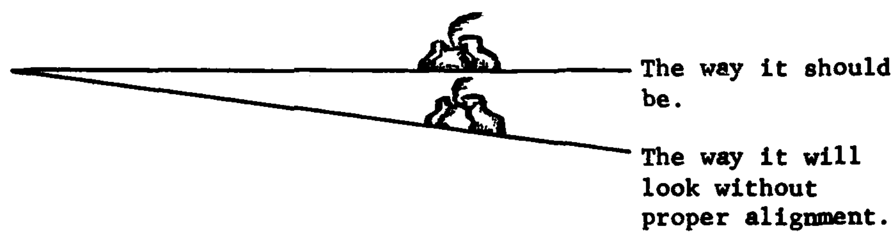


FIGURE 10. SETUP FOR DETERMINING DISTORTION IN THE CAMERA



a. Alignment Error



b. Appearance Error

FIGURE 11. ALIGNMENT ERROR IN PHOTOS

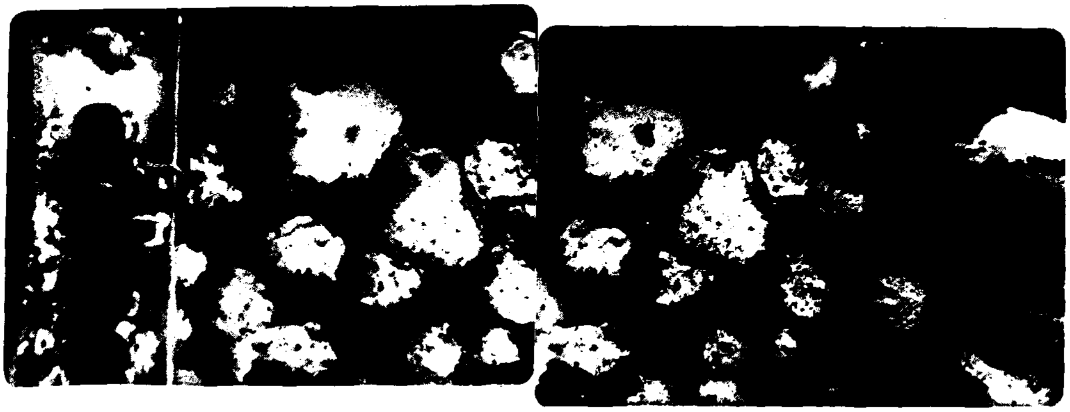
appear to slope away from or up toward the viewer (Figure 11B). To help avaoid this problem, in those cases where accurate measurements are desired, several small marks can be scribed on the outside of the front plexiglas surface. Then, after roughly aligning the photographs, the distances between corresponding pairs of marks are carefully measured and made to be the same for all pairs.

EXAMPLES OF STEREO SHIP HULL INSPECTION PHOTOGRAPHY

On the following pages there are several examples of close up underwater photography. These were originally 3 x 5 in. color prints which were aligned, mounted, and photo reduced to be compatible with the stereo viewer included with this report. Note that in each pair the area of stereo coverage is only the center; the outer 40 percent of each photo is not in stereo. Also, by measuring the size of the color reference dots shown along the left of the left photos, these reproductions are found to be approximately full scale. For critical work it would be appropriate to use color 8 x 10 in. prints instead of small black and whites. Even so, several interesting features can be seen on the black and white pairs.

PAINT FAILURE

This example shows a general failure of the outer paint layer, with relatively little disturbance of the underlying layer. There are, however, small blisters (1/16" - 1/8" diameter) visible in the undercoat. A weld bead runs diagonally across the upper right corner of the stereo area.

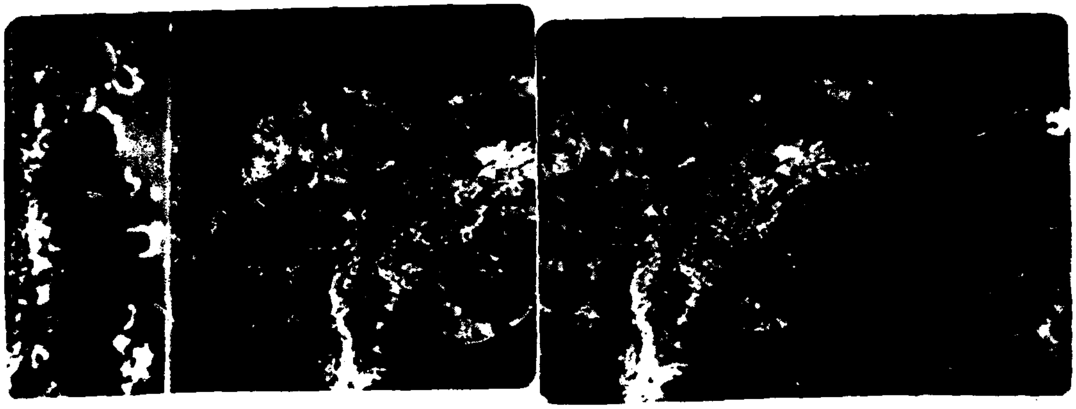


UNPOPPED PAINT BLISTER

In the center of the stereo area there is a paint blister, as yet unpopped. There is a heavy algae slime to the left of the blister, and vestiges of a tubeworm colony to the right. Also, a small stalk of brown algae can be seen about 1/2" right of the blister.

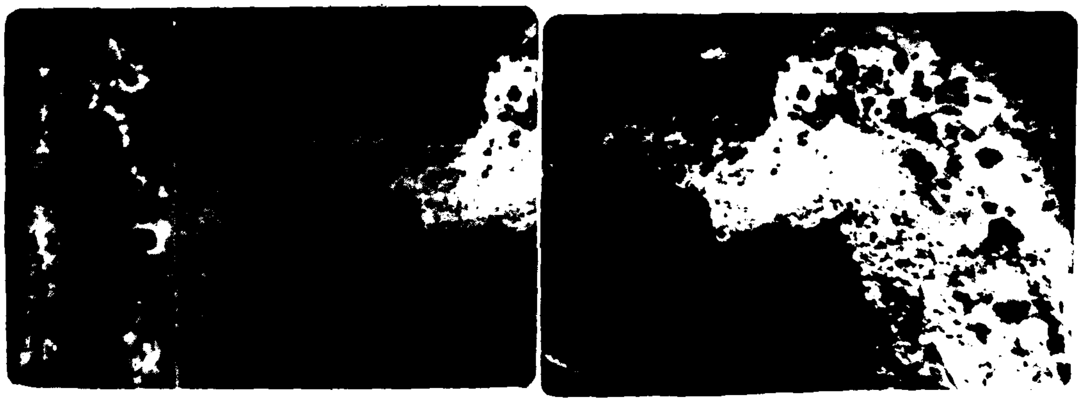
POPPED PAINT BLISTER, STEEL EXFOLIATION

A major paint blister in this picture has broken open, revealing an area of the hull plate where corrosion has lifted a layer of the steel. In the bottom right corner, two distinct layers of paint are visible.



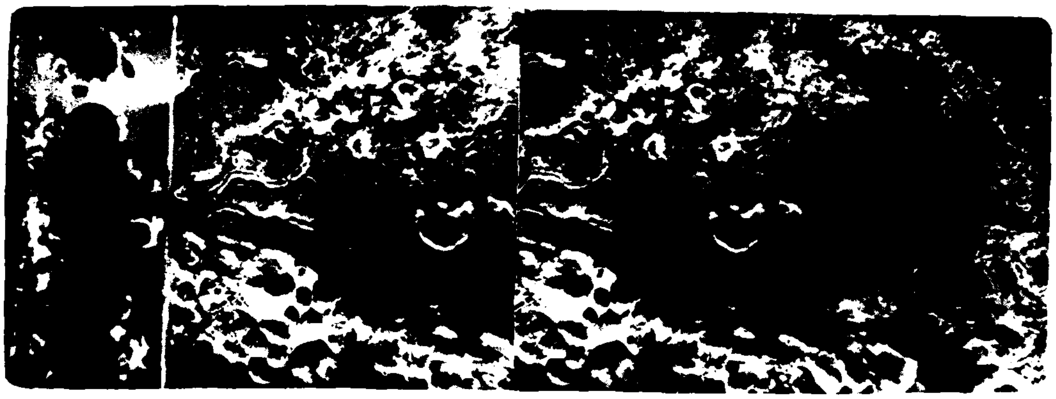
POPPED BLISTER

In this example a major paint blister has popped, but the underlying steel shows no major corrosion effects.



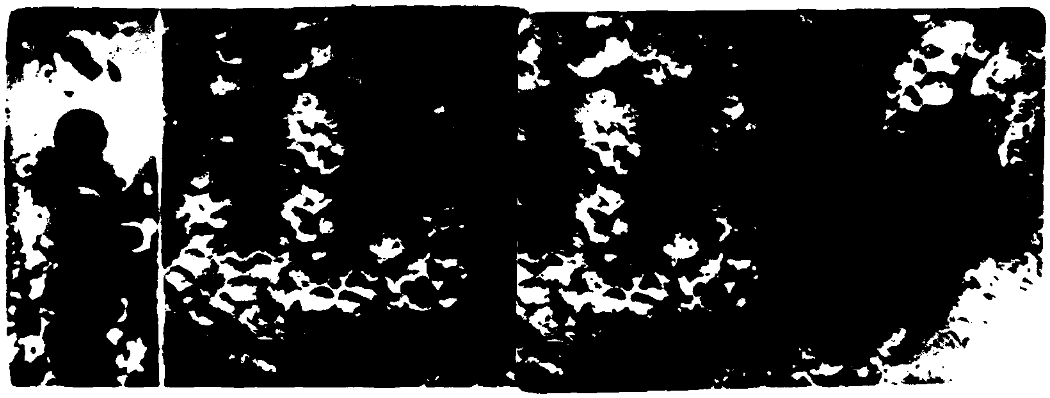
PAINT BLISTER AND CORROSION PRODUCTS

The upper three quarters of this picture shows a large paint blister, broken along the upper edge. Remnants of tubeworms and barnacles are visible on the blister. The lower quarter shows corrosion products which have formed on bare steel.



CORROSION PRODUCTS

A small section of lifted paint is visible along the lower edge of the stereo area. Above this, on the unprotected steel, is a formation of corrosion products. The very dark areas near the center of the stereo area are patches of rust discoloration.



TUBEWORMS AND ALGAE

A light community of tubeworms and algae are visible in this example, along with several small barnacles.

TUBEWORMS AND SLIPPER SHELLS

A few tubeworms and two slipper shells are seen in this example. The slipper shells are distinguishable from paint blisters by the roughness of their shells.

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748	Officer in Charge, Naval Surface Force, U.S. Pacific Fleet, Readiness Support Group, Mayport, FL 32228	(Copy 18)
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107	Commanding Officer, Harbor Clearance Unit Two, FPO New York 09501	(Copy 20)
106	Commanding Officer, Harbor Clearance Unit One, FPO San Francisco 96601	(Copy 21)
750	Commander, Service Group 2, FPO New York 09501	(Copy 22)
751	Commander Service Squadron 2, FPO New York 09501	(Copy 23)
752	Commander Service Squadron 4, FPO New York 09501	(Copy 24)
753	Commander Service Squadron 6, Box 35, FPO New York 09501	(Copy 25)
383	Commander Service Squadron 8, Naval Station, Norfolk, VA, 23511	(Copy 26)

581 Commander, Naval Air Systems Command (Code 5305) (Copy 27)
054 Chief of Naval Research (Code 463) (Copy 28)
754 Managing Editor, FACEPLATE, Potomac Research Institute,
7655 Old Springhouse Rd., Westgate Research Park,
McLean, VA 22104 (Copy 29)
035 Battelle Memorial Institute, Columbus Laboratories,
Columbus, OH 43201 (Attn: Don Hackman) (Copy 30)
755 Jarold M. Bartz, 656 Aurora Ave, Santa Barbara, CA 93109 (Copy 31)
756 E. A. Brown, 6269 Leesburg Pike, Falls Church, VA 20044 (Copy 32)
757 National Oceanic and Atmospheric Administration,
Rockville, MD 20852 (Copy 33)
758 National Marine Research Center, Box 1600, Galveston, TX 77550 (Copy 34)
759 CAPT Eugene B. Mitchell, USN (Ret), 5403 Albemarle,
Westmoreland Hills, MD (Copy 35)
760 Bill Nix, P. O. Box 4117, Pasadena, TX 77502 (Copy 36)
761 Ramsey Parks, Santa Barbara City College, 312 Nopal St.,
Santa Barbara, CA 93103 (Copy 37)
762 Frank B. Prohaska, Diving Consultant, C.D.T. Corps. (Rohr),
1609 Annette Way, El Cajon, CA 92020 (Copy 38)
763 LCDR Lloyd L. Reynolds, USNR-R, 926 Springmill Rd.,
Villanova, PA 19085 (Copy 39)
764 George Sampson, DIVEX, 2245 Breaux Ave., P. O. Box 504,
Harvey, LA 70058 (Copy 40)
765 George Scholley, Alcoa Marine Corporation, 1200 Ring Bldg.,
Washington, DC 20036 (Copy 41)
766 Vernon E. Shelton, Deep Ocean Work Systems, 645 E. 219th St.,
Unit 647, Carson, CA 90745 (Copy 42)
767 Robert J. Shourot, President, Undersea Systems, Inc., 112 West
Main Street, Bay Shore, NY 11796 (Copy 43)
768 D. Michael Hughes, Oceaneering International, Inc.,
9219 Katy Freeway, Houston, TX 77024 (Copy 44)
769 Jim Joiner, Director, Commercial Diving Center,
272 South Fries Avenue, Wilmington, CA 90744 (Copy 45)
770 Bob Kutzleb, Seaward, Inc., 6269 Leesburg Pike,
Falls Church, VA 22044 (Copy 46)
771 General Aquadyne, 3500 Whitney Plaza, Metairie, LA 70002 (Copy 47)
772 Dick Long, Diving Unlimited, 1148 Delevan Drive,
San Diego, CA 92102 (Copy 48)
773 CAPT Joseph Madeo, Murphy Pacific Salvage Corp., Marine
Division, 1 World Trade Center, Fleet 8833,
New York, NY 10048 (Copy 49)
774 Raymond F. McAllister, Professor of Ocean Engineering,
Florida Atlantic University, Boca Raton, FL 33432 (Copy 50)
775 Jim McDole, Taylor Diving & Salvage Co., 795 Engineering Rd.,
Belle Chasse, LA 70037 (Copy 51)
776 W. Tessin, Chairman, Florida Atlantic Univ., Dept of Ocean
Engineering, Boca Raton, FL 33432 (Copy 52)
777 E. A. Wardwell, Seaward, Inc., 6269 Leesburg Pike,
Falls Church, VA 22044 (Copy 53)

778 Commander Service Group 1, FPO San Francisco 96601 (Copy 54)
779 Commander Service Squadron 1, FPO San Francisco 96601 (Copy 55)
780 Commander Service Squadron 3, FPO San Francisco 96601 (Copy 56)
781 Commander Service Squadron 5, FPO San Francisco 96601 (Copy 57)
782 Commander, Submarine Squadron 2, FPO New York 09501 (Copy 58)
783 Commander, Submarine Squadron 4, FPO New York 09501 (Copy 59)
784 Commander, Submarine Squadron 6, FPO New York 09501 (Copy 60)
785 Commander, Submarine Squadron 10, FPO New York 09501 (Copy 61)
786 Commander, Submarine Squadron 14, FPO New York 09501 (Copy 62)
787 Commander, Submarine Squadron 16, FPO New York 09501 (Copy 63)
788 Commander, Submarine Squadron 18, FPO New York 09501 (Copy 64)
789 Commander, Submarine Squadron 1, FPO San Francisco 96601 (Copy 65)
790 Commander, Submarine Squadron 3, San Diego, CA 92132 (Copy 66)
791 Commander, Submarine Squadron 7, FPO San Francisco 96601 (Copy 67)
792 Commander, Submarine Squadron 15, FPO San Francisco 96601 (Copy 68)
309 Commander, Submarine Development Group 1, 139 Sylvester Rd., San Diego, CA 92106 (Copy 69)
793 Officer in Charge, Detachment Alameda, Submarine Development Group 1, Naval Air Station, Alameda CA 94501 (Copy 70)
794 Officer in Charge, Detachment Mare Island, Submarine Development Group 1, Mare Island Naval Shipyard, Vallejo, CA 94592 (Copy 71)
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797 Commanding Officer, USS PUGET SOUND (AD 38), FPO New York 09501 (Copy 74)
798 Commanding Officer, USS SHENADOAH (AD 26), FPO New York 09501 (Copy 75)
799 Commanding Officer, USS SIERRA (AD 18), FPO New York 09501 (Copy 76)
800 Commanding Officer, USS YOSEMITE (AD 19), FPO New York 09501 (Copy 77)
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803 Commanding Officer, USS SAMUEL GOMPERS (AD 37), FPO San Francisco 96601 (Copy 80)
804 Commanding Officer, USS VULCAN (AR 5), FPO New York 09501 (Copy 81)
805 Commanding Officer, USS AJAX (AR 6), FPO San Francisco 96601 (Copy 82)
806 Commanding Officer, USS HECTOR (AR 7), FPO San Francisco 96601 (Copy 83)
807 Commanding Officer, USS JASON (AR 8), FPO San Francisco 96601 (Copy 84)
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830 Commanding Officer, USS FLORIKAN (ASR 9),
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831 Commanding Officer, USS PIGEON (ASR 21), FPO San Francisco,
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837 Commanding Officer, USS TAKELMA (ATF 113),
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838 Officer in Charge, YRST 2, Harbor Clearance Unit 2,
FPO New York 09501 (Copy 115)
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Naval Amphibious Base Little Creek, Norfolk VA 23521 (Copy 119)
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Naval Construction Battalion Center, Port Hueneme, CA 93043 (Copy 120)
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Kaneohe, HI 96863 (Copy 121)
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Annapolis, MD 21402 (Copy 122)
487 Commander, Annapolis Laboratory, David W. Taylor
Research & Development Center, Bethesda, MD 20034 (Copy 123)
845 Officer in Charge, Fort Lauderdale Facility,
Naval Surface Weapons Center, 1650 S.W. 39th St.,
Fort Lauderdale, FL 33315 (Copy 124)

498 Commanding Officer, New London Laboratory, Naval Underwater
Systems Center, New London, CT 06320 (Copy 125)
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Systems Center, Newport, RI 02840 (Copy 126)
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AUTEC Andros Ranges Detachment, FPO Miami 34058 (Copy 131)
851 Commanding Officer, Naval Submarine Base, New London,
Box 00, Groton, CT 06340 (Copy 132)
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853 Commanding Officer, Naval Submarine Base,
Bremerton, WA 98315 (Copy 134)
854 Commander, Naval Base, Box 110, Pearl Harbor, HI 96860 (Copy 135)
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200 Stovall Street, Alexandria, VA 22332 (Copy 142)
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& Development Center, Bethesda, MD 20034 (Copy 143)
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RI 02840 (Copy 144)
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Pearl Harbor, HI 96860 (Copy 152)

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298 Commander, Portsmouth Naval Shipyard, Portsmouth, NH 03801 (Copy 154)
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864 Commanding Officer, RHCU DET 522, Naval Reserve Center, 860 Terry Ave., N., Seattle, WA 98109 (Copy 159)
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872 Commanding Officer, RHCU DET 608, Naval & Marine Corps Reserve Center, Box 44, Bldg. 411, Naval Air Station, Jacksonville, FL 32212 (Copy 167)
873 Commanding Officer, RHCU DET 708, Naval Reserve Center, 2610 Tigertail Avenue, Miami, FL 33133 (Copy 168)
874 Commanding Officer, RHCU DET 813, Naval Reserve Center, Randolph St. at Lake Michigan, Chicago, IL 60601 (Copy 169)
875 Commanding Officer, RHCU DET 110, Naval Reserve Center, Bldg. 84, NAS, Corpus Christi, TX 78419 (Copy 170)
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879 Officer in Charge, Naval Submarine Training Center, Pacific Detachment, 140 Sylvester Road, Ballast Point, San Diego, CA 92106 (Copy 174)
880 Officer in Charge, Naval Education & Training Program, Development Center Detachment, Pensacola, FL 32511 (Copy 175)
881 Officer in Charge, Naval Instructional Program, Development Detachment, Great Lakes, IL 60088 (Copy 176)

882	Officer in Charge, PERA (CSS), Naval Sea Systems Command, c/o Supervisor of Shipbuilding, Conversion and Repair, U.S. Navy, San Francisco, CA 94135	(Copy 177)
002	Director of Navy Laboratories, Room 300, Crystal Plaza Bldg. 5, Washington, DC 20390	(Copy 178)
883	Commandant, U.S. Coast Guard, 400 7th St., SW, Washington, DC 20590	(Copy 179)
884	Commanding Officer, Naval Reserve Center, Portsmouth Naval Shipyard, Portsmouth, NH 03801	(Copy 180)
516	Naval Special Warfare Group 2, Little Creek, Norfolk, VA 23521	(Copy 181)
885	SSF Diving Locker, U.S. Submarine Base, Box 300, Groton, CT 06340	(Copy 182)
886	Sub-Board of Inspection & Survey, Pacific, Bldg. 226, P. O. Box 107, Naval Station, San Diego, CA 92136	(Copy 183)
887	Underwater Construction Team 1, NAB Little Creek, Norfolk, VA 23521	(Copy 184)
888	Commanding Officer, Southern Division, Naval Facilities, Engineering Command (Code 406), P. O. Box 10068, Charleston, SC 29411	(Copy 185)
889	Navy Environmental Health Center, 3333 Vine, Cincinatti, OH 45220	(Copy 186)
890	Office of Naval Research, Code 484, Arlington, VA 22217	(Copy 187)
891	Chairman, Federal Maritime Commission, 1100 L St., NW, Washington, DC 20573	(Copy 188)
892	Supervisor of Salvage, USN, West Coast Representative, Bldg. 7, Room 82, Naval Station Treasure Island, San Francisco, CA 94130	(Copy 189)
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895	Asst. Supervisor of Salvage, USN (Admiralty), Room 1313, Federal Office Building, 90 Church Street, New York NY 10007	(Copy 193)
896	Naval Sea Systems Command (PMS-395), Washington, DC 20362	(Copy 194)
652	Commanding Officer, Pacific Missile Range Facility, Hawaiian Area, Barking Sands, Kekaha, Kauai, HI 96752	(Copy 195)
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898	Commanding Officer, Underwater Demolition Team 22, FPO New York 09501	(Copy 197)
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900	PCO, FRANK CABLE (AS 40), Supervisor of Shipbuilding, Conversion and Repair, USN, Seattle, WA 98115	(Copy 199)
901	PCO, EMORY S. LAND (AS 39), Supervisor of Shipbuilding, Conversion and Repair, USN, Seattle, WA	(Copy 200)
258	Commanding Officer, Naval Submarine Medical Research Laboratory, Box 900, Naval Submarine Base, Groton, CT 06340	(Copy 201)
075	Director, Defense Technical Information Center	(Copies 202-213)