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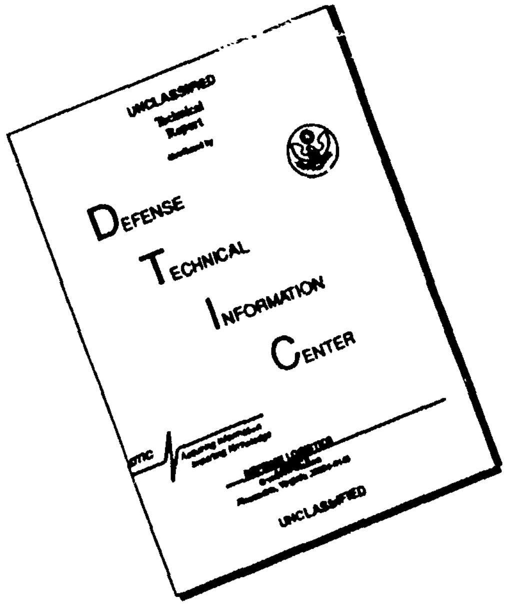

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SHIP CONTROL V

THE EFFECTS OF MOTION AND NUMBER OF SURFACES ON DEPTH CONTROL WITH A CONTACT ANALOG DISPLAY

GENERAL DYNAMICS CORPORATION ELECTRIC BOAT DIVISION

Electric Boat Technical Report

SPD 59-01C

Ship Control V The Effects of Motion and Number of Surfaces on Depth Control with a Contact Analog Display

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General Dynamics Corporation
Electric Boat Division
Groton, Connecticut

FOREWORD

This report was prepared by the Human Factors Section of General Dynamics Corporation's Electric Boat Division as part of the Submarine Integrated Control Program of the Office of Naval Research. Electric Boat Division is Coordinator, under Contract Nonr 2512(00), of this program. CDR C. C. Brock, USN, is Project Officer for ONR. Dr. H. E. Sheets is Project Engineer for Electric Boat Division. Dr. A. E. Hickey is Head, Human Factors Section.

The program is divided into several parts: Ship Control, Weapon and Tactical Control, Engineering Control, Communications, and Environmental Control. This report is one of a series dealing with the requirements for Ship Control.

The authors wish to acknowledge the assistance of Frederick L. Allen in the collection and reduction of the data.

ABSTRACT

Five submarine officers controlled a simulator which incorporated a Contact Analog (CA) display and a single joystick control. They were required to make 200-ft depth changes under four different display conditions. Each operator made 20 depth changes with a one-surface CA and 20 with a two-surface CA. Forward motion was shown during ten of the trials with each type of CA but omitted during the other ten. Each trial was 180 seconds in length. The maneuvers consisted of depth changes only; no changes in heading or speed were involved.

Three criteria were used to evaluate performance under the four experimental conditions. These were: 1) depth error at time 180 seconds; 2) greatest depth error after time 60 seconds; and 3) time within ±30 ft of ordered depth. Each of these three measures was subjected to a separate analysis of variance. The analyses included five variables (displays, motion, direction of depth change, range, and subjects) in a 2 x 2 x 2 x 2 x 5 factorial design.

The results, in summary, indicate that: 1) the use of a second surface representing the air-water interface results in a reduction of the magnitude of depth errors; and 2) the display of forward motion is not required for making depth-only changes.

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INTRODUCTION

The Ship Control research effort of the SUBIC program involves, among other investigations, an evaluation of the Contact Analog (CA) display. A rationale for the use of the CA in submarines and a preliminary evaluation of the principle are discussed in earlier reports (5, 6, 7). In the study described here, two CA design characteristics were investigated: a) the use of one versus two surfaces in the CA; and b) the effect of forward motion in the display.

A previous experiment (6) had shown that depth changes with a one-surface CA were made more accurately and quickly when diving than when rising. One surface, representing the bottom, did not seem to provide enough information for depth control in both directions. An obvious solution calls for a second surface representing the air-water interface. However, the generation of a second surface involves added cost and engineering complexity and may not, in itself, produce better depth-control performance. For this reason, a two-surface CA was empirically tested.

In a similar vein, the high degree of engineering complexity required to display forward motion may be unnecessary in terms of its actual utility to the operator. In the present study, depth-control performance with forward motion displayed was compared to performance without such motion.

DESCRIPTION OF THE EXPERIMENT

The Experimental Situation

Five submarine officers controlled a simulator incorporating a CA display and a single joystick control. They were required to make 200-ft depth changes under four different display conditions. Over a five-day test period, each operator made 20 depth changes with a one-surface CA and 20 with a two-surface CA. Forward motion was shown during ten of the trials with each type of CA but omitted during the other ten. Although the displays and controls moved realistically, the operators remained level; i.e., the pitch and roll of the submarine was not simulated. The maneuvers consisted of depth changes only; no changes in heading or speed were involved.

Apparatus

The one-surface CA was generated by scanning an optically projected, grid-patterned surface with a TV camera and transmitting the image to a 17-in. TV monitor (Figure 1). The surface or "floor" scanned by the camera was a grid pattern of 1/4-in. dark lines forming 1 1/4-in. squares against a light background projected on a 4-1/2 ft by 4-1/2 ft glass-beaded screen by a

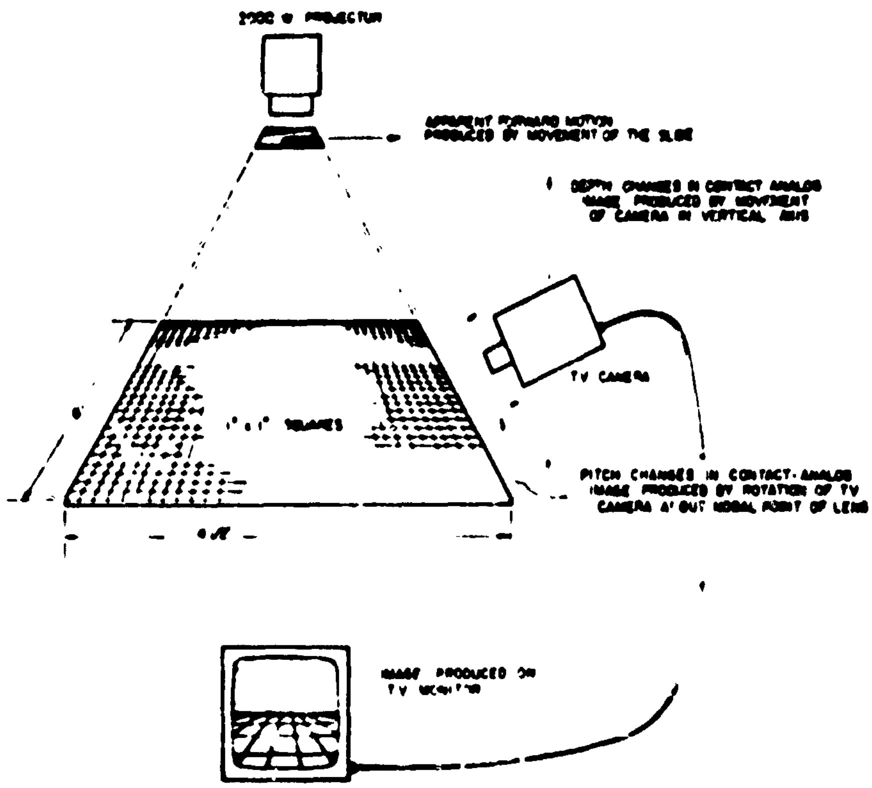

Figure 1. The one-surface Contact Analog image generator

2000-W slide projector. The display incorporated the three degrees of freedom necessary to effect depth changes: apparent forward motion was produced by moving the slide in the projector; motion of the camera in the vertical axis produced changes in apparent depth; and rotation of the camera in the medial plane about the nodal point of the lens changed the apparent pitch angle. This display seen on the TV screen was a perspective image of a plane, rigid surface covered with squares. The squares, arbitrarily designated as being 125 ft on a side, set the scale of the display and of the submarines's dynamics. Based on this scale, the surface extended 4500 feet (36 squares) in front of the submarine and was 500 feet below an assumed air-water interface.

The apparatus for generating the two-surface CA was similar except that the surfaces scanned by the TV camera consisted of two endless belts. Both belts were 4-ft wide loops of canvas stretched over two rollers placed 4-1/2 ft apart (center to center). The texture of the lower surfaces was a grid pattern identical to that of the one-surface CA described above. The texture of the upper surface was a pattern of 1/2-in. black squares spaced 1-1/4 in. between centers painted on a white background. The two canvas "surfaces," posi-

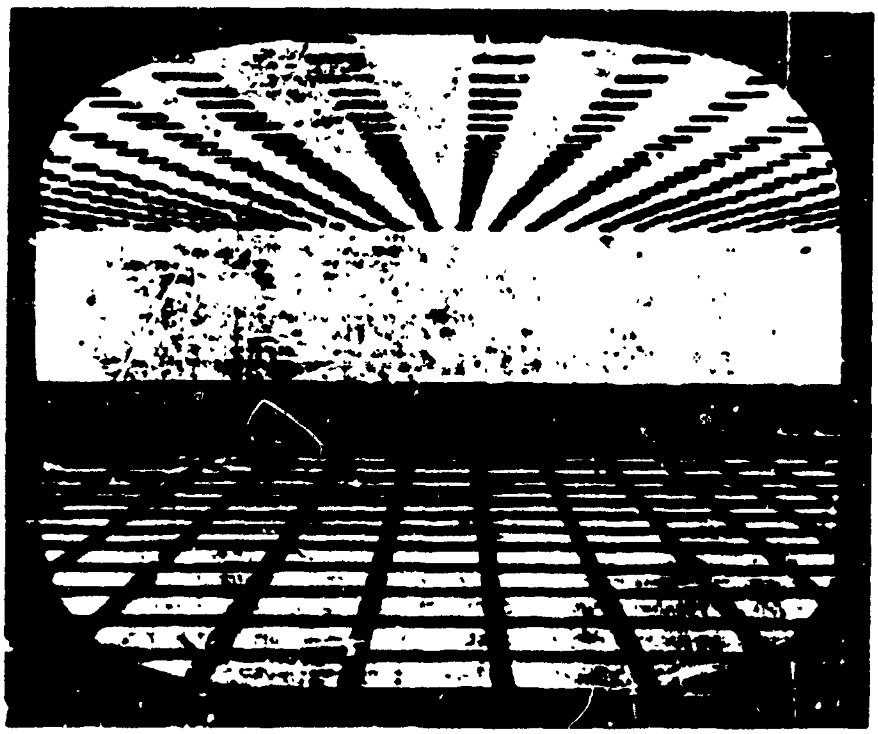

Figure 2. Operator's view of the two-surface Contact Analog

tioned 5 in. apart, corresponded to a separation of 500 ft between the CA surfaces. A servo motor moved the belts toward the camera to produce apparent forward motion. Figure 2 is an illustration of the two-surface CA.

The movement of the camera and the projector slide (or the canvas belts) was determined by two 10-amplifier Donner computers. These computers, programmed with simplified equations of motion of a TRIGGER-class submarine traveling at 20 knots, translated the operators' movements of the joystick control into voltages which produced appropriate motion of the display.

The simulated submarine was controlled with a single, spring-loaded, hydraulically damped joystick mounted below the CA display on the operator's console (Figure 3). The joystick measured 12-in. from top to pivot point and contained a detent at the 0° plane position. During the experiment, only the visual display changed; the operators remained level. The experiment was thus confined to a study of the visual cues of the CA and did not include the vestibular and kinesthetic cues normally associated with submarine dynamics.

Figure 3. The operator's console

Procedure

Each of the five operators performed eight 3-min maneuvers per day for five days. The operators were instructed to make a 200-ft depth change as rapidly as they could and to hold the new depth as closely as possible during the remainder of the trial. The depth changes were made in both directions (rise and dive) between two ranges: 100 to 300 ft and 200 to 400 ft. An equal number of maneuvers were made under the four different display conditions. That is, half the maneuvers were made with the one-surface CA and half with the two-surface CA; half the maneuvers made with each type of CA included forward motion and half lacked forward motion. The order of presentation of the trials was different and non-systematic for each operator each day. The trials on the first day were considered familiarization trials and were not included in the final analysis.

The schedule of trials was arranged so that over the last four days each operator performed two trials under each of the 16 conditions representing all combinations of the two displays (one-surface and two-surface CA), the two forward motion conditions (0 and 20 knots), two directions (rise and dive), and the two depth ranges (100 to 300 and 200 to 400 ft).

RESULTS AND DISCUSSION

Three criteria were used to evaluate performance under the different experimental conditions. These were:

1) Depth error at time 180 sec, i.e., the distance of the submarine from ordered depth at the end of the 180-sec trial. This score indicates the terminal accuracy of the operator in effecting the ordered depth change.

2) Greatest depth error after time 60 sec, i.e., the greatest distance between ordered and actual depth after the first 60 seconds of the trial. Since 60 seconds was long enough for a skilled operator to come very close to the ordered depth, this measure shows the magnitude of the largest errors which were encountered in leveling off at a new depth.

3) Time within ±30 ft, i.e., the amount of time during the 180-sec trial that the operator maintained the submarine within ±30 ft of ordered depth. This score reflects overall smartness and accuracy in executing the ordered maneuver.

Each of these three measures was subjected to an analysis of variance. The analysis included five variables in a 2 x 2 x 2 x 2 x 5 factorial design. These variables were: a) displays (one-surface and two-surface CA); b) motion (zero and 20 knots); c) direction (rise and dive); d) range (100 to 300 and 200 to 400 ft); and e) subjects (five operators). Each operator had two trials under each of the 16 combinations of displays, motion, direction, and range, which provided a within-operator variance for estimating error in the analyses.

Tables 1, 2, and 3 summarize the three analyses of variance. In making the statistical tests, a "fixed" model was used. This means that the confidence level for any comparison within the analysis represents the probability that the findings would be repeated if these same operators were retested. A method of analysis which would give the probabilities that such findings would hold for a repetition of the experiment with other subjects was not used, since the sampling of subjects was fortuitous rather than random. Moreover, even if the operators were considered as representative of the population from which they were drawn, such tests would lack power; i.e., a finding of no significant differences in any comparison could not be relied upon as indicating the true state of affairs. Because the object of this research was to explore basic design characteristics of the CA display rather than to obtain specific quantitative values, the model is appropriate.

[illegible]

The overall averages for all experimental variables are listed in Table 4. Significant differences among the five operators were obtained with all three criteria. This is an expected result and simply shows that some operators were more proficient than others. There was also a significant difference on all three criteria between maneuvers in the rise and dive directions. Table 4 shows that average performance on dive maneuvers was always superior to that for rise maneuvers. This, also, is not unexpected. It was demonstrated previously (6) that large differences exist between rise and dive maneuvers with a one-surface CA. Since the data in Table 4 includes average performance with both the one- and two-surface displays, large one-surface differences would probably be reflected here whether or not such differences exist for the two-surface display. To test the assumption that improvement in rise performance occurs as a function of adding a second surface to the CA, the "displays X direction" interaction was examined. This F-ratio is not significant for any criterion. Thus, no overall advantage for the two-surface CA in performing rise maneuvers was manifest.

The analyses do show, however, that on two criteria - depth error at time 180 sec and greatest depth error after time 60 sec - there is a statistically significant overall difference between the one- and two-surface displays. Table 4 shows that two surfaces are superior to a single surface for both these measures. This indicates that while addition of a representation of the air-water interface may not improve general accuracy of performance as measured by the criterion of time within ±30 ft, it does significantly improve precision in reaching and maintaining ordered depth as measured by the two error criteria. Further, there is a significant interaction with both of these criteria between subjects and displays. Table 5 shows the average error scores of each operator with one-surface and two-surface displays. It is apparent from inspection of this table that all operators did about equally well with two surfaces, but some were less proficient than others with the one-surface display. This suggests that skilled operators may need only a single surface, but that two surfaces improves the performance of less skilled operators.

TABLE 4

Average scores for the five experimental variables

		Absolute error at time 180 sec	Greatest absolute error after time 60 sec	Time within ±30 ft
Motion	zero	[illegible]	84.[illegible]	55.23
	20 knots	46.07	72.85	71.21
Display	one surface	53.72 *	87.04 *	64.92
	two-surface	36.70	70.01	71.40
Direction	rise	57.11 *	89.90 **	58.05
	dive	33.40	67.10	78.38
Range	100 to 300 ft	45.62	79.30	[illegible]8.23
	200 to 400 ft	44.97	77.75	68.19
Operator	1	75.50 **	131.19 **	150.87
	2	139.87	216.37	104.00
	3	121.75	101.56	101.60
	4	80.31	134.19	112.38
	5	65.56	111.94	179.44

* difference significant at the .05 level of confidence

** difference significant at the .01 level of confidence

TABLE 5

Average error scores for the five operators with one surface and two surface CA displays

		Greatest depth error after time 60 sec		Depth error at time 180 sec	
		One surface	Two-surface	One surface	Two surface
Operators	1	64.44 ft	66.75 ft	39.60 ft	[illegible] ft
	2	137.10 ft	79.10 ft	76.44 ft	33.44 ft
	3	111.31 ft	80.25 ft	82.37 ft	39.37 ft
	4	64.62 ft	69.56 ft	36.31 ft	44.00 ft
	5	57.62 ft	54.31 ft	33.81 ft	31.75 ft

Finally, two F-ratios are significant when time within ±30 ft of ordered depth is considered. One ratio shows an interaction between motion and displays. Table 6 gives the mean time on target for various combinations of these two variables and indicates that motion improves performance with a single-surface CA display but has no effect on performance with a two-surface display. There is also a suggestion that a one-surface CA with motion added becomes about as good as the two-surface CA.

The second significant F-ratio shows a triple interaction involving number of surfaces, direction, and depth range. Table 7 gives the mean time scores under these conditions. This simply shows that the two-surface display is greatly superior to a single-surface display for rises from 300 to 100 ft. This is to be expected since a representation of the air-surface interface would be most advantageous when operating near the surface of the sea with an up-angle on the submarine.

TABLE 6

Average time within ±30 ft of ordered depth for one-surface and two-surface CA with zero or 20 knot motion displayed

	Zero motion	20 Knots
One-surface CA	54.95 sec	74.90 sec
Two-surface CA	75.45 sec	67.52 sec

TABLE 7

Average time within ±30 ft of ordered depth for one-surface and two-surface CA in rise and dive directions in the 100-300 and 200-400 ft depth ranges. Maximum time = 180 sec

		Rise	Dive
One-surface CA			
Depth range	100-300 ft	44.00 sec	78.40 sec
	200-400 ft	57.00 sec	80.30 sec
Two-surface CA			
Depth range	100-300 ft	80.80 sec	68.90 sec
	200-400 ft	51.60 sec	84.65 sec

In summary, the data obtained in the present study indicates that: 1) the use of a second surface representing the air-water interface results in a reduction of the magnitude of depth errors; and 2) the display of forward motion is not, of itself, required for control when effecting depth-only maneuvers. This is not to say that such motion would not be necessary or desirable when performing other maneuvers such as course or speed changes.