A Report of Research under Contract with

SPECIAL DEVICES CENTER, OFFICE OF NAVAL RESEARCH

APPRAISAL OF AN EXPERIMENTAL PLAN POSITION INDICATOR PRESENTING SIMULATED BEARING, RANGE, AND HEIGHT INFORMATION

by

J. W. GEBHARD

and

E. A. BILODEAU

SYSTEMS RESEARCH FIELD LABORATORY
and
PSYCHOLOGICAL LABORATORY

The Johns Hopkins University

15 December 1947

CONTENTS

BLANK PAGE

SUMMARY

Two experiments were performed to appraise a conventional polar coordinate display modified to present bearing, range, and height information. The display consisted of a PPI surrounded by an annulus. Each target was represented by two blips on the same bearing: the inner blip on the PPI gave bearing and range, and the outer blip in the annulus gave bearing and height. The display was a synthetic or simulated display. Engineering modifications actually to reproduce bearing, range, and height information on this PPI were not accomplished. The purpose of this appraisal is a psychological one: to determine how accurately a man can understand and extract information from a display of this sort.

The first experiment measured the speed and accuracy with which operators could extract bearing, range, and height information from the experimental display on three remote repeaters: (1) a VJ used normally with the bearing cursor and a movable range marker, (2) a VJ equipped with four range and four height markers without cursor, and (3) a VG with a standard eight ring overlay. The average time per target required on either the VJ with markers or the VG was less than half that required for the VJ with hand cranks (nine seconds compared with 21). The average bearing error obtained on the VG was one degree and on both VJ's about a degree and a half. The average range error on a 40-mile scale was about one-half of a mile for all indicators. The average height error on a 40-thousand foot scale was about 500 feet.

The second experiment measured speed and accuracy of target estimation for the experimental display presented on a VH (5 in.), VD (7 in.), VJ (12 in.), and VG (24 in.) display, each equipped with four range and four height rings. No cursors were used; bearing was estimated directly from the dials. Two range-height scale ratios on the radius were tested for each instrument: 1:1 and 2:1. The average time per target was about seven seconds except for the VG which took a second longer. The average bearing error was about one degree for the VG. It became larger with a decrease in scope size and reached three and a half degrees for the VH. The average range error on a 40-mile scale was a little over half a mile for all scopes and the average height error on a 40-thousand foot scale was about 700 feet. The 2:1 ratio was found better for estimating bearing and range, but the 1:1 ratio was best for height.

These experiments indicate that the extraction of bearing, range, and height information from a radar indicator can be rapidly and accurately accomplished by operators using the PPI-and-annulus display. The display is satisfactory on scopes as small as five inches, but bearing, range, and height accuracies are improved on somewhat larger scopes. The presentation is readily comprehended and experienced radarmen can use the modified scopes with little practice.

ACKNOWLEDGMENT

The interest and suggestions of Dr. A. Chapanis, the cooperation of the Navy radarmen from the Naval Training Facility (Air Intercept) Beavertail who participated in these experiments as operators, and the assistance of the engineers of the Field Laboratory are gratefully acknowledged.

[redacted]d

APPRAISAL OF AN EXPERIMENTAL PLAN POSITION INDICATOR PRESENTING SIMULATED BEARING, RANGE, AND HEIGHT INFORMATION

INTRODUCTION

The Problem. There are available at present a number of search radars which scan both azimuth and elevation. The bearing, range, and height information from these sets makes possible the accurate location of aircraft in space. However, completely satisfactory methods of presenting this information to the observer in an efficient form have not been developed. The engineering difficulties in presenting three-dimensional information are many, but more serious still is the problem of specifying the way in which bearing, range, and height data may be made most meaningful to the men who use them.

This paper is the first of a series of experiments to measure the capacity of radarmen to extract and act upon three-dimensional radar data from different types of display systems. By measuring such functions as speed and accuracy of target indication and raid handling capacity, it is possible to appraise a three-dimensional display in terms of human operability. These findings on different display systems should help decide which presentation is most suitable for given operational conditions of service use.

Ideally, these are the general requirements for a display of three-dimensional information.

1. Bearing, range, and height of aircraft, and bearing and range of surface craft must be displayed simultaneously in the same visual work space.

2. The accuracy with which the information is read by the observer must be of the same order as that of the radar system.

3. The system must be so simple that the observer, without undue training, can act rapidly and intelligently on the information given.

Many specific requirements also exist which vary as the use to which the display is put; i.e., target designation, air interception, etc.

Types of Display. There are many methods of presenting three-dimensional information which, in spite of their diversity, fall into two classes of visual displays. The first tries to create the experience of three-dimensional space by making the perception of depth possible. This may be accomplished stereoscopically, by means of projectors which produce images on the concave surface of a hemispherical screen, or by introducing radar information into the interior of a perspective drawing of a three-dimensional solid. Some conceivable solutions of this kind of approach are shown in Fig. 1 in schematic form. The second class of display system arranges the bearing, range, and height information on two-dimensional surfaces without regard for the perception of depth. Usual methods of cathode ray tube (CRT) presentation show only two variables with reference to each other; i.e., "B" Indicator (bearing and range), "C" Indicator (bearing and elevation), etc. Therefore two such scopes must be paired to display all three variables and the problem reduces to the allocation of the necessary CRT's in the operator's work space. The SX radar console with its Plan Position Indicator (PPI), Map Sector Scan (MSS), and Range Height Indicator (RHI) is an example of such an arrangement now in service. Mounting an RHI at the consoles of the VJ and VK remote repeaters, as has been proposed, would add another arrangement to the many possible. See Fig. 2.

However, bearing, range, and height may be displayed on a single CRT. Several hypothetical ways of accomplishing this are shown in Fig. 3. In most of the solutions suggested, two of the variables are given conventionally and the third is coded in some way, usually by lengthening or shaping the blip.

It seems evident that any depth presentation of radar information involving either stereoscopic or "planetarium" methods will be complex and bulky. The order of accuracy with which the "depth" dimension can be estimated by the observer is largely unknown for either of these systems. Experience with stereoscopic range finders suggests that stereoscopic methods be avoided. The method of introducing radar information into the frame of a perspective drawing of a solid is undesirable because of non-hemispherical coverage,

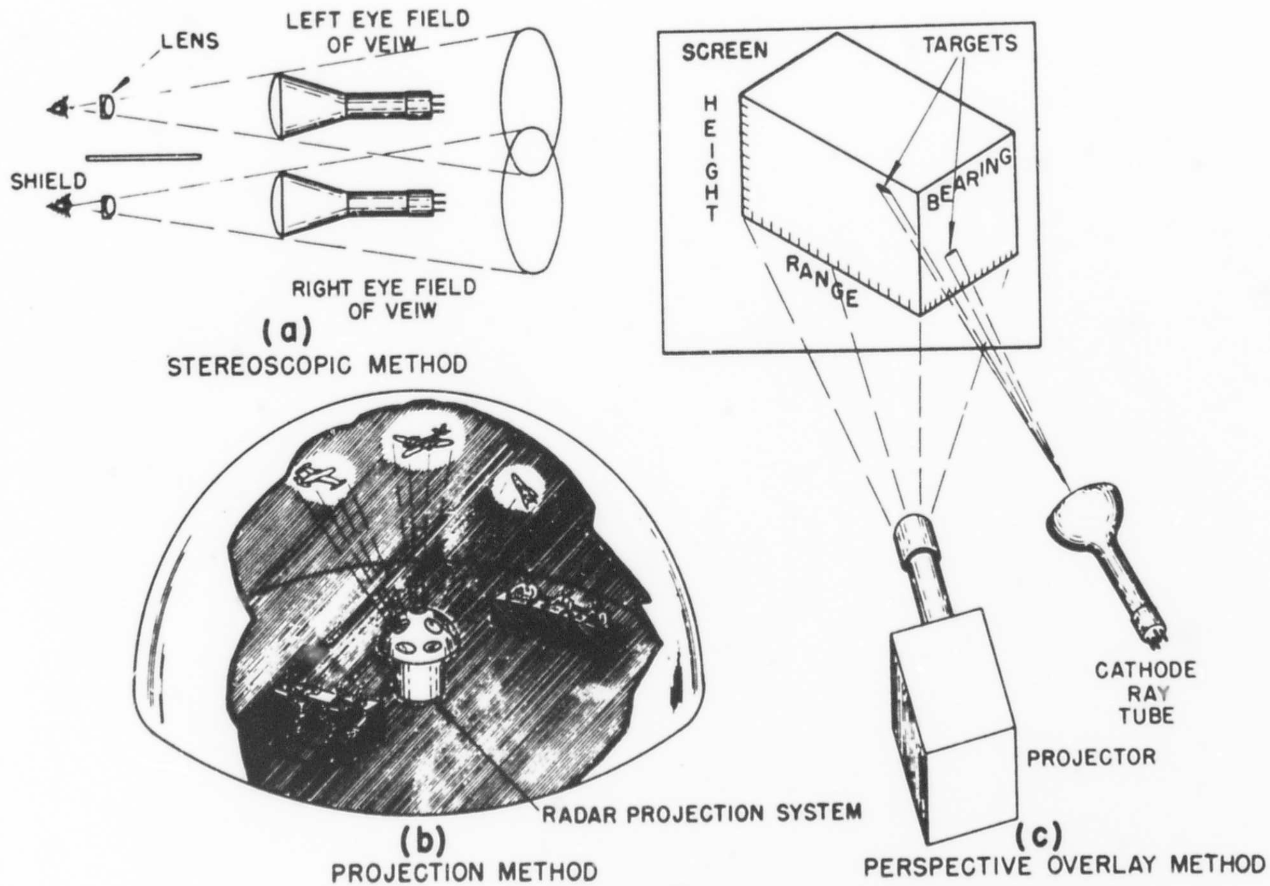


Fig. 1. Display systems designed to achieve the perception of depth.

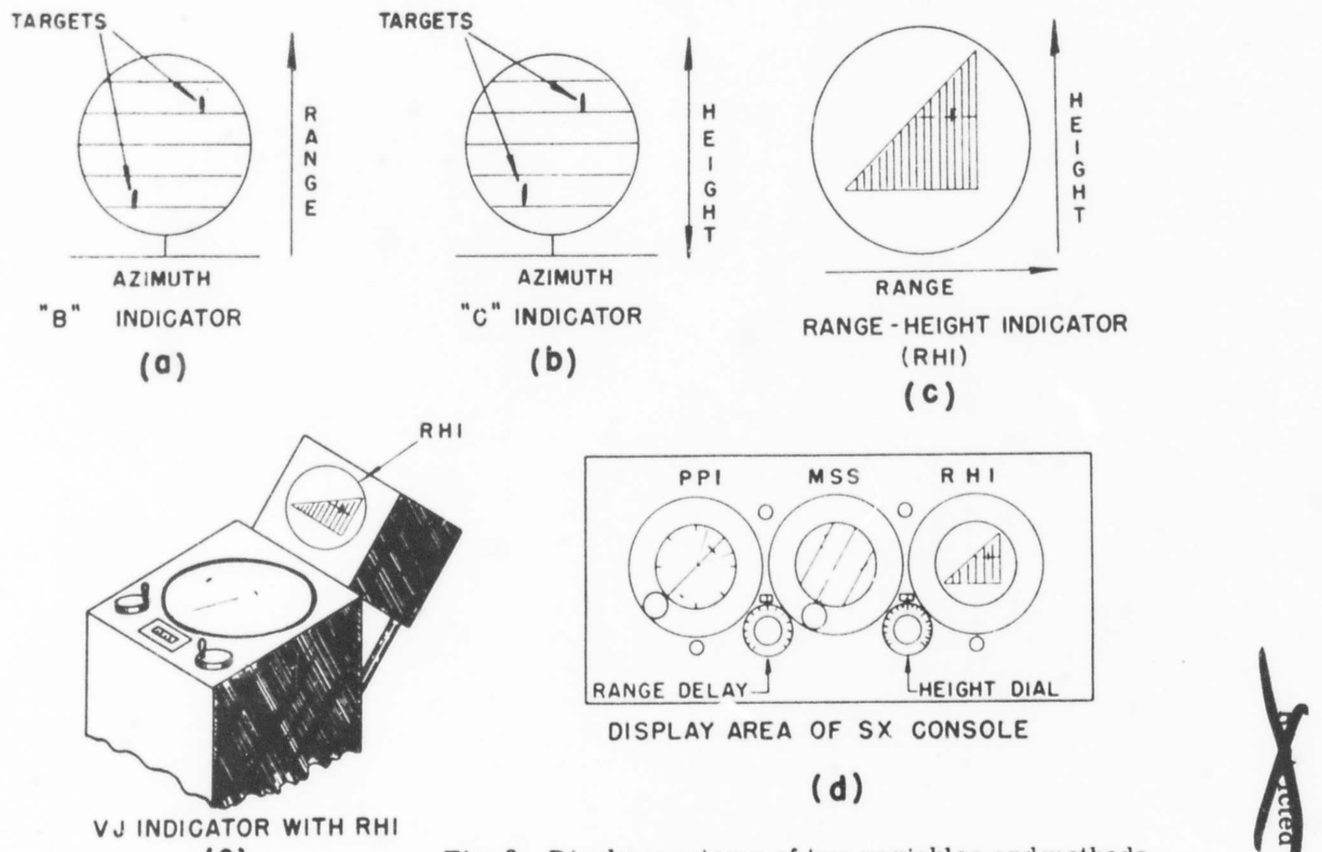


Fig. 2. Display systems of two variables and methods of combining them to give bearing, range, and height.

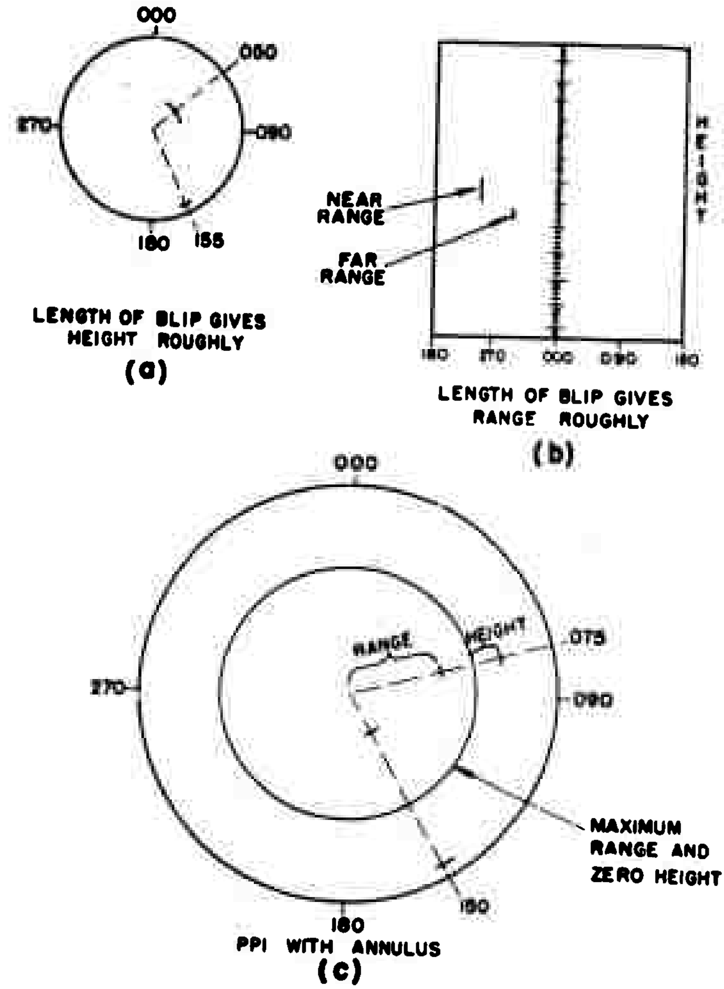


Fig. 3. Display systems of bearing, range, and height given on the same scope.

scale reading difficulties and the possible intrusion of perceptual reversal.*

Of the displays presenting three-dimensional information on one scope, the PPI-and-annulus combination appears to be of promise. This method, as shown in Fig. 3, and hereafter referred to as the experimental BRH (bearing-range-height) display, is a PPI giving bearing and range information, surrounded by a ring which gives bearing and height. Thus, two blips appear on the same bearing, the one on the PPI showing range and the other in the ring showing height.

The advantages of the experimental BRH display seem to be that the radar information is confined to a small visual area and that range and height is estimated from linear scales. Other types of plane displays are either less compact or fail to afford satisfactory quantitative indices of one or another of the variables, usually height. However, a disadvantage arises from having range and height blips on the same bearing. If several targets appear on the same bearing, it will be impossible, without electro-mechanical aid, to ascertain how the range and height blips are paired. It is possible that this difficulty could be overcome by a gating system which enables one target combination to be cut out for a sweep, thus allowing the observer to see which targets pair in range and height.

Purpose. It is the purpose of the two experiments reported here to appraise the experimental BRH method of displaying bearing, range, and height information from the standpoint of speed and accuracy of target indication. Special problems of scaling range and height, and size of scope are studied as related to the display system.

---

* A line drawing of a three-dimensional figure projected upon a plane may be seen by the observer in more than one spatial orientation. There is a strong tendency for such "ambiguous" perspectives to reverse themselves from time to time with prolonged fixation.

PRELIMINARY EXPERIMENT ON THE EXPERIMENTAL BRH DISPLAY

This experiment was designed to give preliminary information on what may be expected from the experimental BRH display presented on two standard pieces of Navy equipment, the VJ and VG remote indicators.

Apparatus

Radar Equipment. A VG projection PPI, two VJ and two VF remote indicators were used in this experiment. The VG and VJ's were used experimentally and were modified first by dividing the viewing surfaces of all three instruments into two regions, a center PPI display and an outer annulus. One-half of the radius was assigned to range and the other half to height. Therefore, the ratio of the range scale to the height scale was 1:1 for each equipment. The unit scale distances were physically equal on the range and height segments of the radius. The range units were miles with a scale of 0 - 40 and the height units were in thousands of feet with a scale of 0 - 40. On the two VJ's the range and height regions were separated by a heavy electronic range marker placed at the midpoint of the sweep; on the VG a black ring was inscribed on the overlay at a corresponding position on the radius.

The experimental units were further modified as follows:

VJ counters. One of the VJ's was equipped with the experimental bearing and range counters used by Chapanis.* This instrument had a bearing counter geared to the bearing hand crank and a combination range-height counter geared to the range hand crank. See Fig. 4. When the target was bisected by the bearing cursor, the bearing counter gave bearing in degrees. The range-height counter was arranged to read miles of range to the nearest tenth mile when the movable range marker was on the range scale. When the movable marker passed over onto the height scale, the counter read thousands of feet to the nearest tenth (i.e., 100 feet).

---

* Chapanis, A. The relative efficiency of a bearing counter and bearing dial for use with PPI presentations. Systems Research, The Johns Hopkins University. Report No. 166-I-26. 1 August 1947. (Restricted)

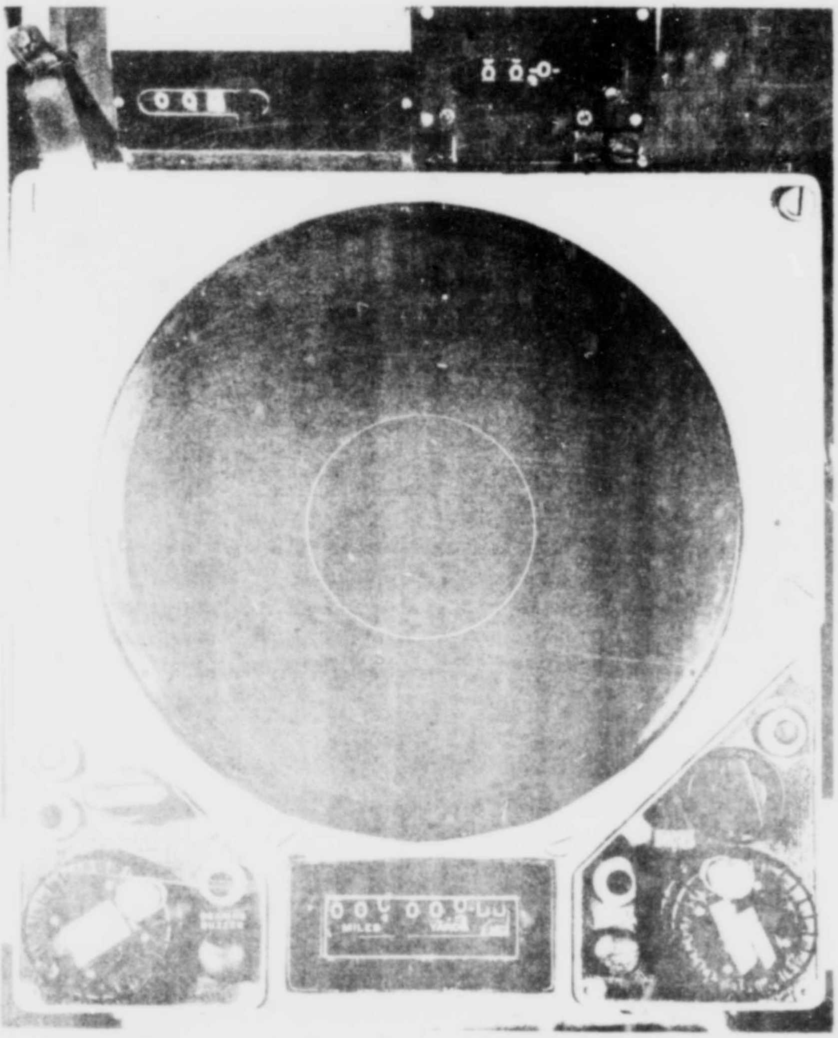


Fig. 4. Experimental BRH display on the VJ remote indicator equipped with bearing and range-height counters.

VJ rings. The other VJ was furnished with eight electronic range markers: the inside four represented 10, 20, 30, and 40 miles; the outside four represented 10,000, 20,000, 30,000, and 40,000 feet. See Fig. 5. On this equipment the bearing cursor and the movable range marker were not used:-bearing was read from the dial by sighting along the targets to the bearing dial and range and height were estimated by interpolation from the rings.

VG overlay. The VG was equipped with the standard Navy overlay which consists of eight concentric rings and 36 bearing reference lines inscribed on opal glass. The four range and four height rings were given the same meaning as on the VJ rings. See Fig. 6.

The choice of multiples of 10 for range and height rings was based on the finding of Chapanis* that scale divisions of 10 constitute one of the most accurate for interpolation.

VF Monitoring. The location of all targets used during the experiment was determined by the use of two VF remote indicators. Since the VF is inherently more accurate than the experimental remotes, average VF measurements served as criteria against which to compare the accuracy of the performance of the operators. Thus, bearing, range, and height errors are defined as the difference between the performance on the experimental equipments and the average VF bearing, range, and height measurements.

Target Simulator. The main target generator system produced two targets at different ranges on the same bearing; the first blip fell on the inside surface or range area of the scopes, and the second fell in the annulus or height area. The target generator and all indicators were set for a 20-mile sweep. The range targets, therefore, varied from 0 to 10 miles, and the height targets from 10 to 20 miles. The targets were all saturated, of a five-degree beam

---

* Chapanis, A. Accuracy of interpolation between scale markers as a function of scale interval number. The American Psychologist, 1947, 2, 346.

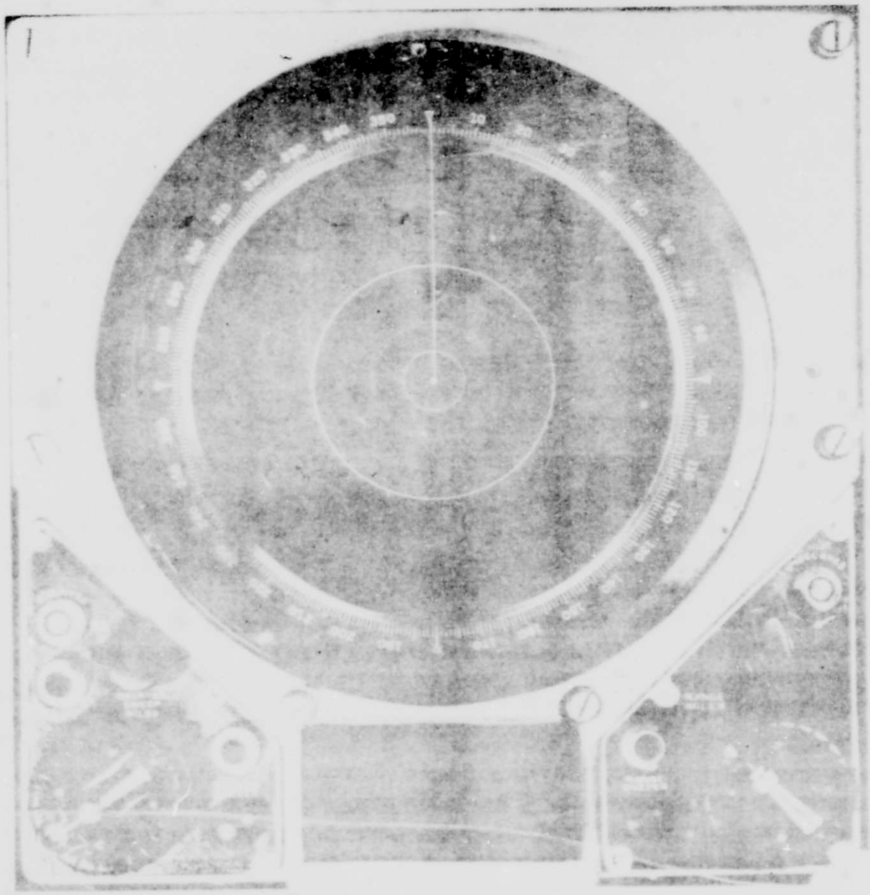


Fig. 5. Experimental BRH display on the VJ equipped with range and height markers.

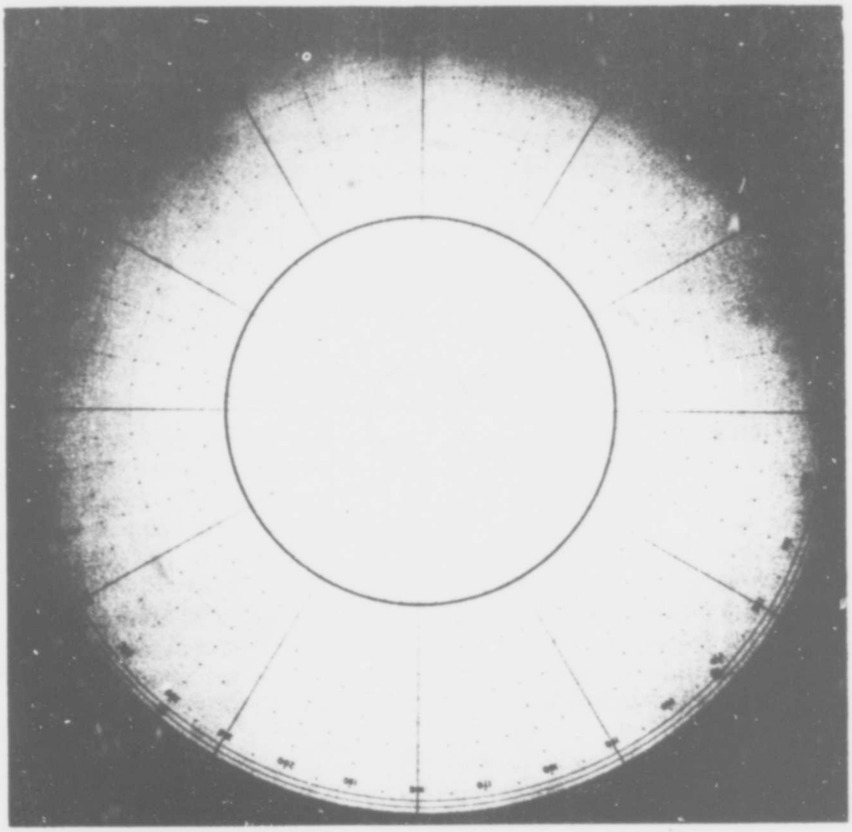


Fig. 6. Experimental BRH display on the VG equipped with the overlay.

width, and about 300 yards thick. The antenna rotation speed was seven rpm. An auxiliary target generator fed a continuously gated target into the video line to produce the dividing marker between the PPI and the annulus.

Timers. The performances of the operators were timed by Standard Electric Clocks operated by the recorders in the manner of stop watches.

General Arrangement. The layout of the equipment is shown in Fig. 7. The three pieces of experimental equipment were located in separate rooms as were the VF's used for monitoring. The VF operators were connected to a recorder at the control panel of the target simulator by sound powered telephones. The whole experiment was coordinated by an intercommunicating system connecting all stations with the control room.

Experimental Methods and Procedures

Design of Experiment. The experimental design is given in Table I. Six Navy radarmen were each tested once on each of the three experimental units. Three men were tested simultaneously with the same target lists. Three target lists were used in such a manner that although each equipment was tested with the same list twice, each operator received the same list only once. The lists contained 36 random settings of bearing, range, and height. Each trial run consisted of three targets (i.e., three bearings, three ranges, and three heights) displayed on the scopes. Each operator was therefore tested with 108 targets and each equipment with 216.

Conditions of Experiment. The administration of the experiment shown in Table I was preceded by a practice experiment identical in all respects with the experimental trials except for target list and order of testing. This was done to minimize learning effects and give greater reliability to the experiment. The practice results were discarded.

The task set for the operator was to fixate the blank scope at a "Ready" signal and to begin reporting bearing, range, and height in that order as soon as the signal "Mark" was given and the tar-

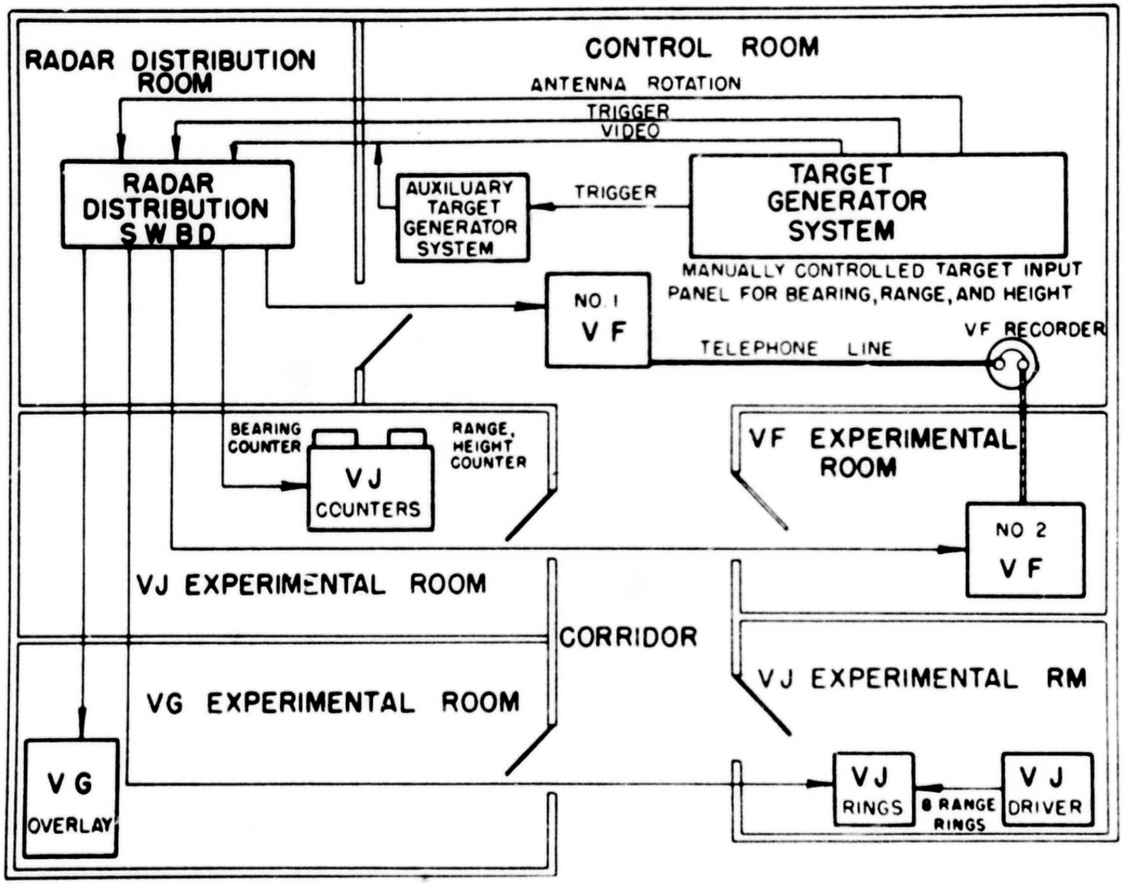


Fig. 7. Experimental set-up for Experiment No. 1.

TABLE I

Experimental Design of the Preliminary Experiment

	Equipment		
Operators	$VJ_{counters}$	VJ_{rings}	$VG_{overlay}$
A	6 (3)*	2 (1)	4 (2)
B	2 (1)	4 (2)	6 (3)
C	4 (2)	1 (1)	5 (3)
D	1 (1)	5 (3)	3 (2)
E	3 (2)	6 (3)	1 (1)
F	5 (3)	3 (2)	2 (1)

gets were sent to the scopes by closing a switch in the control room. The switch activating the targets was thrown when the sweep crossed bearing 000 with the sweep rotating clockwise. The reporting procedure was standardized for all operators. Each was instructed to estimate and report as rapidly and accurately as possible. Bearing was reported conventionally. Range was estimated to the nearest tenth of a mile; height to the nearest tenth of 1000 feet, i.e., to the nearest 100 feet. An example of a full report would be: "zero - three - seven, thirty - point - five, sixteen - point - five"; i.e., bearing = 037, range = 30-1/2 miles, height = 16,500 feet.

The assistant in each experimental room operated the stop clock and recorded times, bearings, ranges, and heights on prepared data sheets. The performance was timed from the signal "Mark" when the targets began to appear, to the completion of the decimal in the last height report. Thus each recorded time was for the report of three targets.

After completion of the operator's run of three targets, each target position was checked and deviations ± 10 degrees of bearing, ± 10 miles of range and ± 10,000 feet of height were reported on the data sheets and treated later as possible reading errors. In this manner, gross estimation errors, especially those arising from confusion of either range or height rings, could be detected and verified immediately.

---

* The entries are the serial orders in which equipments and operators were tested. Numbers in parentheses are target lists used in each test.

Results

Speed of Target Indication. The times per target required for estimating and reporting bearing, range, and height information for each of the three experimental displays are shown for each operator in Table II. Average times are also shown graphically in Fig. 8. It is found that the bearing, range, and height of a target can be estimated from range and height rings in about 9.2 seconds on the VJ_{rings} and the $VG_{overlay}$. Use of the bearing cursor and the movable range marker increases the time to 21.5 seconds, i.e., by a factor of 2.3.

TABLE II

Average Time per Target (in seconds) for Estimating and Reporting Targets from the BRH Display

Operator	$VJ_{counters}$	VJ_{rings}	$VG_{overlay}$	Total	Average
A	22.0	9.9	11.2	43.1	14.4
B	21.6	9.5	10.2	41.3	13.8
C	21.0	12.4	11.3	44.7	14.9
D	20.6	7.2	7.8	35.6	11.9
E	23.5	7.0	9.0	39.5	13.2
F	20.3	6.5	8.3	35.1	11.7
Total	129.0	52.5	57.8		
Average	21.5	8.8	9.6		

The analysis of variance of the time data is given in Table III. It is evident that the time differences between the equipments are highly significant and that the greatest amount of this variance is due to the VJ requiring the use of the hand cranks. The variance between equipments is significantly greater than between operators. The variance between operators is not significant.

[redacted]

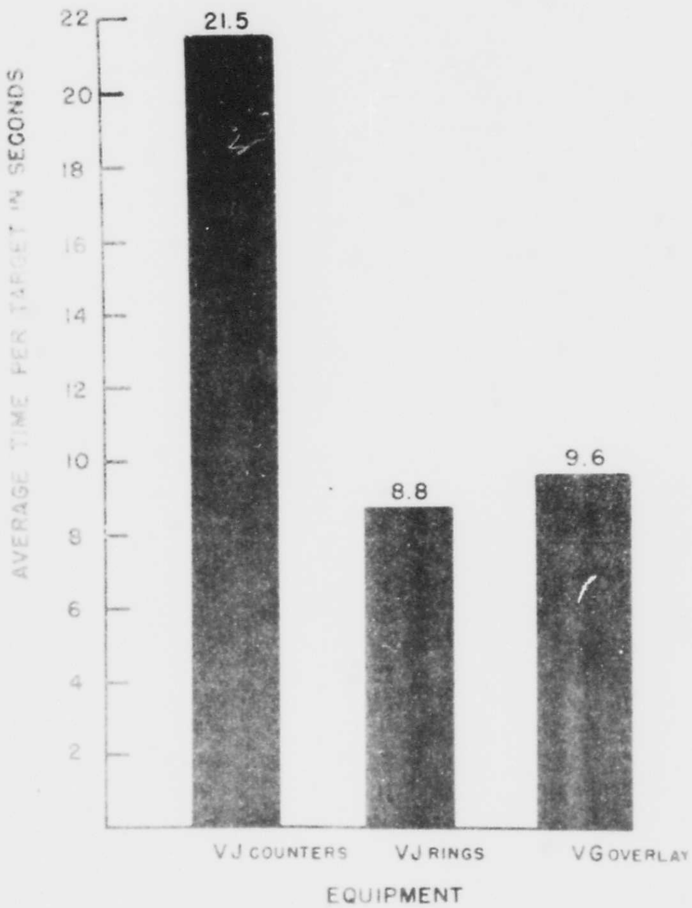


Fig. 8. Average times required by six operators to read bearing, range, and height information from the experimental BRH display on three equipments.

TABLE III

Analysis of Variance of the Time Data of Table II

Source of Variance	Degrees of Freedom	Sums of Squares	Mean Square
Between Equipments	2	608.32	304.16
Between Operators	5	25.64	5.13
Discrepancy	10	17.95	1.79
Total	17	651.91	

$F_{equipment} = \frac{304.16}{1.79} = 169.92$ (Significant at the 1% level)

$F_{operators} = \frac{5.13}{1.79} = 2.86$ (Not statistically significant)

$F_{equipment/operators} = \frac{304.16}{5.13} = 59.29$ (Significant at the 1% level)

Bearing Errors. The errors made in indicating bearing are given for equipments and operators in Table IV and shown graphically in Fig. 9. The highly structured spider-web overlay of the VG shows its influence in keeping average bearing errors small. The large average bearing error made on the VJ counters is out of line with what this instrument should give in the hands of practiced radarmen. Chapanis found few instances in which bearing errors larger than two degrees were made by skilled VJ operators. The Navy radarmen used in this experiment had little experience on the VJ as normally used and frequently made bearing errors as large as six degrees.

The analysis of variance of bearing error data is given in Table V. The differences between equipments are barely significant at the 5% level of confidence, i.e., there is one chance in twenty that they might have been due to chance alone. It is clear that most of the between-equipment variance is due to the low average bearing error obtained on the VG. Differences between operators are not significant nor is the ratio between machine and operator variance significant.

TABLE IV

Average Bearing Errors (in degrees) for Estimating Targets from the BRH Display

	Equipment				
Operator	$VJ_{counters}$	VJ_{rings}	$VG_{overlay}$	Total	Average
A	2.4	1.9	1.0	5.3	1.7
B	1.2	1.7	0.7	3.6	1.2
C	1.0	1.4	1.1	3.5	1.1
D	1.4	1.1	1.1	3.6	1.2
E	1.2	1.8	1.0	4.0	1.3
F	3.0	1.8	1.0	5.8	1.9
Total	10.2	9.7	5.9		
Average	1.7	1.6	1.0		

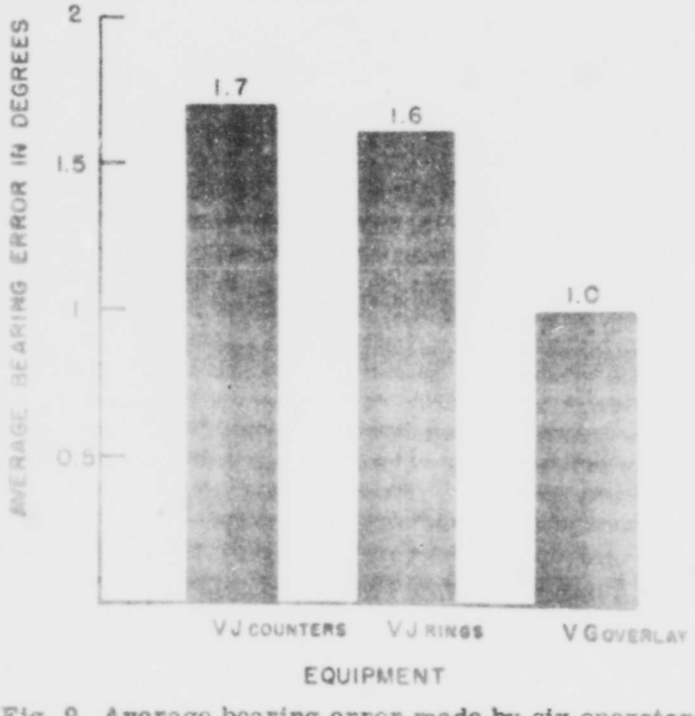


Fig. 9. Average bearing error made by six operators using the experimental BRH display on three equipments.

TABLE V

Analysis of Variance of the Bearing Error Data of Table IV

Source of Variance	Degrees of Freedom	Sums of Squares	Mean Square
Between Equipments	2	1.84	0.92
Between Operators	5	1.65	0.33
Discrepancy	10	2.19	0.22
Total	17	5.68	

$$F_{equipment} = \frac{.92}{.22} = 4.18 \quad \text{(Significant at the 5\% level)}$$

$$F_{operators} = \frac{.33}{.22} = 1.50 \quad \text{(Not statistically significant)}$$

$$F_{equipment/operators} = \frac{.92}{.33} = 2.78 \quad \text{(Not statistically significant)}$$

Range and Height Errors. In the experimental situation where range and height blips were simulated, height was given by a blip that was merely at a greater range. Therefore, unless factors such as scaling and scope size entered to change the perceptual organization of the situation, or calibration differences in the equipment were present, handling range and height blips should differ only as handling near and far ranges. The data for range errors are given in Table VI and shown graphically in Fig. 10. The analogous height error data are presented in Table VIII and Fig. 11.

Range errors for the VG are slightly larger than on the other equipments. The analysis of variance of the range error data is given in Table VII. The differences vetween the equipments again are just significant at the 5% level of confidence. The variance contributed by the operators, and the differences between machines and men are not significant. The VG data are responsible for most of the equipment variance.

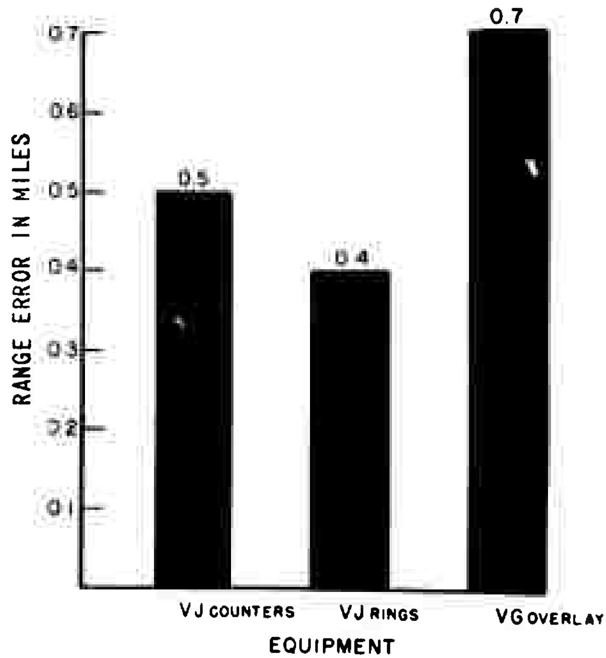


Fig. 10. Average range error made by six operators using the experimental BRH display on three equipments.

[redacted]

TABLE VI

Average Range Errors (in Miles) for
Estimating Targets from the BRH Display

Equipment

Operator	$VJ_{counters}$	VJ_{rings}	$VG_{overlay}$	Total	Average
A	0.6	0.3	0.6	1.5	0.5
B	0.3	0.3	0.6	1.2	0.4
C	0.4	0.4	0.6	1.4	0.5
D	0.4	0.4	0.7	1.5	0.5
E	0.4	0.7	0.7	1.8	0.6
F	0.8	0.5	0.7	2.0	0.7
Total	2.9	2.6	3.9		
Average	0.5	0.4	0.7		

TABLE VII

Analysis of Variance of the Range Error Data of Table VI

Source of Variance	Degrees of Freedom	Sums of Squares	Mean Square
Between Equipments	2	0.15	0.075
Between Operators	5	0.14	0.028
Discrepancy	10	0.16	0.016
Total	17	0.45	

$F_{equipment} = \frac{.075}{.016} = 4.69$ (Significant at the 5% level)

$F_{operators} = \frac{.028}{.016} = 1.75$ (Not statistically significant)

$F_{equipment/operators} = \frac{.075}{.028} = 2.68$ (Not statistically significant)

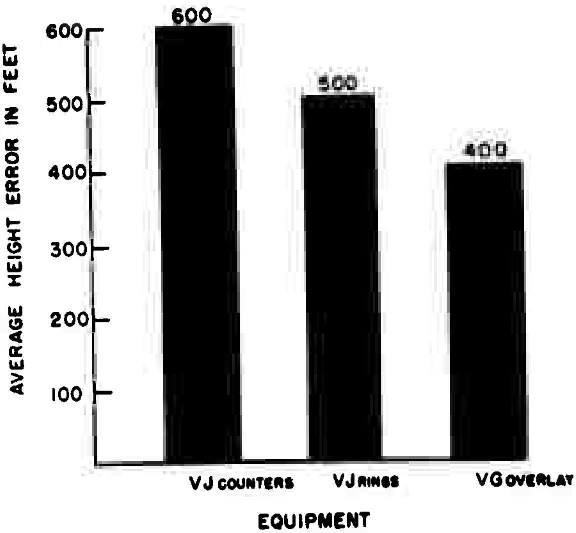


Fig. 11. Average height error made by six operators using the experimental BRH display on three equipments.

Similar treatment of the height error data is given in Table IX. Again the variance difference between equipments is significant at the 5% level and most of it arises from the VG data. Operator variance is non-significant as is variance between operators and machines.

TABLE VIII

Average Height Errors (in feet) for Estimating Targets from the BRH Display

	Equipment				
Operator	$VJ_{counters}$	VJ_{rings}	$VG_{overlay}$	Total	Average
A	800	600	400	1800	600
B	300	400	400	1100	400
C	600	300	300	1200	400
D	500	500	300	1300	400
E	600	600	400	1600	500
F	700	500	500	1700	600
Total	3500	2900	2300		
Average	600	500	400		

TABLE IX

Analysis of Variance of the Height Error Data of Table VIII

Source of Variance	Degrees of Freedom	Sums of Squares	Mean Square
Between Equipments	2	0.12	0.06
Between Operators	5	0.13	0.026
Discrepancy	10	0.11	0.011
Total	17	0.36	

$F_{equipments} = \frac{.06}{.011} = 5.45$ (Significant at the 5% level)

$F_{operators} = \frac{.026}{.011} = 2.36$ (Not statistically significant)

$F_{equipments/operators} = \frac{.06}{.026} = 2.31$ (Not statistically significant)

As with the bearing error, the average range and height error on the VJcounters is much greater than would be expected from thoroughly practiced operators and should not be taken as representative of the best VJ performance.

Calibration Differences. The scaling of range and height was such as to make them directly comparable. It will be noticed from Tables VI and VIII that the two VJ's give somewhat better range accuracy than height and that with the VG this relationship is reversed. The significance of these differences between range and height on the same instrument is given in Table X. From these statistics it is clear that on the two VJ's the accuracy of the inside of the scope as compared with that of the outside differs only as chance. On the VG, however, the difference is real and is due to the failure of the time delays in the electronic system to correspond with the fixed range rings inscribed on the overlay. At the time of the present experiment this could be compensated for only in part, and the error turned out to be less at long ranges than at short. In the second experiment reported below this difficulty was eliminated.

TABLE X

Significance of Average Error Differences between Range and Height

The Preliminary Experiment

	$VJ_{counters}$	VJ_{rings}	$VG_{overlay}$
Average Range Error (miles)	0.5	0.4	0.7
Average Height Error (1000s of feet)	0.6	0.5	0.4
t test	1.94*	0.81*	7.99**

* Not statistically significant.
** Significant at 1% level.

Errors in Confusing Range and Height Markers. The range and height rings on the VJ_{rings} and the $VG_{overlay}$ were not numbered or designated in any way. Therefore, their values could be known only by recognizing the position of the ring on the scope or by counting from a reference point; i.e., center of scope or the electronic range-height division marker. Consequently, there were many instances of confusing one ring with another. Inasmuch as all rings, both range and height, were multiples of 10, a constant of ± 10 was added whenever such confusions occurred. For example, the target is at range 19.5 miles; the operator calls this either 9.5 (-10) or 29.5 (+10). These errors were eliminated from the data and were not treated in the foregoing analyses on the ground that errors due to the confusional factor are a different process from that of range and height estimation between range rings and might be reduced by a suitably designed overlay or scale numbering system. It was desired not to load the data with these occasional gross deviations.

The number of ring confusions was too small to admit of systematic treatment, but their frequency for the VJ_{rings} and the $VG_{overlay}$ is shown in Table XI for each operator. They appear to be equally distributed on the two instruments.* Some operators may be more prone to this type of confusion than others, although the data are too meagre to show this.

Conclusions. The findings of the first experiment are summarized in Table XII for the experimental BRH display on the three remote repeaters. Here the average time per target required to estimate and report bearing, range, and height is given with the average bearing, range, and height errors. The significance of the variance ratios for equipments and operators is given for times

---

* On the $VJ_{counters}$ only two reading errors were made during the experiment. Reading errors occur rarely with use of the experimental counters as was shown in Chapanis, A., Speed of reading target information from a direct-reading, counter-type indicator versus conventional radar bearing and range dials. Systems Research, The Johns Hopkins University. Report No. 166-I-3. 1 November 1946. (Restricted)

and errors in the same table. As would be expected, time is markedly shortened by estimating from bearing dials and range and height rings. Cranking operations double the time per target. With unskilled VJ operators, such as used in this experiment, the use of the cursor and movable range marker does not increase the accuracy of the estimates. The overlay on the VG holds the bearing errors significantly low. Nothing appears to be gained in range and height accuracy by using the 24-inch VG surface instead of the 12-inch surface of the VJ.

TABLE XI

Number of Instances in Which the Numerical Designation of the Range and Height Rings Was Incorrectly Read

	Equipment and Conditions				
	VJ_{rings}		$VG_{overlay}$		
Operators	Range	Height	Range	Height	Operator Total
A	2*		1		3
B				2	2
C	1	2			3
D			2		2
E		3	1	3	7
F	1	2		2	5
Instrument Totals	4	7	4	7	22

* Cell entries are number of times out of a total of 36 readings the operator misread the numerical values of the markers.

TABLE XII

Summary of the Preliminary Experiment on the Experimental BRH Display

	Time and Error Data Equipment			Analysis of Variance Findings Obtained Levels of Significance	
	$VJ_{counters}$	VJ_{rings}	$VG_{overlay}$	$F_{equipments}$	$F_{operators}$
Average time per target	21.5 seconds	8.8 seconds	9.6 seconds	1%	*
Average bearing error	1.7 degrees	1.6 degrees	1.0 degrees	5%	*
Average range error	0.5 miles	0.4 miles	0.7 miles	5%	*
Average height error	600 feet	500 feet	400 feet	5%	*

* Not statistically significant

EXPERIMENT ON EFFECTS OF SCOPE SIZES AND SCALE RATIOS

The second experiment was designed to examine the effect of four scope sizes and two scale ratios of range to height on the performance of operators using the experimental BRH display.

Apparatus

Radar Equipment. The VH, VD, VJ, VG, and two VF remote indicators employed in this study are standard Navy units. The VH, VD, VJ, and VG repeaters were used experimentally and the two VF's monitored all targets. Five, seven, and twelve-inch CRT tubes are furnished with the VH, VD, and VJ indicators respectively. The projection surface of the VG is 24 inches in diameter. The VH and VD equipments were used without cursors and the VJ was operated with neither cursor nor movable range marker. The VG was equipped with a modified overlay made by ruling bearing guide lines on the plain plotting surface every 10 degrees. The 10-degree azimuth positions were numbered on the outside of the display at the terminus of each guide line and the standard projection bearing dial located in the center of the display was used as well. See Fig. 12.

VF Monitoring. Two VF remote indicators were used as standards from which bearing, range, and height errors were computed as in the first experiment.

Range-Height Scale Ratios. Electronic range and height rings were generated in the VJ Driver Unit and fed into all four experimental PPI's. This eliminated variations due to range marker systems in the individual remote indicators. Two sets of range markers were generated with different time constants to produce two range-height scale ratios. For the 1:1 ratio, a heavy electronic range marker from the auxiliary target generator was gated at the mid-point of the sweep. This divided the display into two regions of equal radial segments. The range markers used with this arrangement consisted of eight equidistant rings, as in the first experiment: four for range designated 10, 20, 30, and 40 miles; four for height designated 10,000, 20,000, 30,000, and 40,000 feet. For

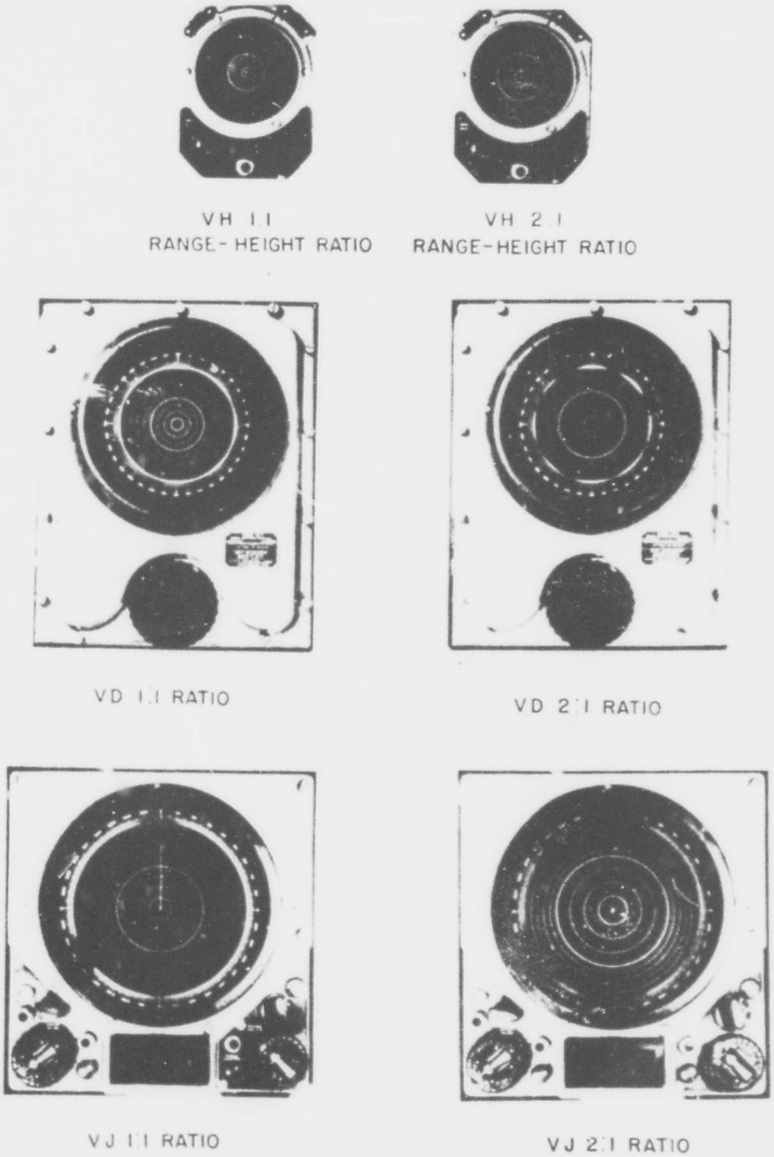
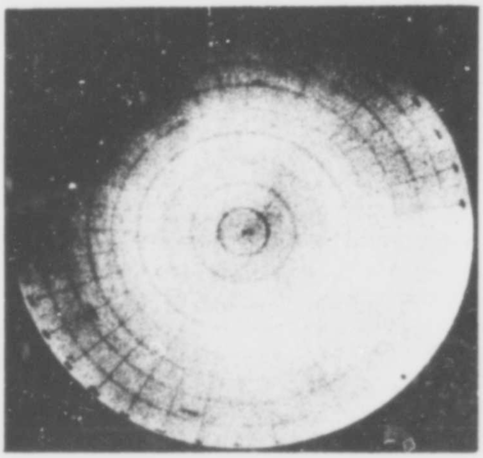
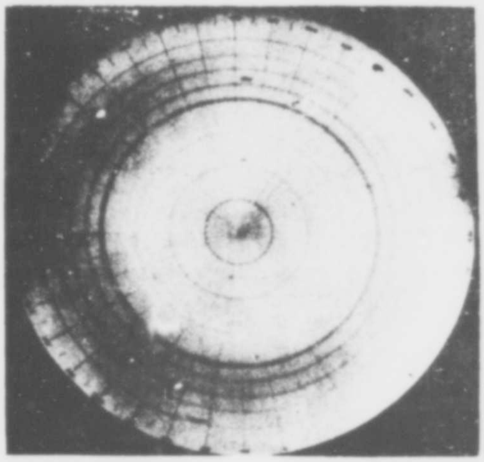


Fig. 12a. The experimental BRH display shown on the VH (upper); VD (center); and VJ (lower) remote repeaters for the 1:1 and 2:1 range-height scale ratios. All photographs are on the same scale: 1 in. = 10 in. (approximately).



VG 1:1 RATIO



VG 2:1 RATIO

Fig. 12b. The experimental BRH display shown on the VG remote repeater for the 1:1 (upper) and 2:1 (lower) range-height scale ratios. Both photographs are on the same scale: 1 in. = 10 in. (approximately).

the 2:1 ratio the heavy electronic marker was gated two-thirds of the way out on the sweep, again dividing the display into two regions. For the 2:1 ratio condition, the portion of the radius assigned to range was one-sixth larger than with the 1:1 ratio; the portion assigned to height correspondingly smaller. For use with the 2:1 ratio six markers were generated and used as follows: the inside four were designated 10, 20, 30, and 40 miles and comprised the range scale. Halfway between each of the remaining two rings were placed two continuously gated targets from the auxiliary target generator. This provided four height rings which were designated 10,000, 20,000 30,000, and 40,000 feet.

The appearance of the four experimental displays with the 1:1 and 2:1 range-height scale ratios is shown in Fig. 12.

Target Simulator. The target simulator was used as in the first experiment.

Timers. The Standard Electric Timers were used as in the first experiment.

General Layout. The layout of the equipment for the size and scaling experiment is shown in Fig. 13. Again all equipments were in separate experimental rooms.

Experimental Methods and Procedures

Design of Experiment. The experimental design, consisting of four duplicated experiments with one replication is shown in Table XIII. Six Navy radarmen, four of whom were used in the first experiment, were each tested twice on each of the four experimental units. Four men were tested simultaneously with the same target settings and received, during any one run, three series of three targets each, nine targets in all. The target input varied throughout the experiment and no operator or instrument received the same targets twice. Testing of operators, range-height scale ratios, and replications was randomized to distribute the error. Each operator was tested, therefore, with 144 target settings, each equipment with 216, and each range-height ratio with 108.

[redacted]

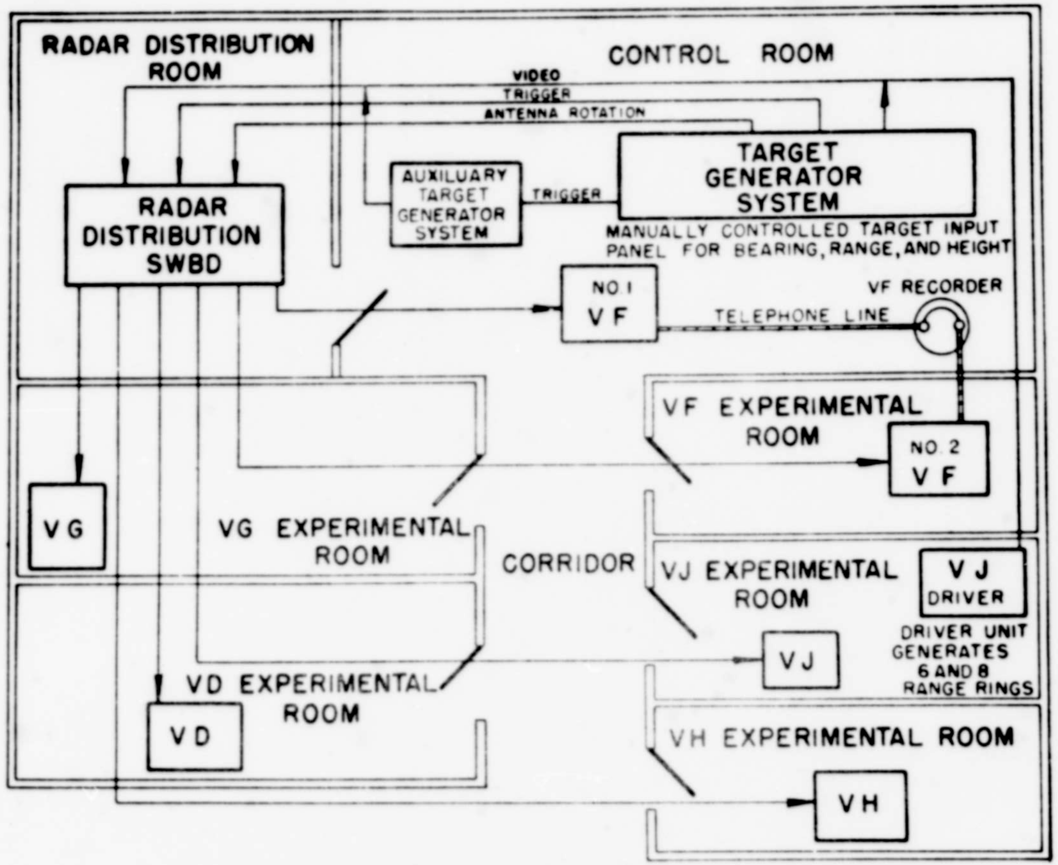


Fig. 13. Experimental set-up for Experiment No. 2.

Conditions of Experiment. The administration of the experiment was preceded by practice trials identical in all respects with the experimental trials except for number of target settings, and order of testing. The practice run was half as long as each experimental session. The results of the practice trials were discarded.

TABLE XIII

Experimental Design of Experiment on Scope Sizes and Scale Ratios

Equipment and Range-Height Scale Ratios

Range-Height Ratios / Operators		VH 1:2	VH 2:1	VD 1:1	VD 2:1	VJ 1:1	VJ 2:1	VG 1:1	VG 2:1
A	Trial 1	9*	12	4	13	18	6	14	7
	Trial 2	21	24	10	15	22	17	23	19
B	Trial 1	14	2	22	6	4	1	3	13
	Trial 2	20	5	23	12	21	11	8	15
C	Trial 1	18	13	16	5	3	12	4	11
	Trial 2	22	17	21	7	23	15	20	24
D	Trial 1	8	6	3	1	10	2	9	5
	Trial 2	16	19	18	11	20	7	21	12
E	Trial 1	3	11	9	17	8	13	10	1
	Trial 2	23	15	20	24	14	19	16	2
F	Trial 1	4	1	8	2	9	5	18	6
	Trial 2	10	7	14	19	16	24	22	17

* The entries are the serial orders in which equipments and operators were tested

The method of reporting the bearings, ranges, and heights was the same as in the first experiment and the role of the operators and assistants was unchanged. At the end of each run the assistant recorded the time for extracting the information for three targets on the prepared data sheet.

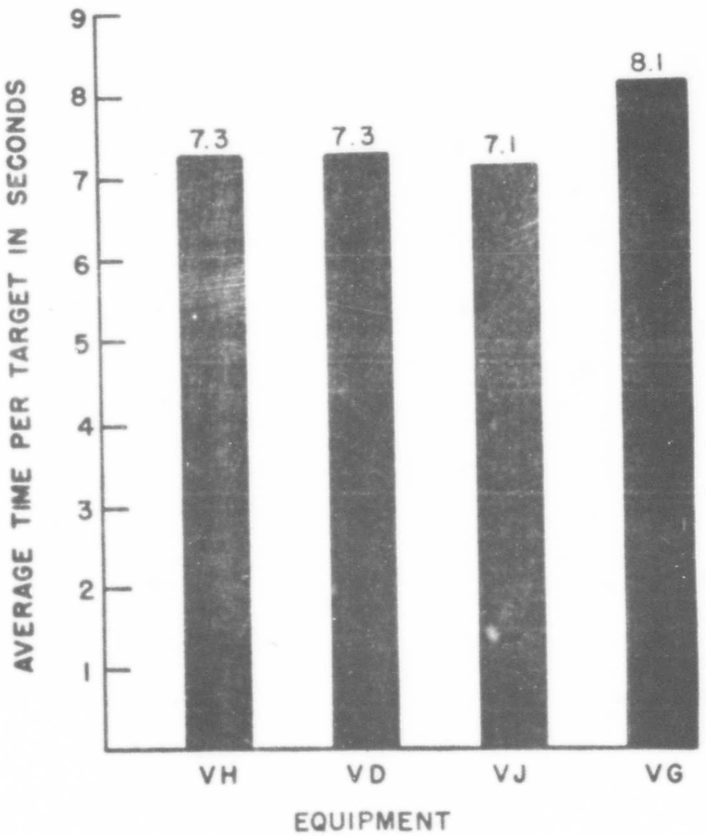


Fig. 14. Average times required by six operators to read bearing, range, and height information from the experimental BRH display on four equipments.

Results

Speed of Target Indication. The average times required by the operators for reporting bearing, range, and height information on a group of three targets are given in Table XIV for the four experimental equipments and the two scale ratios. The average times per target are shown graphically in Fig. 14 for the equipments only. The data indicate that the operators require, on the average, about seven seconds to estimate and report target information from the experimental BRH display. This is about two seconds faster than under comparable conditions in the first experiment reported in this paper, but the difference is not statistically reliable. The same amount of time is required whether operators use the five-inch VH scope, the seven-inch VD, or the twelve-inch VJ. The 24-inch VG, however, is a little slower and requires another second, on the average, for each target. The time required for target extraction is seven and a half seconds for either the 1:1 or 2:1 range to height scale ratios.

The analysis of variance of the time data in Table XIV is given in Table XV. It is evident that the largest variance is introduced by the radar operators (O). This variance is significant at the one per cent level of confidence when evaluated against the best estimate of error, the within class (WC) variance. The between-equipment variance (E) is also statistically significant at the one per cent level when tested on the same basis. The between ratio variance (R) is not statistically significant indicating that on the whole the 1:1 and 2:1 ratios have no influence on the times. However, the interaction variance, E x R, tested against the WC variance is significant at the five per cent level. Inspection of Table XIV shows that the 2:1 ratio yields better times on the VH, VD, and VJ indicators but that the 1:1 ratio is somewhat better on the VG. This time reversal may result from the type of overlay used on the VG. With the 1:1 ratio more targets may have been referred to the projection bearing dial which, graduated in degrees, and always closer to the range blip, enabled a more rapid estimation of bearing. The 2:1 ratio, on the other hand, distributed range blips more widely about the projection dial and referred the height blips to the coarsely graduated dial at the periphery of the display. Thus, with ratio 2:1, more time would be required of the operator to estimate either (1) the bearing of a range blip at a greater distance from the center dial, or (2) the bearing of the corresponding height blip from the

~~Restricted~~

TABLE XIV

Time (in Seconds) Required to Estimate Three Targets from the BRH Display

Equipment and Range-Height Scale Ratios

Range-Height Ratios	VH				VD				VJ				VG				
	1:1		2:1		1:1		2:1		1:1		2:1		1:1		2:1		
1st and 2nd Runs Operators	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	Operator Average
A	26.9	22.2	25.1	22.8	23.8	26.3	19.1	24.9	20.7	22.6	18.8	23.8	23.8	22.5	23.0	25.5	23.2
B	28.4	23.5	24.6	27.8	23.6	23.9	27.6	26.4	26.0	24.7	22.3	23.7	27.0	29.4	32 6	29.6	26.3
C	15.8	15.7	18.8	14.9	18.7	16.1	16.5	18.3	17.7	19.8	17.5	18.1	19.8	18.6	20.1	18.1	17.7
D	23.5	22.1	19.2	18.1	23.0	18.5	18.0	21.3	24.9	23.1	21.7	18.3	23.2	22.3	31.0	26.1	22.1
E	23.3	22.2	21.4	21.2	24.8	20.0	20.1	23.1	22.9	23.2	19.0	19.6	23.5	24.4	19.6	23.8	22.0
F	21.9	24.9	19.9	25.7	26.7	22.0	21.9	21.7	21.5	22.3	23.9	21.6	21.8	25.4	22.6	31.0	23.4
Equipment Average	22.0				21.9				21.5				24.3				
Ratio 1:1 Average	22.6																
Ratio 2:1 Average	22.2																

TABLE XV

Analysis of Variance of the Times Data of Table XIV

Source of Variance	DF	Sum of Squares	Mean Square	F
Between Operators (O)	5	617.89	123.57	25.01*
Between Equipments (E)	3	116.03	38.67	7.83*
Between Ratios (R)	1	3.84	3.84	
Interactions				
O x E	15	82.31	5.49	
O x R	5	22.56	4.51	
E x R	3	41.57	13.86	2.81**
O x E x R	15	77.47	5.16	
Within Class	48	236.89	4.94	
Total	95	1198.56		

* Significant at the 1% level
** Significant at the 5% level

outer dial where more careful interpolation was necessary. On the hypothesis that use of the projection dial was faster and/or more accurate, one would predict that VG bearing errors would be lower with the 1:1 ratio than the 2:1. That this is true, relative to the other equipments, is seen in Table XVI for bearing errors.

Bearing Errors. The data for average bearing errors are given for instruments, operators, and ratios in Table XVI. These averages are presented graphically in Fig. 15. The modified spider-web overlay used on the VG holds the average bearing error to about one degree. The operators average about two degrees of error on the VJ and nearly three and three and a half degrees on the VD and VH respectively. It will be remembered that the two

TABLE XVI

Average Bearing Errors in Degrees from the BRH Display
Equipment and Range-Height Scale Ratios

Range-Height Ratios	VH				VD				VJ				VG				
	1:1		2:1		1:1		2:1		1:1		2:1		1:1		2:1		
1st and 2nd Runs Operators	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	Operator Average
A	1.7	2.8	1.7	2.1	1.6	2.1	1.4	2.3	2.8	1.3	1.3	1.8	1.1	0.7	0.9	0.8	1.6
B	2.8	5.4	3.9	5.1	2.9	5.8	4.4	3.5	3.2	5.1	3.4	2.4	0.9	0.7	1.3	0.7	3.2
C	6.5	3.4	4.0	3.8	3.6	2.9	1.9	2.4	3.0	2.0	1.4	2.8	1.6	2.2	1.1	1.6	2.7
D	3.4	4.4	2.8	3.0	3.8	5.2	2.2	3.2	2.1	2.2	1.7	1.4	0.7	2.3	1.0	1.5	2.5
E	3.9	5.7	2.7	3.2	2.9	2.7	2.1	3.0	2.3	1.4	2.2	2.1	1.2	0.8	1.8	1.1	2.4
F	4.0	2.6	2.8	1.6	1.8	1.9	2.6	2.0	1.7	1.9	1.4	2.1	0.8	0.9	0.7	0.7	1.8
Equipment Average	3.4				2.8				2.2				1.1				
Ratio 1:1 Average	2.6																
Ratio 2:1 Average	2.1																

[redacted]

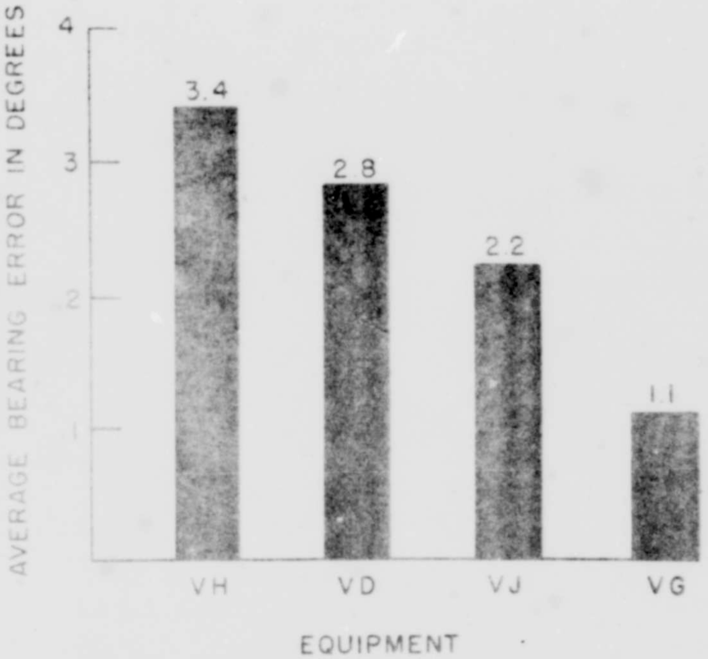


Fig. 15. Average bearing error made by six operators using the experimental BRH display on four equipments.

smaller scopes, VH and VD, have bearing dials inscribed at two-degree intervals, whereas the VJ dial and the projection dial at the center of the VG are graduated in one-degree units. It is apparent, therefore, that the largest bearing errors occur on the two displays that are smallest and have the coarsest scales.

The analysis of variance of the bearing error data is found in Table XVII. It is clear that the largest variance is contributed by the equipments. This variance tested against the WC variance is statistically significant at the one per cent level. Most of the E variance is due to the VG. The operator and ratio variances are also significant at the one per cent level. The 2:1 range-height scale ratio is clearly superior on all indicators except the VG. This appears due to the effect of the narrower annulus of the 2:1 ratio which locates the height blips more closely to the bearing

TABLE XVII

Analysis of Variance of Bearing Errors of Table XVI

Source of Variance	DF	Sum of Squares	Mean Square	F
Between Operators (O)	5	27.19	5.44	8.91*
Between Equipments (E)	3	71.83	23.94	39.24*
Between Ratio (R)	1	4.96	4.96	8.13*
Interactions				
O x E	15	16.68	1.11	1.82+
O x R	5	1.88	0.37	
E x R	3	1.79	0.59	
O x E x R	15	6.32	0.42	
Within Class	48	29.26	0.61	
Total	95	159.91		

* Significant at the 1% level

\+ Significant at the 6% level

dials where they can be accurately estimated. On the VG this does not apply because the outer bearing dial (See Fig. 12) is coarsely graduated. There is no way of determining from the data which of the two bearing dials of the VG overlay was used, or as a matter of fact, how the experimental overlay influenced bearing accuracy.

The interaction variance O x E is significant at about the six per cent level. This suggests that it makes a difference which operator uses which machine. Examination of the data in Table XVI indicates some disturbance of the rank order which operators take on the four equipments; i.e., operator A is not always best on all remotes, operator F not second best, etc. This particular interaction is not strong but its statistical significance is such that it cannot be ignored.

Range Errors. The data on the range errors are given in Table XVIII and also appear in Fig. 16. The operators show more variability than the equipments and show average errors ranging from about one-half of a mile to a mile. The best equipment performance was obtained on the VJ with an average error of a half of a mile; the worst was on the VH with an average error of seven-tenths of a mile. The 1:1 and 2:1 ratios averaged six-tenths and five-tenths of a mile of error respectively with all equipments considered.

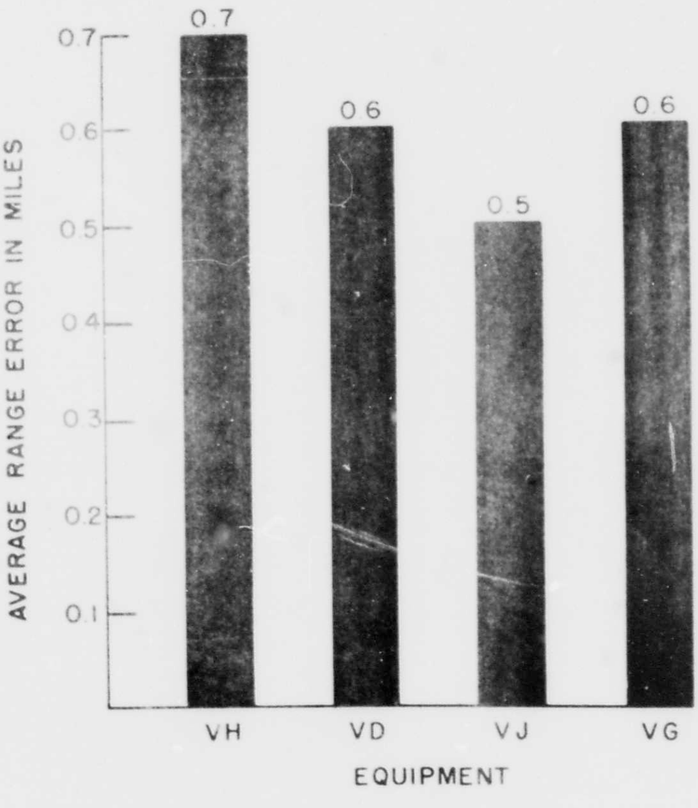


Fig. 16. Average range error made by six operators using the experimental BRH display on four equipments.

TABLE XVIII

Average Range Errors (in Miles) from the BRH Display

Equipment and Range-Height Scale Ratios

Range-Height Ratios	VH				VD				VJ				VG				
	1:1		2:1		1:1		2:1		1:1		2:1		1:1		2:1		
1st and 2nd Runs Operators	1	2	1	2	1	2	1	2	1	2	1	2	1	2	1	2	Operator Average
A	0.4	0.5	0.3	0.5	0.4	0.5	0.6	0.4	0.5	0.6	0.6	0.5	0.4	0.7	0.3	0.4	0.5
B	0.6	0.4	1.0	0.6	0.3	0.5	0.5	0.3	0.6	0.4	0.2	0.3	1.0	0.6	0.4	0.4	0.5
C	1.0	1.0	0.7	0.6	0.6	0.5	0.7	0.5	0.7	0.4	0.3	0.6	0.5	0.5	0.9	0.4	0.6
D	1.4	0.9	0.9	1.1	0.9	1.3	0.5	0.4	0.9	0.8	0.7	0.5	0.7	1.0	1.0	0.6	0.9
E	0.6	0.5	0.2	0.5	0.2	0.5	0.6	0.4	0.2	0.6	0.3	0.3	0.4	0.4	0.4	0.2	0.4
F	0.6	0.3	0.5	0.7	0.8	0.6	0.7	0.7	0.6	0.8	0.7	0.5	0.7	0.4	0.4	0.6	0.6
Equipment Average	0.7				0.6				0.5				0.6				
Ratio 1:1 Average	0.6																
Ratio 2:1 Average	0.5																

The analysis of variance of the range data is given in Table XIX. It shows that the operator variance, significant at the one per cent level, contributes the largest share of the range error variance. Differences between equipments are just significant at the five per cent level when evaluated against the WC variance and it is apparent that the VH and VJ are largely responsible for this.

TABLE XIX

Analysis of Variance of Range Error Data of Table XVIII

Source of Variance	DF	Sum of Squares	Mean Square	F
Between Operators (O)	5	2.01	0.402	14.36*
Between Equipments (E)	3	0.24	0.080	2.86**
Between Ratios (R)	1	0.19	0.19	6.79**
Interactions				
O x E	15	0.69	0.046	
O x R	5	0.19	0.038	
E x R	3	0.03	0.010	
O x E x R	15	0.73	0.048	
Within Class	48	1.39	0.028	
Total	95	5.47		

* Significant at the 1% level

** Significant at the 5% level

The difference between the ratios is statistically significant at the five per cent level with the 2:1 ratio giving consistently a somewhat better range accuracy. This finding is in the expected direction, since the 2:1 ratio gives more space for interpolation between range rings.

Height Errors. The height error data are given in Table XX in terms of 1000's of feet. This makes the height units directly comparable to the range units of Table XVIII, since the scale units for estimation of both range and height were the same. These data are shown graphically in Fig. 17 in hundreds of feet, a more readily visualized height unit. The four equipments vary little and their accuracy performances cluster around 700 feet. Operators differ greatly as to average error, varying from about 500 to 1000 feet. The two ratios differ by nearly 200 feet, the superior accuracy being obtained with use of the 1:1 ratio.

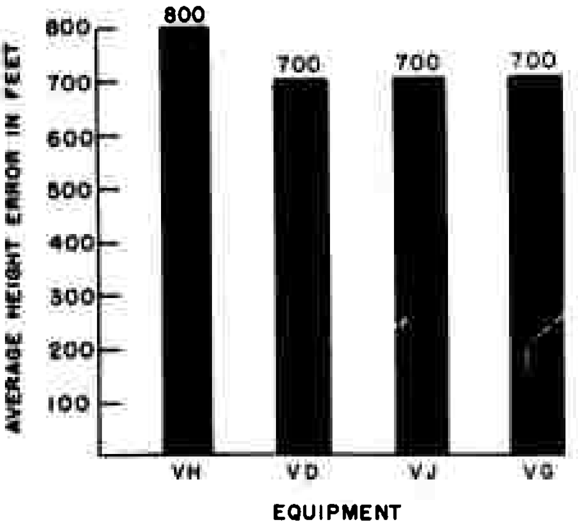


Fig. 17. Average height error made by six operators using the experimental BRH display on four equipments.

The analysis of variance of these data is given in Table XXI. The variance contributed by the operators is again significant at the one per cent level. An equally significant variance is due to

[redacted]

TABLE XX

Average Height Errors (in 1000s of feet) from the BRH Display

Equipment and Range-Height Scale Ratios

Range-Height Ratios / 1st and 2nd Runs / Operators	VH 1:1 1	VH 1:1 2	VH 2:1 1	VH 2:1 2	VD 1:1 1	VD 1:1 2	VD 2:1 1	VD 2:1 2	VJ 1:1 1	VJ 1:1 2	VJ 2:1 1	VJ 2:1 2	VG 1:1 1	VG 1:1 2	VG 2:1 1	VG 2:1 2	Operator Average
A	0.4	0.6	1.3	0.8	0.4	0.4	0.6	0.6	0.5	0.4	0.6	0.9	0.6	0.4	0.5	0.6	0.60
B	0.4	0.5	0.8	0.6	0.4	0.3	0.5	0.8	0.5	0.4	0.6	0.8	0.5	0.6	0.4	0.7	0.55
C	0.7	0.8	0.9	1.0	1.5	0.6	0.6	0.6	0.8	0.7	1.4	0.7	0.9	0.6	0.5	0.9	0.82
D	0.6	1.7	1.1	1.1	0.9	1.3	1.3	0.7	0.8	0.8	1.5	0.9	1.1	0.7	1.2	1.4	1.06
E	0.7	0.5	0.5	1.0	0.2	0.6	0.6	0.7	0.3	0.5	0.5	0.6	0.5	0.9	0.9	0.9	0.61
F	0.6	0.3	0.7	0.7	0.2	0.5	0.8	0.7	0.4	0.8	0.4	0.7	0.4	0.9	0.6	0.9	0.60
Equipment Average	0.76				0.65				0.68				0.73				
Ratio 1:1 Average	0.63																
Ratio 2:1 Average	0.79																

TABLE XXI

Analysis of Variance of the Height Error Data of Table XX

Source of Variance	DF	Sum of Squares	Mean Square	F
Between Operators (O)	5	3.20	0.64	10.16*
Between Equipments (E)	3	0.15	0.05	
Between Ratios (R)	1	0.66	0.66	10.48*
Interactions				
E x O	15	0.47	0.031	
R x O	5	0.17	0.034	
E x R	3	0.09	0.030	
E x O x R	15	0.78	0.052	
Within Class (WC)	48	3.03	0.063	
Total	95	8.55		

* Significant at the 1% level.

the effect of the ratios. The statistically significant superiority of the 1:1 ratio for scaling height is evidently due to the greater space for interpolation between rings. This is the reverse of the effect of the scale ratios on range accuracy and is consistent with it if it is assumed that the larger the scale divisions, within the limits studied in this experiment, the better for accuracy of estimation.

Physical Distance between Scale Rings vs. Scope Size. The finding that the 1:1 ratio is better for height estimation and the 2:1 ratio for range estimation introduces a problem. On the hypothesis that a greater physical distance between rings allows for more accurate interpolation, it would be expected that increasing scope size would increase accuracy. The physical distances between the rings as measured on the radius are shown in Table XXII. However, the large scale divisions on the VG do not make for any superiority over the smaller scopes. There must be, then, an interaction between the scale size of range rings, the thickness of the rings and the thickness of the blip. Since the pulse length of

TABLE XXII

Physical Distances Between Rings

	Ratio 1:1		Ratio 2:1	
	R	H	R	H
VH	1/4 in.	1/4 in.	3/8 in.	1/8 in.
VD	3/8 in.	3/8 in.	1/2 in.	1/4 in.
VJ	5/8 in.	5/8 in.	7/8 in.	3/8 in.
VG	1-1/2 in.	1-3/8 in.	2 in.	1 in.

both target and range marker video was the same on all four equipments, the thickness of all targets and markers varied with the length of sweep of the different repeaters. Therefore, the thickness of all targets and rings was proportional to sweep length and to the scale interval on the radius; i.e., the small VH scope displayed thin targets and markers, the large VG proportionately thicker ones. This relationship appears to hold the accuracy of interpolation between range rings more or less constant from one scope size to another. The effect can be seen from the ratios 2:1/1:1 for range and 1:1/2:1 for height shown for the four scopes in Table XXIII. It is clear that the effect of the physical dimensions of the scale is constant from one scope size to another.

Calibration Differences. In the first experiment it was shown that on the $VJ_{counters}$ and the VJ_{rings} the differences in accuracy between estimating range and height were not statistically significant. On the $VG_{overlay}$, however, the failure of correspondence of the electronic system with the rings inscribed on the overlay produced highly significant differences between range and height accuracy. In the second experiment all range and height

TABLE XXIII

Margin of Superiority Expressed as a Ratio of the 1:1 and 2:1 Range-Height Scale Ratios as a Function of Scope Size

		VH	VD	VJ	VG
Range Error	2:1* / 1:1	1.1	1.1	1.3	1.2
Height Error	1:1* / 2:1	1.3	1.2	1.4	1.2

markers were generated from the same VJ Driver Unit and mixed with the video voltages from the target generator. Under this condition, "t" tests computed for the VH, VD, VJ, and VG indicators show that range and height error differences differ only as chance. See Table XXIV. Garner+ reports in his study of the VG that range errors vary directly as a function of range: "the greater the range, the greater the average range error," and that range errors at the edge of the scope are roughly double those near the center. He states further that, "There seems to be little reason for this relation, and there is some possibility that it is in part at least a spurious effect." There is no evidence for this error relationship for near and far ranges+ in the data of the second experiment when calibration difficulties were minimized. The reverse of Garner's finding was obtained with the overlay used on the VG in the first experiment. But in the first experiment it was known that the electronic system could not be made to match the overlay accurately

---

* In the case of both range and height the range-height ratio yielding the smaller error was taken as the numerator. It is seen that the 2:1 ratio was best for range interpolation and the 1:1 was best for height.

+ Garner, W. R. Some perceptual problems in the use of the VG remote PPI. Systems Research, The Johns Hopkins University. Report No. 166-I-2. 15 September 1946. (Restricted)

+ It should be borne in mind that under the simulated conditions investigated here, range and height are in reality ranges from 0 - 10 miles and from 10 - 20 miles, respectively.

TABLE XXIV

Significance of Average Error
Differences between Range and Height

The Experiment on Scope Sizes and Scale Ratios

	VH	VD	VJ	VG
Average Range Error (miles)	0.7	0.6	0.5	0.6
Average Height Error (1000s of feet)	0.8	0.7	0.7	0.7
t test	.728*	.129*	.359*	.190*

* Not statistically significant

and a compromise fit was made which was intended to distribute the calibration error as uniformly over the range as possible. It is evident from the data of the first experiment that this was not achieved and that the errors on the near ranges were much larger than on the far. In the second experiment, range and height errors differ only as a random sampling of a population.

Errors in Confusing Range and Height Markers. The difficulties encountered by the operators in determining the correct numerical values of the range and height markers were treated as confusion errors, as in the first experiment, and were eliminated from the data. They cannot be treated systematically and are included as a simple frequency tally for equipment, operators, and ratios in Table XXV. These errors are about equally distributed over the four experimental equipments and the two ratios. However, the operators vary considerably in the number of confusions they make and it is perhaps noteworthy that the fastest operator (C) makes most. Also, the height rings are consistently less often confused with each other than are the range rings. It seems reasonable to believe that the range area, near the center of the scope and surrounded by the height rings, is a more cluttered and confusing region perceptually than the annulus.

TABLE XXV

<u>Number of Instances in which the Numerical Designation of the Range and Height Rings was Incorrectly Read</u>

<u>Equipment and Conditions</u>

Range-Height Ratios / Operators	VH Range 1:1	VH Range 2:1	VH Height 1:1	VH Height 2:1	VD Range 1:1	VD Range 2:1	VD Height 1:1	VD Height 2:1	VJ Range 1:1	VJ Range 2:1	VJ Height 1:1	VJ Height 2:1	VG Range 1:1	VG Range 2:1	VG Height 1:1	VG Height 2:1	Operator Total
A		1*	1			1					1						4
B				2	1				1		1					1	6
C	3				1	2	1	2	4				1	4			18
D	3		1		2		2			2				1	1		12
E	1							2	2						1		6
F		1	1		3	2		1				1		3			12
Range Height Totals	9		5		12		8		9		3		9		3		
Instrument Totals	14				20				12				12				

* Cell entries are the number of times out of a total of 18 readings the operator misread the numerical values of the markers.

Conclusions. The results of the second experiment are shown in Table XXVI, which summarizes the average times per target and average bearing, range and height errors for the experimental BRH display on four remote repeaters. The relevant data of the variance analyses are shown as well. The large VG display requires significantly more time to operate than the smaller scopes. The VG is more accurate than the other displays in the estimation of bearing. Here the small scopes are at a disadvantage. Range errors are significantly lower on the VJ than on the VH; the errors on the VD and VG are the same. Height errors are the same for all scopes. In all cases the operator differences are highly significant. The range-height ratios show significant differences for bearing, range, and height errors. The 2:1 ratio is best for bearing and range; the 1:1 ratio is best for height. Two interaction variances are significant: for rapid operation it makes a difference which scale ratio is used on which equipment; for accurate bearing estimation, which operator uses which equipment.

DISCUSSION

A detailed discussion of three-dimensional systems for displaying radar information is impossible until at least two methods of presentation have been compared. The experiments reported here introduce the PPI-and-annulus method of displaying bearing, range, and height information. This study is an internal comparison of a single method and therefore cannot be shown to be better or worse than other three-dimensional systems. The experimental BRH display was chosen for appraisal because it appears to be simple and workable. As an extension of the conventional polar coordinate display, instruction in its use is a matter of minutes, and a competent radarman requires little or no practice to use the system efficiently. The experimental presentation is capable of use on both small and large scopes. Since the radius of the polar display must be shared by two scales, it was thought at first that 15 or 20-inch scopes would be necessary. The evidence shows clearly that for the operations tested in these experiments the 12-inch VJ is satisfactory.

TABLE XXVI

Summary of the Second Experiment on the Experimental BRH Display

	Time and Error Data				Analysis of Variance Findings				
	Equipment				Obtained Levels of Significance				
	VH	VD	VJ	VG	$F_{operators}$	$F_{equipments}$	F_{ratio}	F_{ExR}	F_{OxE}
Average time per target in seconds	7.3	7.3	7.1	8.1	1%	1%	*	5%	*
Average bearing error in degrees	3.4	2.8	2.2	1.1	1%	1%	1%	*	6%
Average range error in miles	0.7	0.6	0.5	0.6	1%	5%	5%	*	*
Average height error in feet	800	700	700	700	1%	*	1%	*	*

* Not statistically significant

[redacted]

An appraisal of the three-dimensional presentation of the SX radar console is under way at the Field Laboratory. Concurrently, the experimental BRH display is being compared with the SX. These studies will include measures of speed and accuracy of target indication, air intercept direction, and simultaneous raid handling capacity of the different displays. The results will make possible specific recommendations as to the requirements of three-dimensional systems for service use.

END