

NRL Report 6232

An Experimental Evaluation of Four Types of Altimeters Using Both Pilot and Enlisted Men Subjects

R. CHERNIKOFF AND P. N. ZIEGLER

*Engineering Psychology Branch
Applications Research Division*

December 18, 1964

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ABSTRACT

Eighteen pilots and seven Navy enlisted men participated in an evaluation of four altimeters: counter-pointer (CP), counter-drum-pointer (CDP), drum-pointer (DP), and three-pointer (3P). The experimental situation required the subjects to track a dot on a crt while reading altimeter settings suddenly presented by the opening of a shutter. Subjects operated a hand switch to close the shutter after reading the altitude presented. Measures were taken of the length of the exposure time and the accuracy of the reported altitude.

The results indicated that for both pilots and enlisted men the CP and CDP altimeters yielded nearly identical exposure times, with the DP and 3P showing progressively longer times. Both groups made considerably more errors in reading the 3P than any of the other altimeters. On the basis of all the data obtained, the rankings of the altimeters, from best to worst, are: CP, CDP, DP, and 3P, with the difference between CP and CDP considered to be very slight.

PROBLEM STATUS

This is an interim report; work on this problem is continuing.

AUTHORIZATION

NRL Problem Y02-11
BuWeps Task RAV 09R002/6521/F012-04-06

Manuscript submitted December 4, 1964.

CONFIDENTIAL

AN EXPERIMENTAL EVALUATION OF FOUR TYPES OF ALTIMETERS USING BOTH PILOT AND ENLISTED MEN SUBJECTS

INTRODUCTION

In a preceding study,* four altimeters were compared for accuracy of altitude control and for speed and accuracy of reading random altitude presentations. The altimeters used were the counter-pointer (CP), counter-drum-pointer (CDP), drum-pointer (DP), and the three-pointer (3P). Five Navy enlisted men, with no experience in using altimeters, served as subjects. The results of this study showed CP and CDP to be best, followed by DP, with 3P the poorest, as measured by tracking performance. The results for reading accuracy ranked CP first followed by CDP, DP, and 3P in that order.

The present experiment was designed to extend the information obtained in the previous study by comparing the same four types of altimeters with experienced pilots as subjects. As part of the overall program of determining an optimum altimeter, flight tests of the four instruments were performed at U.S. Naval Air Test Center, Patuxent River. The pilot subjects used in this study were taken from the participants in the flight evaluations. (The portion of the program involving the flight-evaluation study is the subject of a separate report prepared by USNATC and hence will not be discussed here.)†

The prior NRL study was conducted in two phases: (a) the tracking of a dot on a cathode-ray tube (crt) with one hand while simultaneously tracking a command altitude profile with the other, and (b) the reading of preset altitudes, with no secondary task. To permit increasing both the number of subjects and the number of experimental trials in the limited time available, the two-phase experiment previously run was modified so as to provide an experimental situation which required the subject to read preset altitudes while simultaneously tracking a crt dot. To facilitate a cross comparison between this study and the previous phases of the investigation, a group of enlisted men as well as the pilot subjects were used in this experiment.

PROCEDURE

The four types of altimeters used in this study are shown in Fig. 1. A complete description of the altimeters can be found in the appendix of the previous NRL report. Figure 2 depicts a subject seated at the experimental apparatus. His task was to keep a marker dot centered on the crt display by means of the control stick held in his right hand. The partition to the subject's right obscured the experimenter and the altimeter from the subject's view, but permitted a clear presentation of the altimeter when a shutter was open. The shutter could be closed by the subject operating the pushbutton switch held in his left hand. A timer was started by opening the shutter to expose the altimeter and stopped by the subject pressing the pushbutton switch, thus recording the length of time that the altimeter was exposed. With the exception of the partition and shutter, the apparatus used was the same as for Phase I of the preceding report, and details such as the tracking dynamics, placement of displays, and the vacuum system for controlling the altimeter setting can be found in that report.

*R.E. Reilly, P.N. Ziegler, J.H. Hill, and R. Chernikoff, "A Comparison of Four Types of Altimeters: Phase I. Tracking a Command Profile, Phase II. Reading Preset Altitudes," NRL Memo. Rept. 1522, Apr. 1964.

†R.P. Lee, "Flight Evaluation of Servo-Altimeter Displays for the Air Traffic Control Radar Beacon System/IFF/Mark 12/System (AIMS) Program," USNATC Technical Report ST 32-92R-64, Nov. 23, 1964.

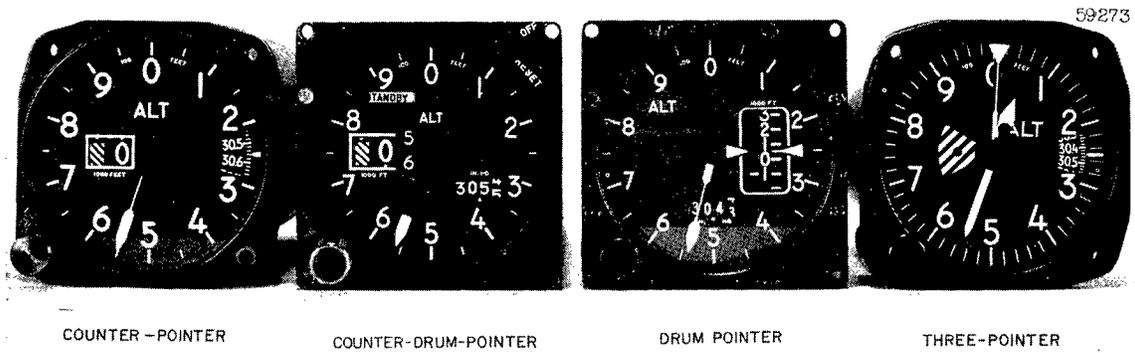


Fig. 1 - The four altimeters used in this study

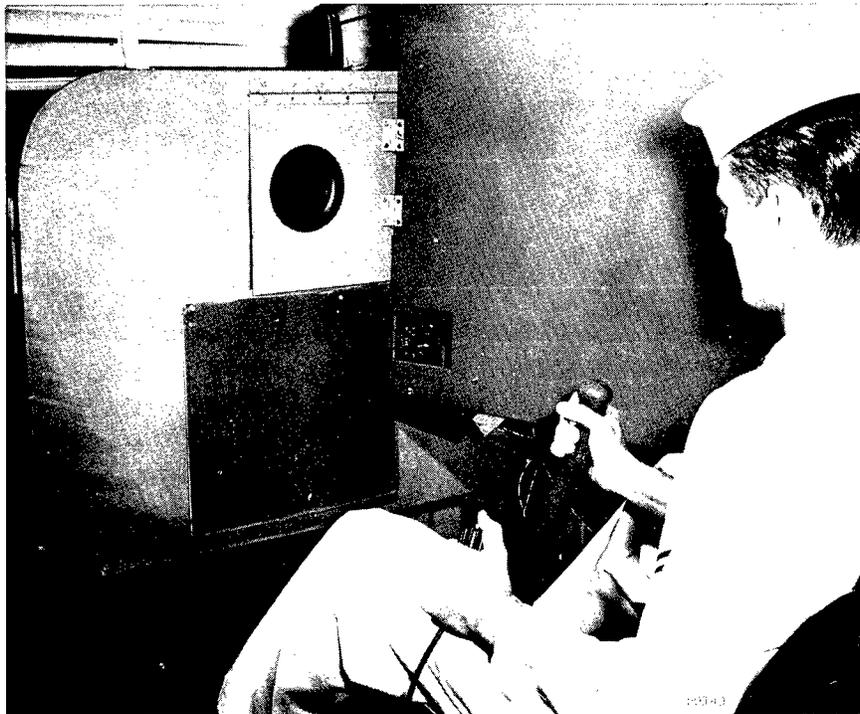


Fig. 2 - Subject seated at the experimental apparatus

Two groups of subjects participated in this study. The first group was composed of seven naval enlisted men who had been trained to track higher order systems, but who had no previous experience in using altimeters. This group was instructed on how to read the different altimeters and was given a demonstration of each altimeter in operation. Each subject was then individually placed in the experimental situation and given 20 practice readings on each altimeter. The second group of subjects consisted of 18 flight officers: seven Navy, six Air Force, three Marine, and two Army pilots. Before taking part in the experiment, each pilot had participated in a flight evaluation of the four altimeters at the U.S. Naval Air Test Center. During this evaluation, approximately two hours of flight time was obtained on each altimeter. This altimeter experience is, of course, in addition to that which each pilot has had during the course of his normal flight routines. In order to familiarize the pilot subjects with the experimental equipment and procedure, several practice trials were given before starting the experiment.

In the present laboratory experiment, the subject was instructed to try to keep the crt marker dot near the center of the crt by manipulating his control stick. As soon as he heard the shutter door open, he was to look directly at the altimeter, read the displayed altitude, and press the button in his left hand to close the shutter. He would then call out the altitude and return to tracking the marker dot. If he were correct, the experimenter would proceed to the next setting of the altimeter. If a mistake were made, the altimeter was again exposed so that both the subject and experimenter could check the actual altitude presented. The subject was instructed that the exposure time of the altimeter was being recorded, and that he should read the altimeter as rapidly and as accurately as possible. Subjects were told that the altimeters should be read to the nearest 100 ft. The experimenter recorded the length of each exposure time and any errors that were made.

There were four sessions in this experiment; in each one, a different profile was read on each of the four altimeters. The term profile, as used in this study, simply refers to a predetermined sequence of 15 altimeter settings to be read. Four profiles were composed, with altitudes ranging from a minimum setting of 1900 ft to a maximum of 44,900 ft. The exact pairing of altimeters to profiles was determined from a 4×4 Greco-Latin square design, so that by the end of the fourth session all possible pairings of the altimeters and profiles were completed. Each subject was given a different combination of pairings, so that any effects due to order of profiles or altimeters would be eliminated. There was a five-minute rest interval between the first two sessions and about a 45-minute break for lunch between the second and third sessions. Another five-minute rest followed the third session. Thus, data collection for each subject was completed during one day.

In selecting the altitudes comprising the profiles, no attempt was made to emphasize any special region of the display, to avoid introducing an unintentional bias. Instead, all the digits were used equally, and were randomly assigned in composing the various altitudes to be read. A list of the altitudes comprising each of the four profiles is presented in Appendix A.

RESULTS AND DISCUSSION

Each subject received a total of 60 altitude settings on each of the four altimeters. A measure was taken of the length of the exposure time for each altitude setting, and whether or not the altitude given was correct. The mean exposure time and total number of errors made by the 18 pilot subjects in the 1080 altitude presentations is given in Table 1 and shown graphically in Figs. 3 and 4. The mean exposure-time data and total errors made by the seven enlisted-men subjects in 420 trials is presented in Table 2 and in Figs. 5 and 6. For both the pilot and enlisted-men subjects, nearly identical exposure

Table 1
Mean Exposure Time and Number of Errors
for Pilots on Each Altimeter (1080 trials)

Measure	Altimeter			
	CP	CDP	DP	3P
Exposure Time (sec)	0.80	0.84	1.38	2.28
Errors (number)	7	14	26	80

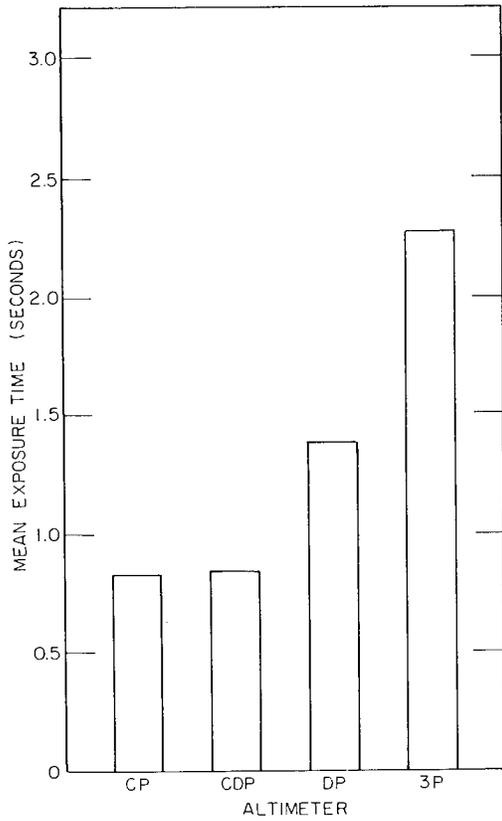


Fig. 3 - Mean exposure time for the 18 pilot subjects on each of the four altimeters

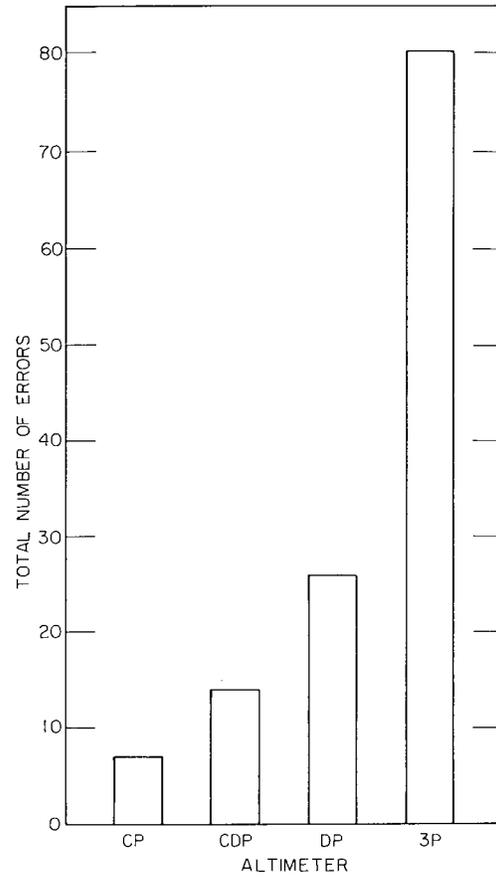


Fig. 4 - Total number of errors made by the 18 pilot subjects on each of the four altimeters

Table 2
Mean Exposure Time and Number of Errors for
Enlisted Men on Each Altimeter (420 trials)

Measure	Altimeter			
	CP	CDP	DP	3P
Exposure Time (sec)	0.85	0.86	1.50	2.93
Errors (number)	5	2	10	52

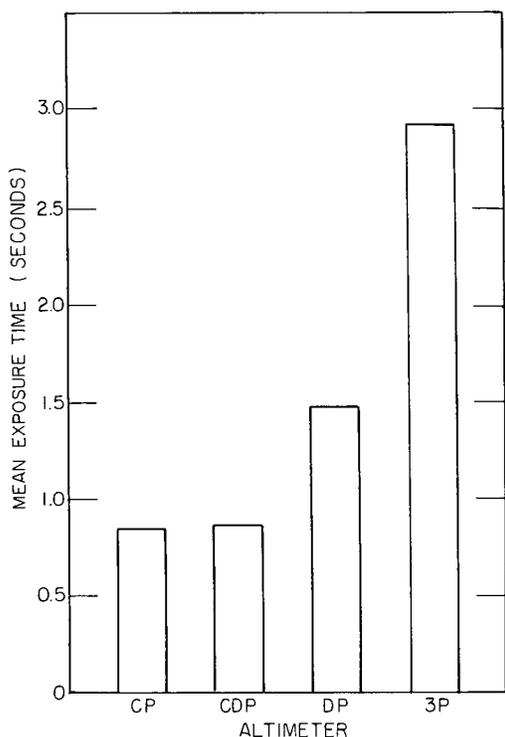


Fig. 5 - Mean exposure time for the seven enlisted men subjects on each of the four altimeters

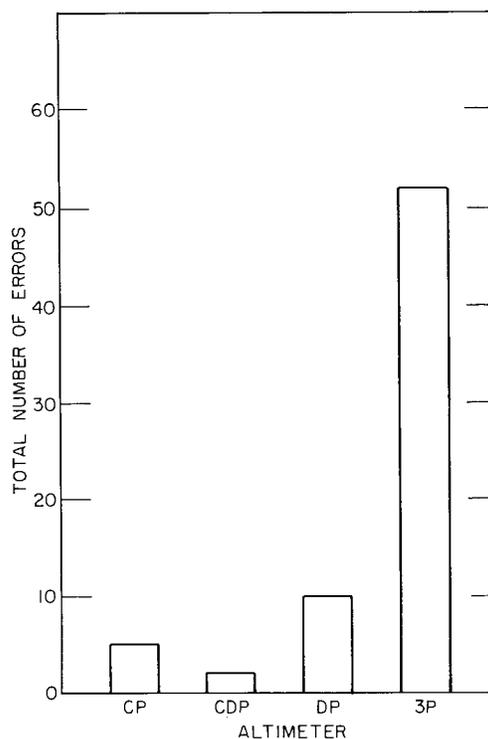


Fig. 6 - Total number of errors made by the seven enlisted men subjects on each of the four altimeters

Table 3
Mean Number of Errors Made on Each Altimeter

Subjects	Altimeter			
	CP	CDP	DP	3P
Pilots (18)	0.39	0.78	1.44	4.44
Enlisted Men (7)	0.71	0.29	1.43	7.43

times were obtained for the CP and CDP altimeters, with the DP and 3P showing progressively longer exposure times. Both groups of subjects made considerably more errors in reading the 3P than any of the other altimeters. For the enlisted men, the order of increasing accuracy on the other altimeters was DP, CP, and CDP, while for the pilot subjects this order was DP, CDP, and CP.

Since a different number of subjects was used in the pilot and enlisted-men groups, a direct comparison between groups can be more easily made by converting the total group error into mean error. Table 3 presents the mean number of errors made on each altimeter by both groups.

To determine whether the observed differences among exposure times were statistically significant, an analysis of variance was performed on the exposure-time data for the pilots, and also for the enlisted men. In both analyses, the overall difference among altimeters was found to be significant ($P < .01$). A range test was then applied to the

exposure-time data to compare adjacent means. The results of this test indicated that for pilot and enlisted-men subjects all comparisons among the altimeters were significant except CP vs CDP.

The Wilcoxon paired-replicates test was applied to the error data to test for statistical significance among the various altimeters. The results of this test indicated that for the pilot subjects all comparisons except CP vs CDP were significant. For the enlisted men, all but the CP vs CDP and CDP vs DP comparisons were significant ($P < .02$).

Tables 4 and 5 present breakdowns of the number of errors made on each altimeter by the various subjects. It is interesting to note that on CP and CDP no subject made more than two errors, with a considerable number of subjects showing no errors on these instruments. At the other extreme, very few subjects made as few as two errors on the 3P, with over half the subjects registering five or more errors. Lists of all the errors made on each altimeter are presented in Appendix B (pilot subjects) and Appendix C (enlisted-men subjects).

Since the importance of both speed and accuracy in reading altitude was stressed in this study, it was of interest to determine whether the errors were related to the length of the exposure time. Table 6 presents the mean exposure times for the correct and incorrect readings on the various altimeters. Only the data for the pilot subjects were used. The data in this table indicate that for all altimeters the incorrect readings took longer than the correct readings. The exposure-time comparison ranged from practically no difference with DP to a considerable difference for CP.

In assessing the overall findings of this study in terms of the practical question as to the relative merits of the various altimeters tested, one conclusion seems apparent: with both the length of exposure time needed to read the altimeter and the number of erroneous readings as criteria, the 3P altimeter is markedly inferior to any of the other three compared with it. On the other hand, although no single altimeter stands clearly differentiated from the others as "best," there are sufficient differences in the error and exposure-time data to permit a ranking of the altimeters. The order of altimeters from best to worst is CP, CDP, DP, and 3P, with the difference between CP and CDP considered to be very slight.

In general, the data obtained for the enlisted men and pilots were in close agreement, with the only difference between the two subject groups being a reversal in the CP and CDP error data. Further, the overall ranking of the altimeters in this study is the same as that found in Phases I and II of the previous study. These results, taken in conjunction with the flight-test evaluations performed at Patuxent River USNATC on the same altimeters, should provide a firm basis for the selection of an effective altimeter.

ACKNOWLEDGMENT

The writers are indebted to Mrs. Cecelia E. Burke for performing the statistical analyses presented in this report.

Table 4
Number of Errors Made by Pilots
on Each Altimeter

Subject	Altimeter			
	CP	CDP	DP	3P
A	0	0	1	3
B	0	1	0	7
C	0	1	1	3
D	1	1	1	5
E	1	0	3	2
F	0	2	3	3
G	0	1	2	5
H	0	1	1	4
I	0	0	1	1
J	0	0	0	1
K	2	0	0	0
L	0	1	0	2
M	0	1	2	4
N	0	0	3	6
O	1	1	3	9
P	1	0	3	6
Q	0	2	0	10
R	1	2	2	9
Total	7	14	26	80

Table 5
Number of Errors Made by Enlisted-Men
on Each Altimeter

Subject	Altimeter			
	CP	CDP	DP	3P
A	1	0	1	6
B	0	1	0	4
C	1	0	2	11
D	1	1	2	7
E	2	0	4	9
F	0	0	0	6
G	0	0	1	9
Total	5	2	10	52

Table 6
Mean Exposure Time for Correct and Incorrect
Readings by Pilots on Each Altimeter

Altimeter	Correct Readings		Incorrect Readings	
	Number	Exposure Time (sec)	Number	Exposure Time (sec)
CP	1073	0.80	7	1.32
CDP	1066	0.84	14	0.98
DP	1054	1.37	26	1.38
3P	1000	2.25	80	2.58

APPENDIX A

ALTITUDES COMPRISING THE FOUR PROFILES
USED IN THIS STUDY

17,400	25,200	2,100	16,000
30,300	41,900	14,300	2,900
1,900	22,800	26,000	42,200
26,400	13,100	35,700	28,800
44,200	9,500	27,500	34,300
36,000	39,600	40,800	44,100
18,700	7,500	6,400	37,900
4,600	15,300	44,900	9,700
38,100	43,200	38,600	10,100
27,000	22,800	13,700	23,600
42,700	31,000	21,600	11,500
35,500	20,900	18,200	33,100
19,800	19,100	40,300	41,700
40,600	41,400	39,500	29,500
3,300	8,200	5,800	3,000

APPENDIX B

ERRORS MADE BY THE 18 PILOT SUBJECTS ON EACH ALTIMETER

CP Altitude		DP Altitude		3P Altitude		3P Altitude	
<u>Presented</u>	<u>Reported</u>	<u>Presented</u>	<u>Reported</u>	<u>Presented</u>	<u>Reported</u>	<u>Presented</u>	<u>Reported</u>
31000	31900	17400	18400	18700	20700	1900	2900
41900	40900	17400	18400	42200	22200	22800	24800
1900	900	14300	4300	28800	30800	19100	29100
26000	26900	17400	18400	18700	19700	27500	37500
33100	35100	28800	8800	31000	30000	28800	39800
20900	19900	17400	7400	41700	40700	37900	38900
41900	40900	41900	42900	18700	19700	18700	19700
		13700	3700	22800	23800	19800	20800
		13100	3100	20900	21900	41900	42900
		14300	4300	16000	6000	22800	23800
		16000	15000	42200	2300	20900	21900
		14300	4300	44100	42100	42200	22200
		27500	28500	37900	38900	28800	29800
		5800	6900	40800	41800	37900	38900
		38100	37100	25200	20500	41700	42700
		17400	18400	39600	30600	30300	33000
		41900	42900	23600	21600	44200	40200
		22800	23800	41900	19400	36000	40000
		17400	7400	44200	40200	16000	15000
		15300	5300	20900	21900	28800	29800
		14300	4300	28800	29800	37900	38900
		22800	23800	37900	38900	18700	19700
		20900	21900	28800	29900	41900	14800
		5800	15800	29500	39500	22800	23800
		30300	29300	2900	3900	20900	19900
		19800	20800	28800	38800	27500	37500
				29500	39500	44900	45900
				22800	32800	13700	14800
				22800	23800	5800	16800
				13700	14700	28800	29700
				28800	29800	23600	30500
				37900	38900	18700	19700
				40800	41800	41900	42900
				44900	45900	20900	21900
				42200	43200	35700	36700
				28800	29800	40800	41800
				28800	29800	5800	6800
				44100	34100	2900	3900
				2900	300	28800	29800
				9700	10700	37900	38900

CDP
Altitude
Presented Reported

APPENDIX C

ERRORS MADE BY THE SEVEN ENLISTED MEN ON EACH ALTIMETER

CP Altitude		DP Altitude		3P Altitude		3P Altitude	
<u>Presented</u>	<u>Reported</u>	<u>Presented</u>	<u>Reported</u>	<u>Presented</u>	<u>Reported</u>	<u>Presented</u>	<u>Reported</u>
35700	33700	29500	30500	42700	43700	37900	38900
27000	27900	36000	35000	7500	8500	18700	19700
44900	43900	16000	15000	44900	45900	40600	41600
26000	26900	41900	42900	9700	14900	35700	25700
44900	43900	13100	3100	11500	12500	40800	41800
		40300	39300	26400	36500	44100	43100
		16000	16900	27500	25700	11500	12500
		44100	43000	44900	45900	42700	43800
		1900	2900	37900	38900	19800	17900
		2900	3900	1900	2900	41900	31900
				41900	42900	22800	23800
				22800	23800	19100	29100
				20900	21900	41400	42400
				19100	18100	44900	45900
				26000	15100	5800	6800
				44900	45900	11500	12500
				40300	43000	1900	19000
				16000	10600	27000	37000
				2900	3900	20900	21900
				10100	9100	19100	21900
				17400	18400	8200	18200
				25200	15200	18200	28200
				41900	42900	2900	3900
				22800	23800	28800	29800
				20900	21900	29500	39500
				40800	41800	19800	27800

CDP Altitude	
<u>Presented</u>	<u>Reported</u>
31000	31900
27000	27900

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13. ABSTRACT <p>Eighteen pilots and seven Navy enlisted men participated in an evaluation of four altimeters: counter-pointer (CP), counter-drum-pointer (CDP), drum-pointer (DP), and three-pointer (3P). The experimental situation required the subjects to track a dot on a crt while reading altimeter settings suddenly presented by the opening of a shutter. Subjects operated a hand switch to close the shutter after reading the altitude presented. Measures were taken of the length of the exposure time and the accuracy of the reported altitude.</p> <p>The results indicated that for both pilots and enlisted men the CP and CDP altimeters yielded nearly identical exposure times, with the DP and 3P showing progressively longer times. Both groups made considerably more errors in reading the 3P than any of the other altimeters. On the basis of all the data obtained, the rankings of the altimeters, from best to worst, are: CP, CDP, DP, and 3P, with the difference between CP and CDP considered to be very slight.</p>			

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Altimeters Evaluation Pilot tests of altimeters Enlisted men tests of altimeters Error measure Exposure time Counter-pointer Counter-drum-pointer Drum-pointer Three-pointer						

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