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FACTORS AFFECTING DWELL TIMES ON DIGITAL DISPLAYS

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ABSTRACT

A series of exploratory tests were conducted to investigate the effects of advanced display formats and display media on pilot scanning behavior using Langley's oculometer, a desktop flight simulator, a conventional electromechanical meter, and various digital displays. The primary task was for the test subject to maintain level flight, on a specific course heading, during moderate turbulence. A secondary task of manually controlling the readout of a display was used to examine the effects of the display format on a subject's scan behavior. Secondary task scan parameters that were evaluated were average dwell time, dwell histograms, and number of dwells associated with the subject's controlling of the meter to a commanded value. The round dial meter demonstrated shorter dwell times and fewer dwells per meter change than the digital displays. The following factors affected digital display scanning behavior: (1) the number of digits; (2) the update rate of the digits; (3) the display media; and (4) the character font. The size of the digits used in these tests (0.28 to 0.50 inches) did not affect scan behavior measures.

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SUMMARY

Tests were conducted to explore certain factors that might affect the transfer of digital information from instruments to the pilot. These tests were part of a series of experiments to investigate the effects of advanced display formats and display media on pilot scanning behavior. Several exploratory tests were conducted using a desktop flight simulator, an electro-mechanical meter, various digital meters, and Langley's oculometer. The primary task was to maintain level flight, on a specific course heading, during moderate turbulence. A secondary task of manually controlling the readout of a display was used to examine the effects of the display format on a subject's scan behavior. Secondary task scan parameters that were evaluated were average dwell time, dwell histograms, and number of dwells associated with the subject's controlling of the meter to a commanded value. First, a comparison of the baseline round dial and digital meters was performed. The round dial meter demonstrated shorter dwell times and fewer dwells per meter change. The following factors affected scanning behavior measures: (1) the number of digits; (2) the update rate of the digits; (3) the display media; and (4) the character font. The size of the digits (0.28 to 0.50 inches high) does not apparently affect scan behavior measures.

INTRODUCTION

Advanced technology is increasingly used in the cockpit of today's aircraft. Associated with the use of advanced technology is the opportunity to improve the transfer of information from aircraft systems to the pilot. The use of digital information is especially appealing because it is so simple to output alphanumeric data to a cathode-ray-tube (CRT) and many other advanced technology display media. Digital displays can also increase the accuracy and resolution of the data presented. Since digital meters may be used in the future, an understanding of the factors which affect information transfer from the meters to the pilot is very important. Based upon such tests, it will be possible to determine from a human factors point of view if there are situations in which purely digital formats are not the optimum presentation format.

As part of a series of experiments to investigate the effects of advanced display formats and display media on pilot scanning behavior, seven exploratory piloted tests were conducted using a desktop flight simulator, various electro-mechanical and digital meters, and Langley's oculometer system. The experiments consisted of a primary simulated flying task and a secondary display controlling task. The primary flying task was to maintain level flight, on a specific course heading, during moderate turbulence. The secondary task was modified for each test by changing the type of display used in the task. The readout of the display was manually controlled to specific values with a throttle-type of controller; thereby permitting an examination of the effects of the meter display format on a pilot's scan behavior. Eye scan parameters of the secondary task that were evaluated were average dwell time, dwell time histograms, and number of dwells per number of meter changes requested by the experimenter.

EQUIPMENT AND TESTS

In order to evaluate the effects of display formats on pilot scanning, it was decided to use a side task with the display to be evaluated, while the test subject was performing an ongoing primary task. In this manner, the subject would not be looking at the evaluation display constantly, i.e. staring at it. In addition, the subject would be using the display in a manner similar to the way in which it might be used during an actual flight operation.

A desktop simulator (figure 1) was used for all the experiments as the primary task. This task required the subjects to fly straight and level, at a given altitude, on a given compass heading. Simulated turbulence was turned on to give the subject an ongoing task to perform. Therefore, the subject was required to constantly monitor all the instruments shown in figure 1, except for the ADF controls, NAV-COM, transponder, and fuel gauge. For most of the test subjects, the power and trim controls were set prior to the run and required no further adjustment.

A secondary task was used that consisted of manually controlling the meter readout to values that were called out to the subject by the experimenter during the execution of the test runs. The subject was instructed verbally during the tests when to change the meter position. The subject changed the displayed meter reading by adjusting the position of a throttle-type of control level (figure 2). Each testing period involved approximately 75 meter changes. In an attempt to minimize the memory load on the subject, all of the numbers called out to the subject were integers. This procedure was carried out with digital meter number one (Table 1) and an electro-mechanical meter, using three different first order time lags of 2, 4, and 6 seconds in the meter response. The other digital meters (Table 1) used a constant time lag of 2 seconds. The throttle position was read into a microprocessor, and equations simulating first order time lags were used to calculate voltages to be outputted to the side task meter.

A total of six different digital meters were used for these tests. Figures 3 thru 7 show what they looked like to the test subject and Table 1 lists their characteristics in terms of the type of display (gas discharge, LED, or CRT), the font or style of the number, the color of the numbers, the height of the number, the range of numbers that could be displayed, and the rate at which the numbers were changed or updated.

The subject was seated so that his eyes were approximately 28 inches from the instrument panel while operating the simulator. The secondary task meter was placed on the right side of the instrument panel so as to be in the subject's peripheral vision, requiring the subject to actually look at the display in order to read it and make changes to it. The meter was 18 inches to the right of the simulator's center line and 3 inches below the center of the top row of instruments.

To observe and record the subject's scanning behavior, an oculometer system was used. The lookpoints from the oculometer were then entered into a microprocessor-based experiment-controller and data-acquisition system that kept a record of the number of lookpoints for each fixation. The fixations were defined as the number of continuous lookpoints within a radius of a half inch from the center of the fixation. A more complete description of the oculometer hardware is given in reference 1. The data analysis procedure was to calculate the side task average dwell times, side task dwell time histograms, and the number of dwells on the secondary task display divided by the number of times the test subject was requested to change the meter reading.

A total of four subjects participated in the tests. Two of the subjects were not pilots and, consequently, needed more training prior to performing their test runs than the other two subjects. This training consisted of performing the primary flying task without the secondary task until the subjects felt that they could perform the task easily. The third subject was a low time pilot and the fourth subject, was very experienced on the simulator as a test subject. The first three subjects only participated in the first two experiments. The most experienced subject was used to collect the rest of the data since similar data was obtained from all of the subjects. Therefore, for the purposes of these experiments, the data would be sufficient to observe the proper trends in scan behavior.

RESULTS AND DISCUSSION

Baseline, Round Dial

The first test was conducted to develop a baseline for the side task methodology. The baseline consisted of using a circular dial indicator with 4 tic marks on either side of zero, see figures 1 and 2. The combined dwell histograms for all test subjects on the dial indicator for first order time lags of 2, 4, and 6 seconds is shown in figures 8, 9, and 10, respectively. Kolmogorov-Smirnov tests (ref. 2) of the dwell histograms indicated that the 6 second time lag histogram, for the round meter, differs from the 2 or 4 second time lag histograms at the 1 percent significance level. The peaks of the histograms occur at the same dwell times. The average dwell times, for the three time lags are 0.99, 1.02, and 1.07 seconds, respectively.

The strategy of the subjects was to make an input to change the meter reading and then wait to see what the new meter reading would be. Because of the time lags, the subjects would look back at the main task and then later look back at the secondary task to ascertain the new readout value. The subjects would make further correcting inputs using the throttle to move the displayed value closer to the value desired. The average number of dwells (transitions to the secondary task display), the subjects used to change a meter readout from one value to another, for the three time lags, was 5.3, 5.3, and 5.5, respectively.

One-Digit Display

The first digital meter that was tested had a single digit with a range of -9 to 9 (meter 1 of Table 1). For this study, the four test subjects were also used. The subject's task was the same as the baseline experiment. The resulting dwell histograms are shown in figures 11, 12, and 13 for the same three time lags. Kolmogorov-Smirnov tests indicated that the dwell histogram, when using the 4 second time lag, was different from the dwell histograms when using either the 2 or 6 second time lag. The average dwell times for the 2, 4, and 6 second time lags were 0.74, 0.64, and 0.71 seconds, respectively. The number of dwells per meter display change were 6.0, 7.8, and 7.2 for the three time lags, respectively. This increase in number of dwells per meter change of the 4 and 6 second time lags over the 2 second time lag could indicate a change in strategy to work with longer time lags.

The average dwell times for the one-digit displays were shorter than for the baseline, round dial display. By comparing figures 8-10 with figures 11-13, it can also be seen that the peaks of the dwell histogram curves occur at a much shorter dwell time for the one-digit display than for the baseline, round dial display. It cannot be determined from these data whether or not the difference in dwell time peaks is because of the quality of the display or because of a difference in the amount of information in the two displays. Perhaps the primary reason for the differences in the dwell time is the greater amount of information in the round dial display than in the single digit display. Round dial displays certainly have more resolution than just one digit and they certainly have motion present which could help the pilot judge the progress of the needle at arriving at the specified readout. Therefore, it would seem that the increased dwell time would be reflective of increased information gathering by the test subjects.

The remainder of the data presented in this report has been collected from one of the test subjects, the most experienced subject. This subject was selected because he was the most proficient of the four test subjects as evidenced by the smoothness and compactness of his dwell histograms. The baseline and one-digit dwell histograms for this subject are given in figures 14 and 15 for a time lag of 2 seconds. The average dwell time for this subject on the round dial display was 0.61 seconds and the dwell time on the one-digit display was 0.46 seconds. The number of dwells per meter movement was 6.3 for the round dial and 7.4 for the one digit meter. It should be noted, that in spite of the greater number of longer dwells, for the group taken as a whole, that the peak of the dwell histograms occur at the same dwell time. It was felt that fewer data runs would have to be used to obtain the data required for the remaining comparisons by using this one test subject. It is believed that the long dwell times in the other test subjects' dwell histograms is a function of learning, particularly learning to use these types of displays. Therefore, changes in the dwell histograms of the other subjects could be a function of learning, as well as a function of the displays being tested, thus, making it difficult to distinguish the effects of the digital displays from the effects of learning. It is further believed that the untrained subjects are using these longer dwells to observe the pattern of movements of the needle or flicker of the digits, trying to learn this pattern of movement. When this pattern is learned, then the task becomes second nature and the long dwells disappear because they no longer have to look at the movement; they can predict how they will move.

Three-Digit Display

The single digit display, while interesting, would probably not be used in an aircraft environment, but was used in these tests to examine the effects of the number of digits on the subject's scan behavior. Therefore, additional tests were performed, with the most experienced test subject, using a time delay of 2 seconds to investigate other parameters of the digital display media. This set of tests involved using a three-digit display ranging from -9.99 to 9.99 (meter 2 of Table 1), with the addition of greater resolution (100 counts instead of 1 count with the one-digit display) between each integer number. The resulting dwell histogram is found in figure 16. The Kolmogorov-Smirnov test for the same subject indicated that it is different from the one digit meter (figure 15) at the 1 percent significance level. The peak of the histogram, as anticipated, occurs at a much longer dwell time, and an average dwell time of 0.77 seconds was observed, versus 0.46 seconds with the single digit meter. This would be consistent with other human factors data showing longer reaction time to increased information processing (ref. 3). The subject also has to use more dwells in positioning the meter at the desired reading, 8.4 dwells per meter change versus 7.4 for the single digit display.

Update Rate

Another variable that was available to the experimenters was the update rate on the digital displays. The update rate is the number of times the digits are electronically changed per second. The update rate used with the previous three-digit display was 10 updates per second. Additional tests were conducted with the update rate changed to 2.5 updates per second (meter 3 of Table 1). Figure 17 is the dwell histogram for subject four of the 2.5 updates per second with the 0.5 inch digital display. Kolmogorov-Smirnov tests showed a significant difference between the 2.5 updates per second and the 10 updates per second at the 1 percent level. The average dwell time for the 2.5 updates per second was 0.84 seconds versus the 0.77 seconds at 10 updates per second. The number of dwells per meter change was 9.3 with the 2.5 updates per second versus the 8.4 with the 10 updates per second. Thus, it would appear that over a relative small range of update rates, the effect on the scanning behavior is measurable both in dwell time and the number of dwells required to change the meter reading to a given value.

Size of Digits

Another effect investigated was the size of the digits; the prior tests were with digits of 0.5 inches in height. Additional tests were conducted with a display whose digits were 0.28 inches high (meter 4 of Table 1). Figure 18 shows the dwell time histogram for the 0.28 inch digits. Kolmogorov-Smirnov test showed no significant difference between the 0.5 and the 0.28 inch digits with similar update rates (refer to meters 3 and 4 of Table 1 respectively). The average dwell time was 0.86 seconds with the 0.28 inch digits versus 0.84 seconds with the 0.5 inch digits. The number of dwells per meter change were 9.4 with the 0.28 inch digits versus 9.3 with the 0.5 inch digits.

Segmented Digits

Degradation of the image quality of digits could be thought of to occur as portions of the digits are removed, such as in missing line segments of the digits. In an attempt to simulate degradation of digit quality, digits with 14 segments (figure 6) instead of normal 7 segments (2 line segments instead of 1 line segment, refer figures 3 to 5) were used in a series of tests. Figure 19 shows the dwell histograms from these tests. Kolmogorov-Smirnov tests indicated at the 10 percent level no statistically significant differences in the dwell histogram curves between the 7-segment and the 14-segment displays (meters 4 and 5 of Table 1). The average dwell time was 0.87 seconds with the 14-segment digits versus 0.86 seconds with the 7-segment digits. The average number of dwells per meter change was 10.9, the highest of all digital displays tested, with the 14-segment digits versus 9.4 with the 7-segment digits. This indicates that the test subject had to look at the display more often to be sure of its value.

CRT Digits

Data from a previous study (ref. 4) has been plotted in histogram format (figure 20). The histograms illustrate the fact that a CRT altimeter took longer to read than a three-pointer altimeter. Therefore, additional tests were conducted using the current side task procedure to determine the dwell times on the CRT generated digits (meter 6 of Table 1) and compare those data with that of the LED generated digits. Due to equipment constraints, the digits in the CRT tests ranged for 1.00 to 19.00. (However, it could be argued that the negative sign of the LED digits could also be considered as a digit making the LED digits equivalent to 4 digits.) Figure 21 shows the dwell time histogram of the CRT display with 0.28 inch high digits. The peak of the CRT display curve is displaced to the right of the peak of the LED display curve. Kolmogorov-Smirnov test indicated that the CRT dwell histograms were different from the 0.28 inch LED digit dwell histograms at the 1.5 percent level. The average CRT dwell time was 0.98 seconds versus the 0.28 inch LED dwell times of 0.86 and 0.87 seconds. There is, however, a reduction in the number of dwells per meter change of 9.4 versus 10.9 dwells per meter change for the 0.28 inch LED display to 8.1 dwells per meter change for the CRT digits. The number of dwells per meter change are comparable to the 8.4 associated with the 0.5 inch LED operated at 10 updates per second (CRT update rate was 15 per second).

Further analysis was performed on the CRT display to try to determine if there was a difference in dwell times while looking at 3 versus 4 digits (figure 22). Kolmogorov-Smirnov tests of the histograms indicated no significant differences due to the number of digits displayed on the CRT display. Similar reduction in reading speeds of text presented on a CRT display versus text printed on paper have been noted (refs. 5 and 6). No evidence was given as to what factor made the CRT produce a slower reading speed than printed paper. Training was not found to be a factor (ref. 5) and contrast ratios showed no difference (ref. 6) and the number of raster lines per letter (about 50 in this study as opposed to 9 in normal text on CRTs) still resulted in slower dwell times. All of this indicates that there is some factor in the CRT generated display which slows down information transfer between the display and the subject, as compared to the LED display.

Across Study Comparisons

Table 2 summarizes the average dwell time and average dwells per meter change for all of the digital display tests. The number at the left of Table 2 corresponds to the number of the digital display in Table 1. The effect of update rate upon average dwell time is illustrated by the comparison of display 2 versus displays 3, 4, and 5 (recall that no statistical differences were found in the dwell histograms of displays 3 and 4 or 4 and 5). The average dwell time for display 2 is 0.77, and the three displays 3, 4, and 5 have average dwell time of 0.86. Therefore, it appears that the effect of increasing the update frequency from about 2 times per second to 10 times per second is to reduce the dwell time by about 0.1 seconds.

Another effect of the update rate is to change the number of dwells per meter change. To see this, compare the number of dwells per meter change for the three- and/or four-digit displays 2 and 6 with that of three-digit displays 3, 4, and 5. The first two have update rates equal to or greater than 10 times a second and the later three have update rates equal to or less than 3 times a second. The number of dwells per meter change for the first two is less than 8.5 and the number for the last three is greater than 9.2. Therefore, it appears that an effect of increased update rate is to decrease the number of dwells needed for every change in meter position. It should be noted that these effects of the update rate were completely oblivious to the test subject. He felt that the difference in the update rate did not affect him or the way he accomplished either the flying task or the secondary task. In most cases he could not even tell that a difference in update rate existed from one testing period to another.

Finally, in comparing the digital displays with the baseline, round dial display (figure 14), a longer dwell time was found for all of the digital displays except for the one digit display (0.77, 0.84, 0.86, 0.87, and 0.98 versus 0.61 seconds) with the peak of the histograms occurring at longer dwell times (figures 16, 17, 18, 19, and 21 versus 14). There is also a greater number of dwells per meter change with all of the digit displays, including the one digit display, with 7.4, 8.4, 9.3, 9.4, 10.9, and 8.1 compared to 6.3 dwells per meter change for the baseline round meter. It could be that graphic information, such as a round dial indicator, can be perceived more quickly (fewer mental processes and consequently shorter dwell time) than digital information.

CONCLUDING REMARKS

A series of tests was conducted in an exploratory evaluation to determine some of the factors which affect the transfer of digital information from instruments to the pilot. It should be noted that the side task used in these studies involved controlling the readout of a display, and that the results may not directly apply to other situations such as monitoring in which no conscious decision is made every time the display is looked at.

More digits increased the dwell time and the number of dwells on the instrument to make a reading change. Therefore, the designer of digital displays should determine the resolution needed based upon the pilot's needs. It may also be advisable in cases of large numbers to display only the most significant digits.

Faster update rates decrease dwell times and the number of dwells on the instrument to make a reading change. It would, therefore, seem advisable to use an update rate as fast as practical. These data did not extend beyond 10 updates per second so that a trade-off could be made between display update rate requirements and the imposed dwell time.

These data would suggest that if possible alpha-numeric data should not be displayed on a CRT because of the slower reading times associated with the CRT display. However, it may not be practical to do this all the time, therefore, use of as few digits as possible, and as fast an update rate as possible, may help ameliorate the effects of the CRT on dwell times.

The effects of digit size on dwell time showed that in the range of 0.28 to 0.50 inches there was no apparent change in dwell times with the seven-segment type of displays. Therefore, it would appear that the display designer has some latitude as to the size of digits that can be placed in a display.

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Table 1. Summary of digital display characteristics

No.	TYPE	FONT	COLOR	HEIGHT#	RANGE	UPDATE RATE*
1	Gas	7-segment	red	0.55	-9 to 9	5.0
2	Gas	7-segment	red	0.50	-9.99 to 9.99	10.0
3	Gas	7-segment	red	0.50	-9.99 to 9.99	2.5
4	LED	7-segment	red	0.28	-9.99 to 9.99	3.0
5	LED	14-segment	red	0.28	-9.99 to 9.99	2.0
6	CRT	raster	white	0.28	0.00 to 19.99	15.0

#Height measured in inches
*Rate measured in updates per second

Table 2. Comparison of average dwell times and dwells per input of digital displays for single test subject

No.	Average Dwell Time	Dwells/Input
1	0.46	7.4
2	0.77	8.4
3	0.84	9.3
4	0.86	9.4
5	0.87	10.9
6	0.98	8.1

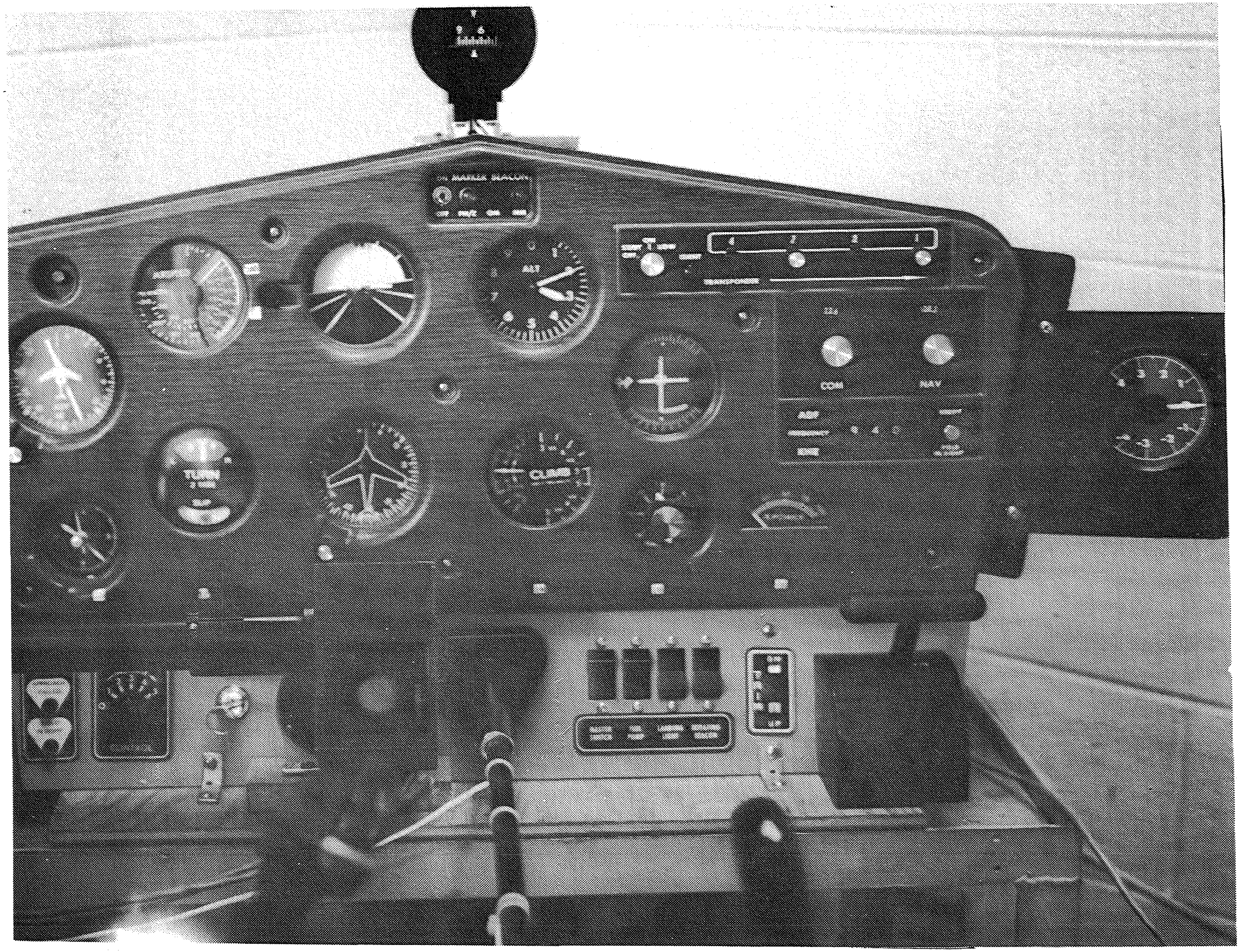

Figure 1.- Desktop simulator instrument panel.

Figure 2.- Test subject flying simulator with round-dial meter side task.

Figure 3.- One-digit, 0.55 inch, 7-segment, gas discharge meter.

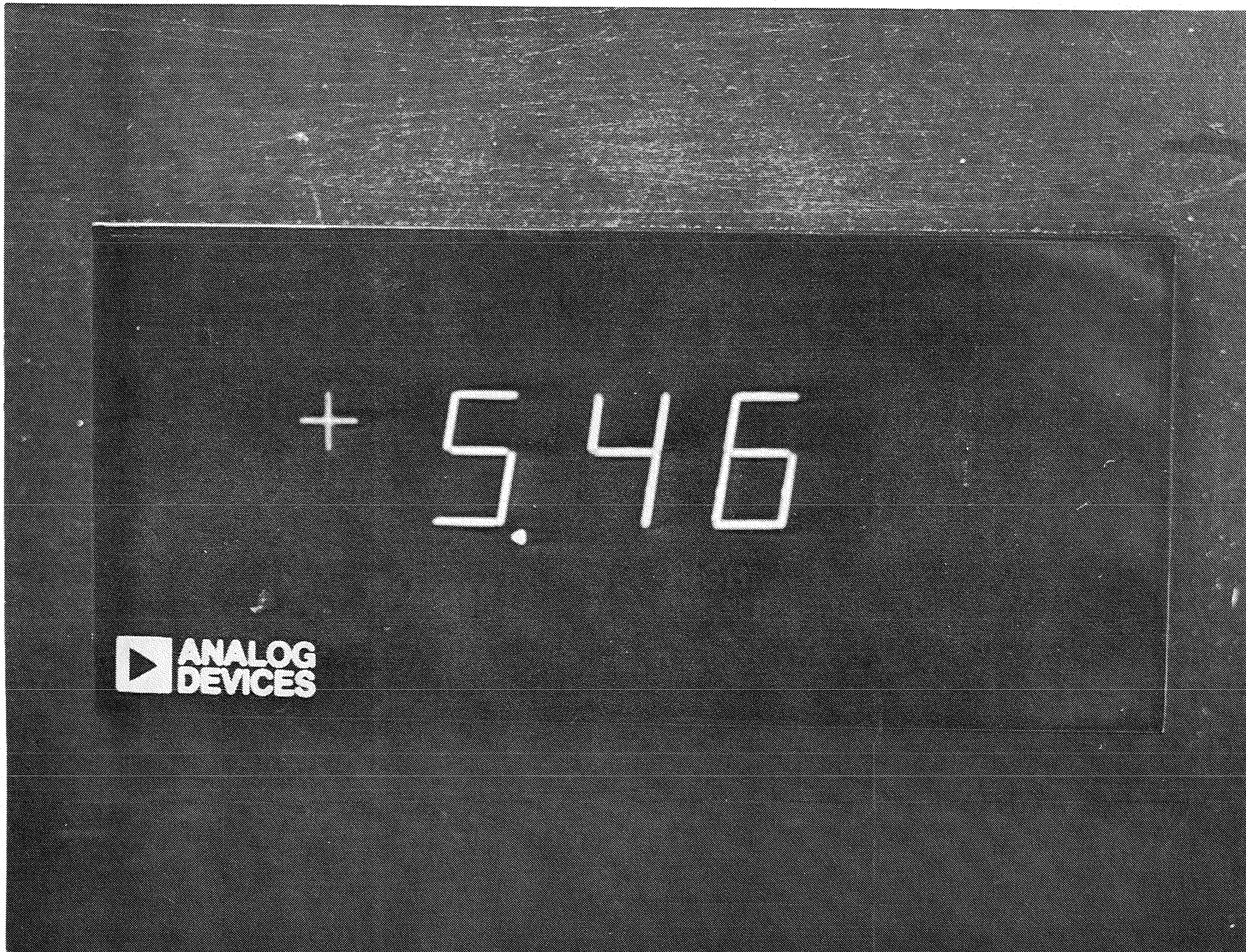

Figure 4.- Three-digit, 0.5 inch, 7-segment, gas discharge meter.

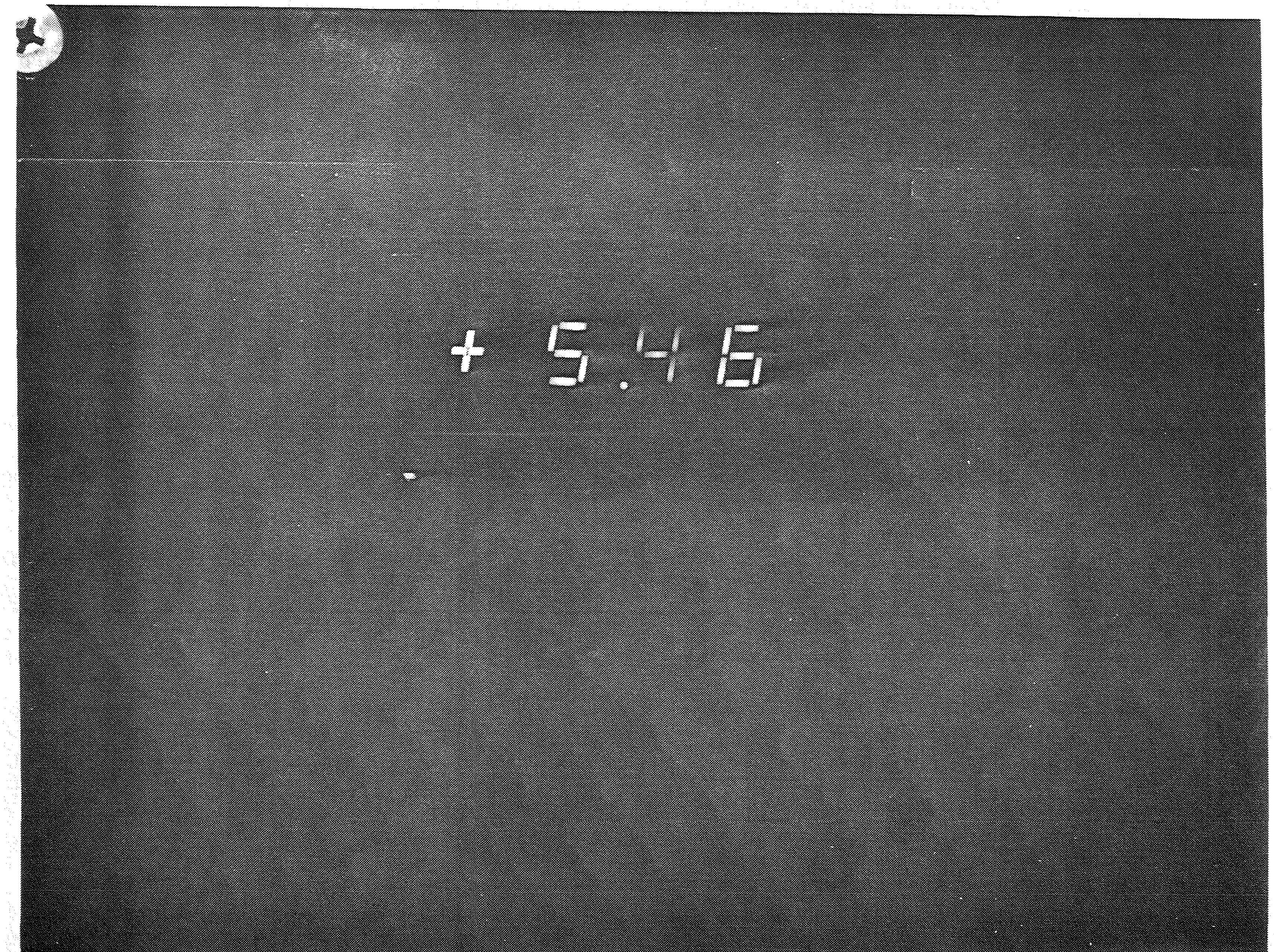

Figure 5. Three-digit, 0.28 inch, 7-segment, LED meter.

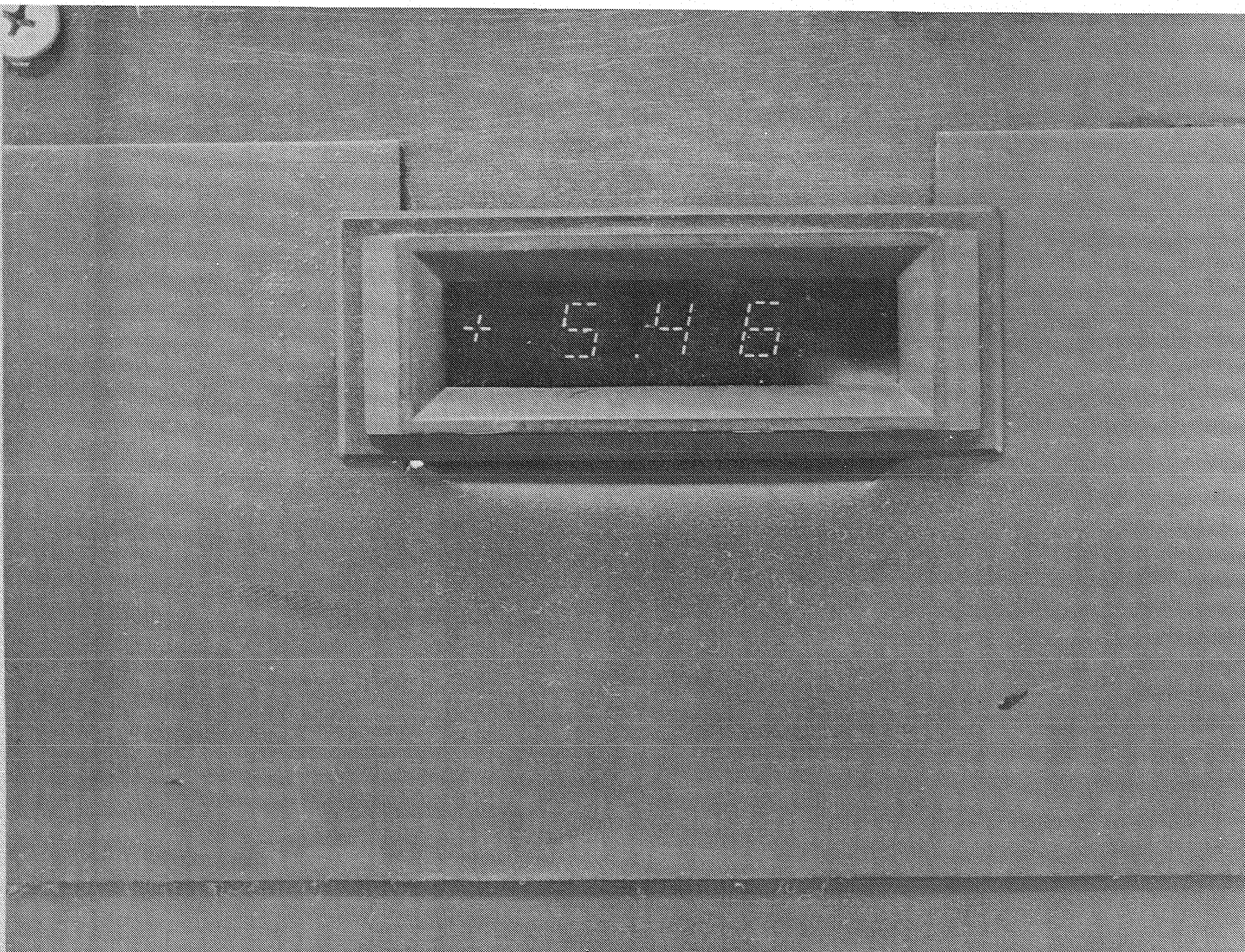

Figure 6.- Three-digit, 0.28 inch, 14-segment, LED meter.

Figure 7.- Three/four-digit, 0.28 inch, CRT meter.

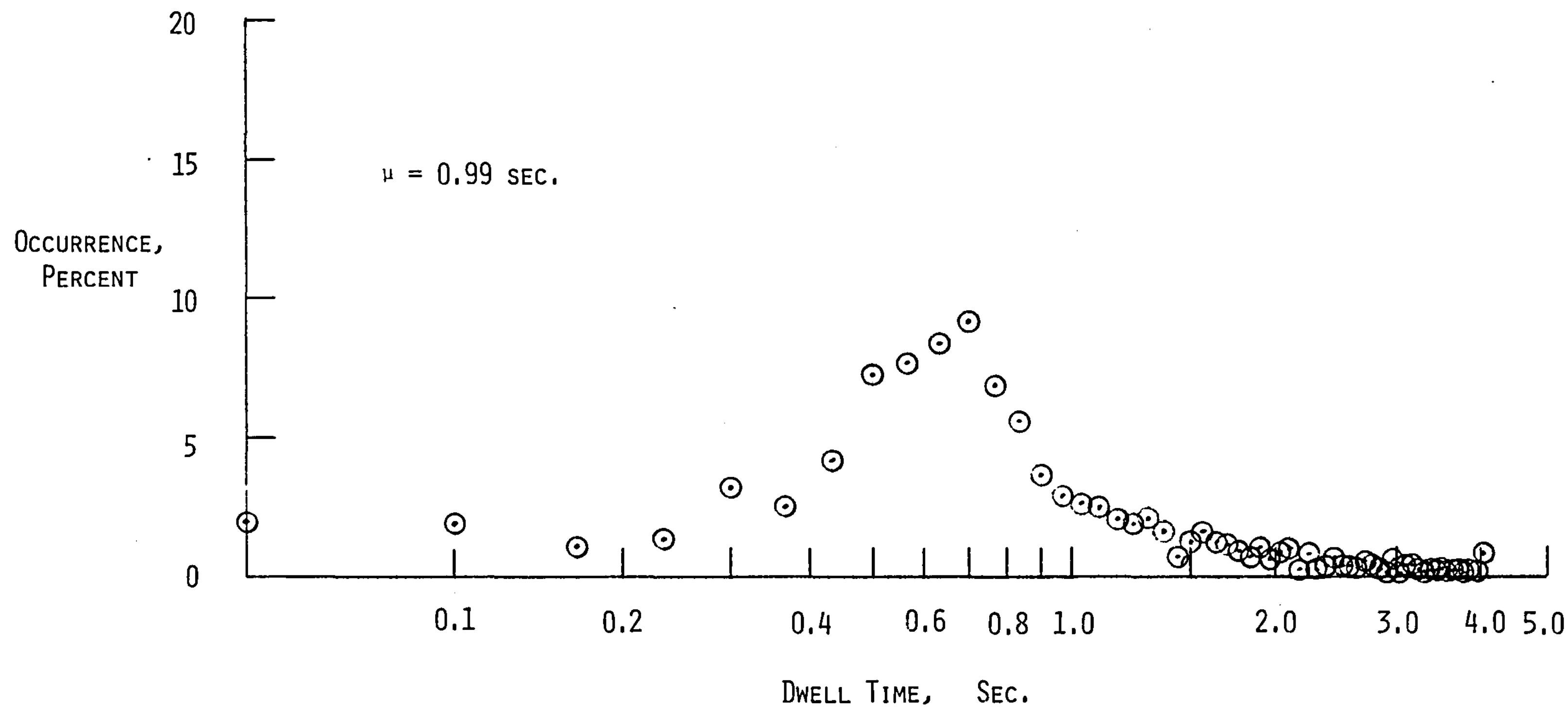

Figure 8.- Dwell histogram of round-dial meter with 2 second time lag.

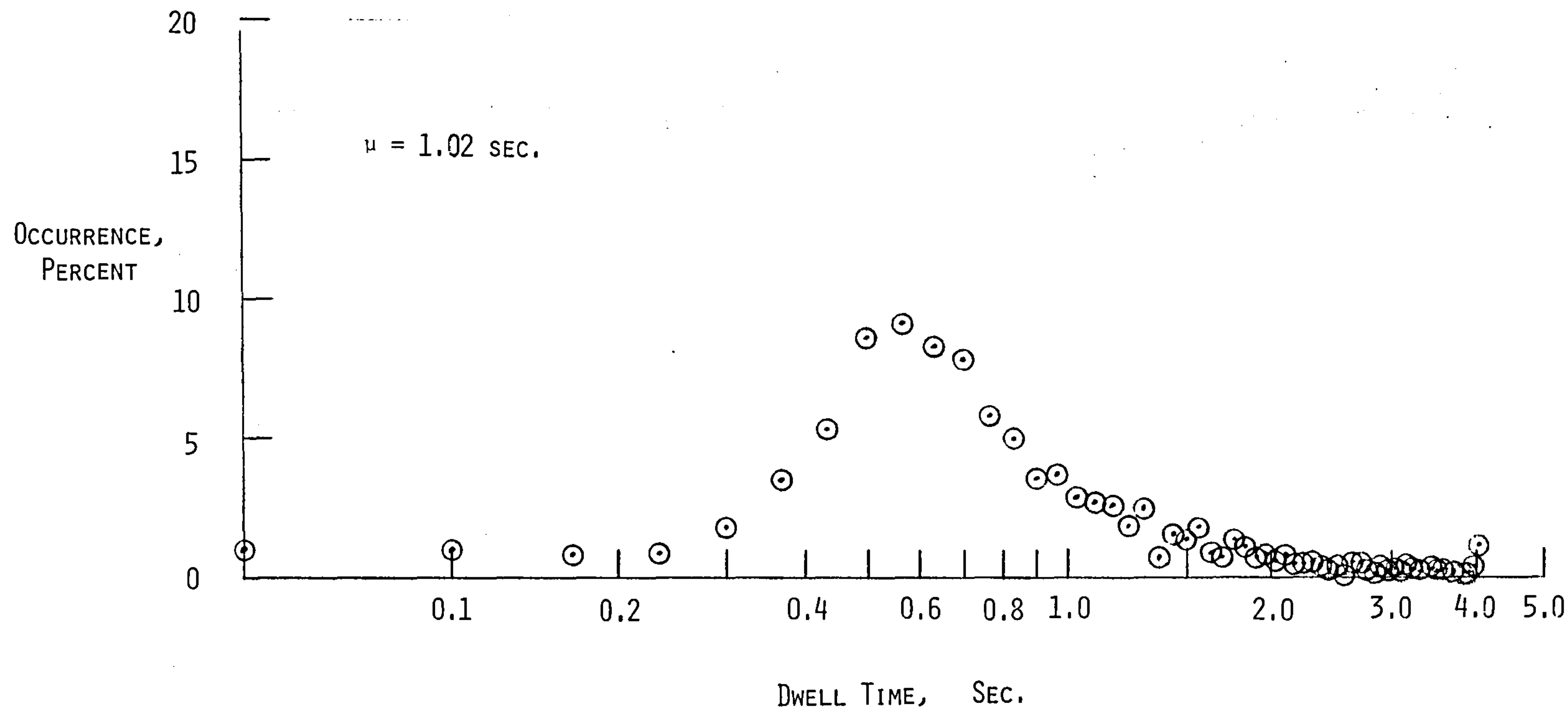

Figure 9.- Dwell histogram of round-dial meter with 4 second time lag.

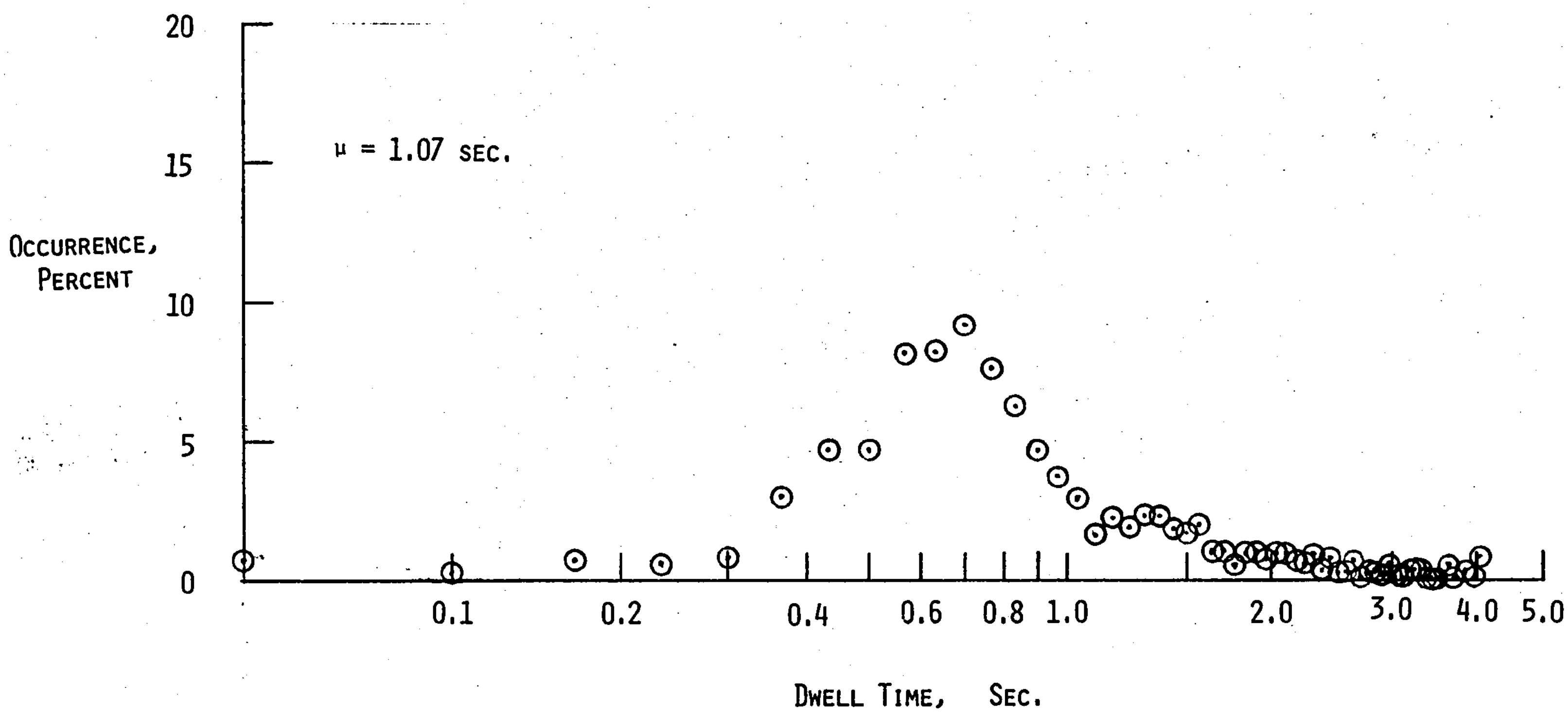

Figure 10.- Dwell histogram of round-dial meter with 6 second time lag.

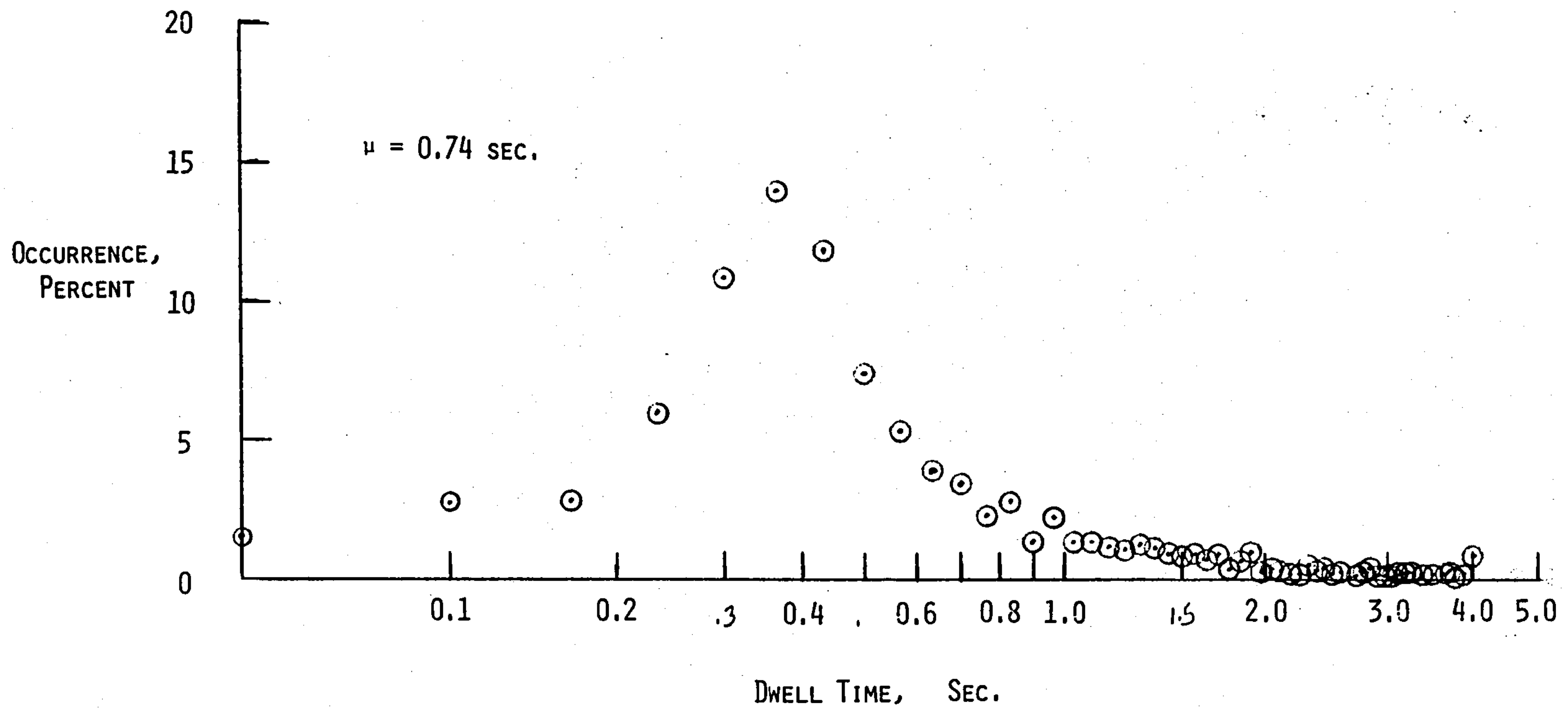

Figure 11.- Dwell histogram of 1-digit LED meter with 2 second time lag.

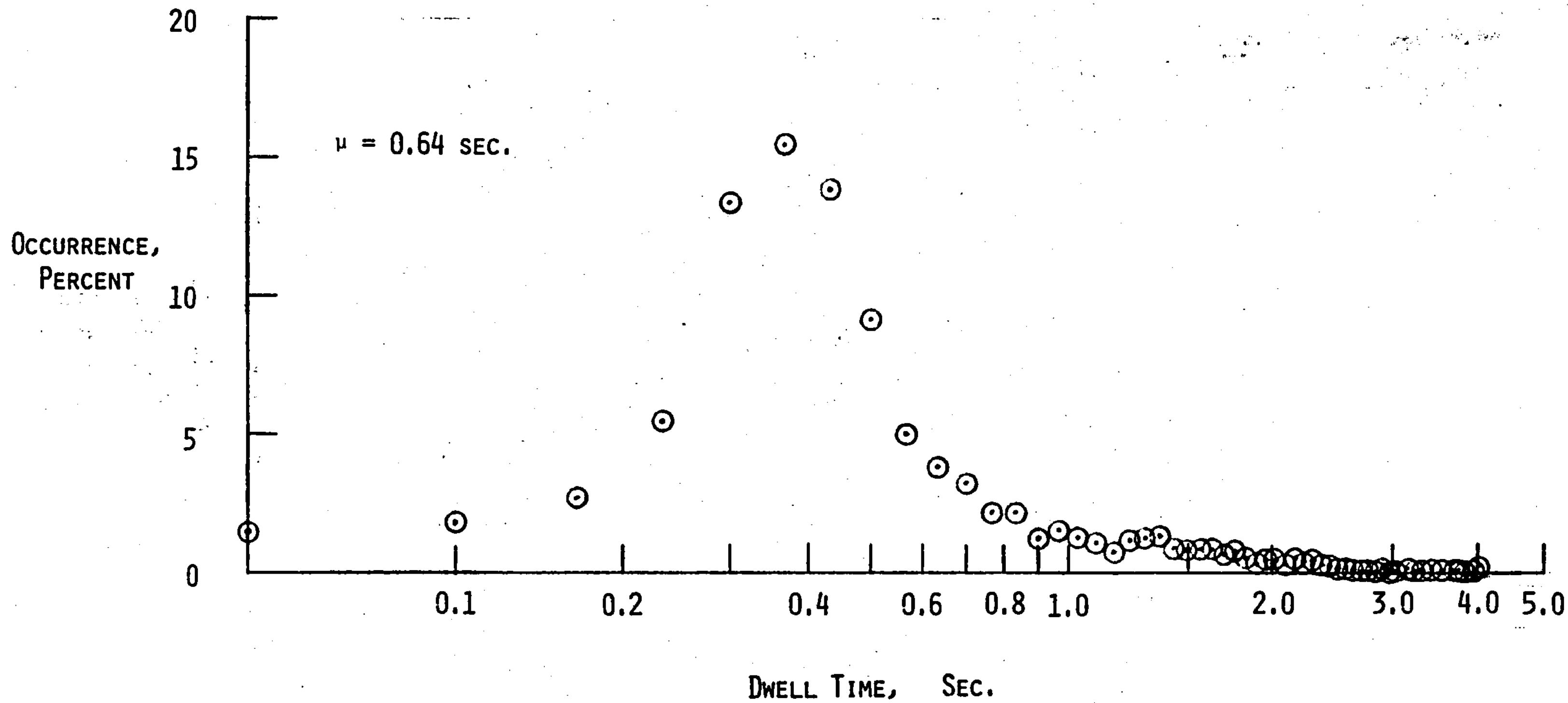

Figure 12.- Dwell histogram of 1-digit LED meter with 4 second time lag.

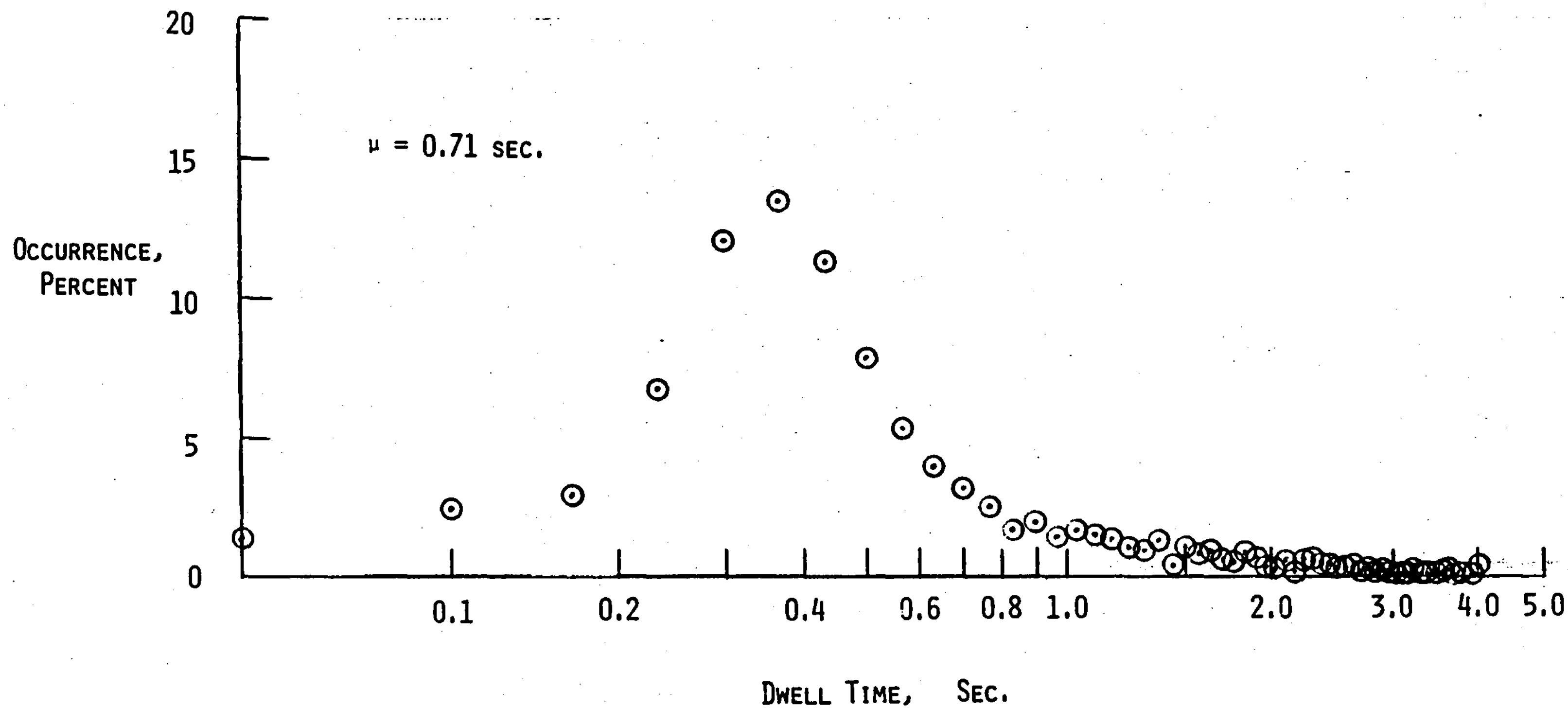

Figure 13.- Dwell histogram of 1-digit LED meter with 6 second time lag.

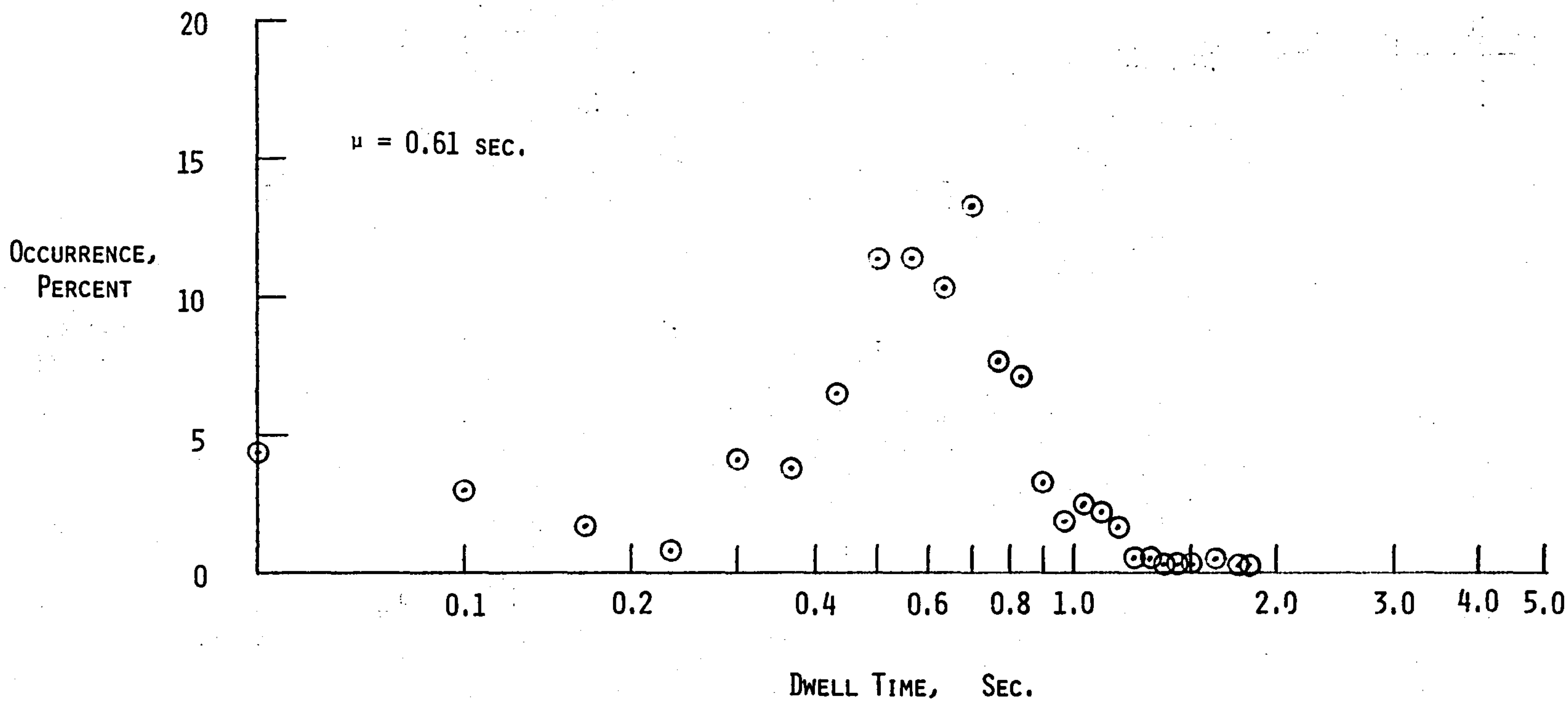

Figure 14.- Dwell histogram for subject four with round-dial instrument with 2 second time lag.

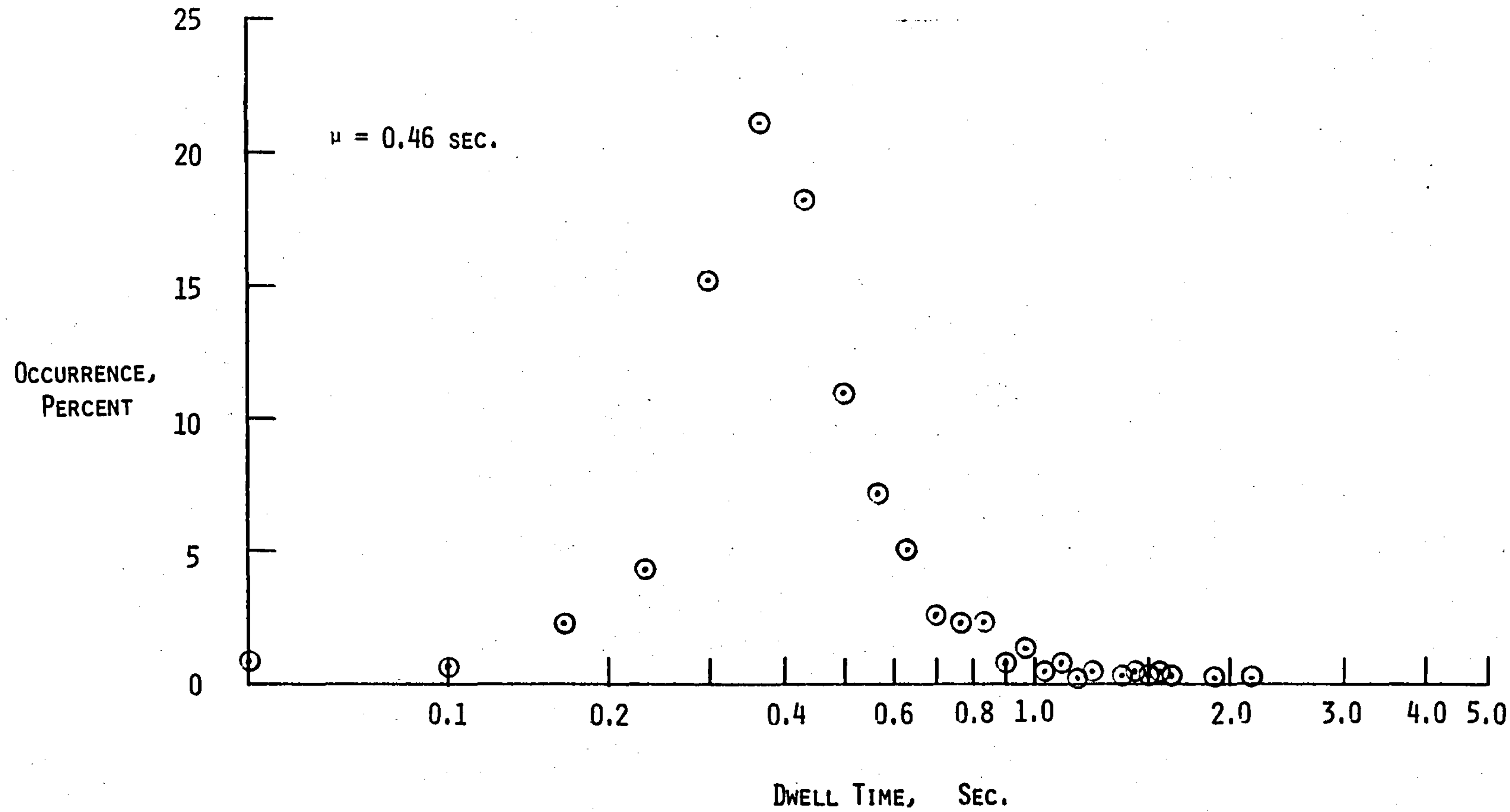

Figure 15.- Dwell histogram for subject four with 1-digit LED meter with 2 second time lag.

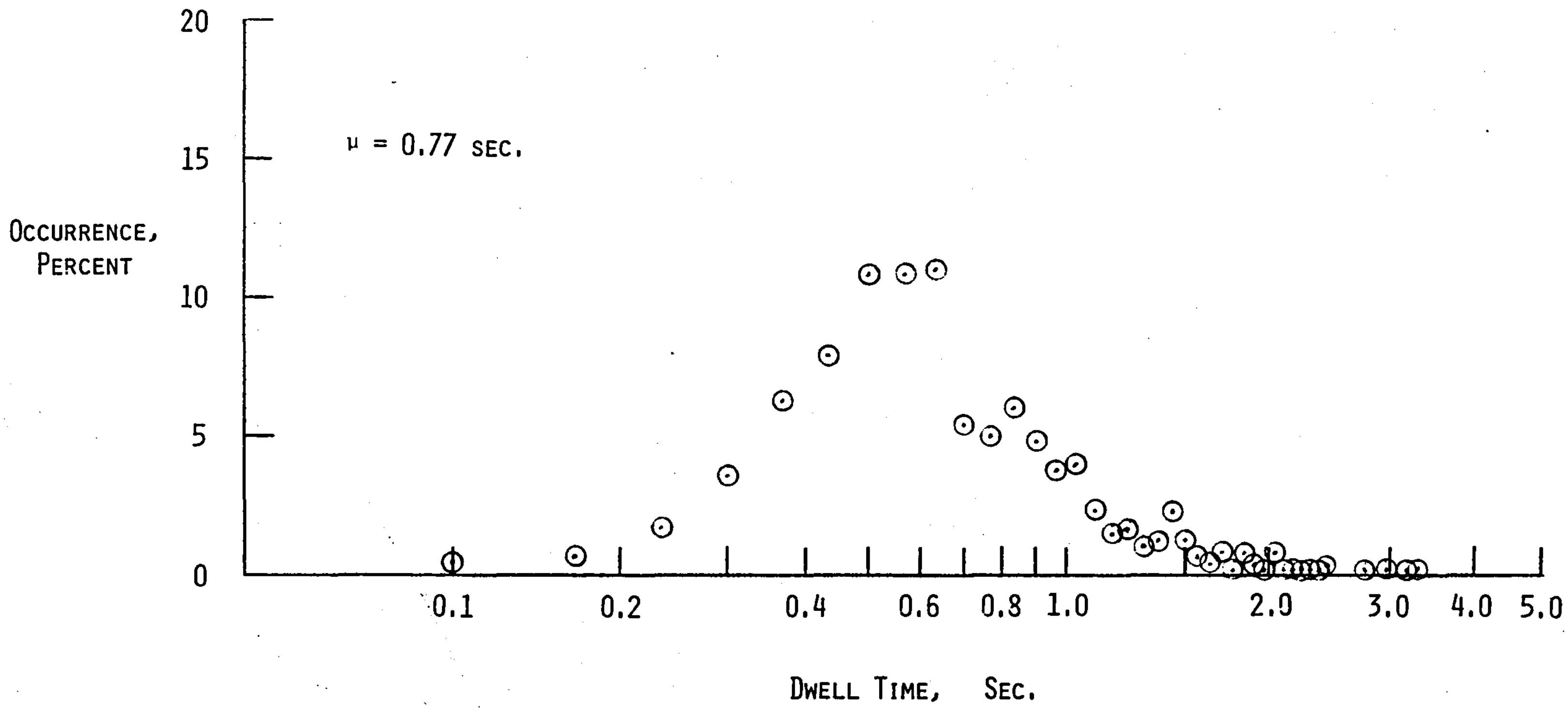

Figure 16.- Dwell histogram of 3-digit, 7-segment, 0.5 inch LED meter with 2 second time lag for subject four.

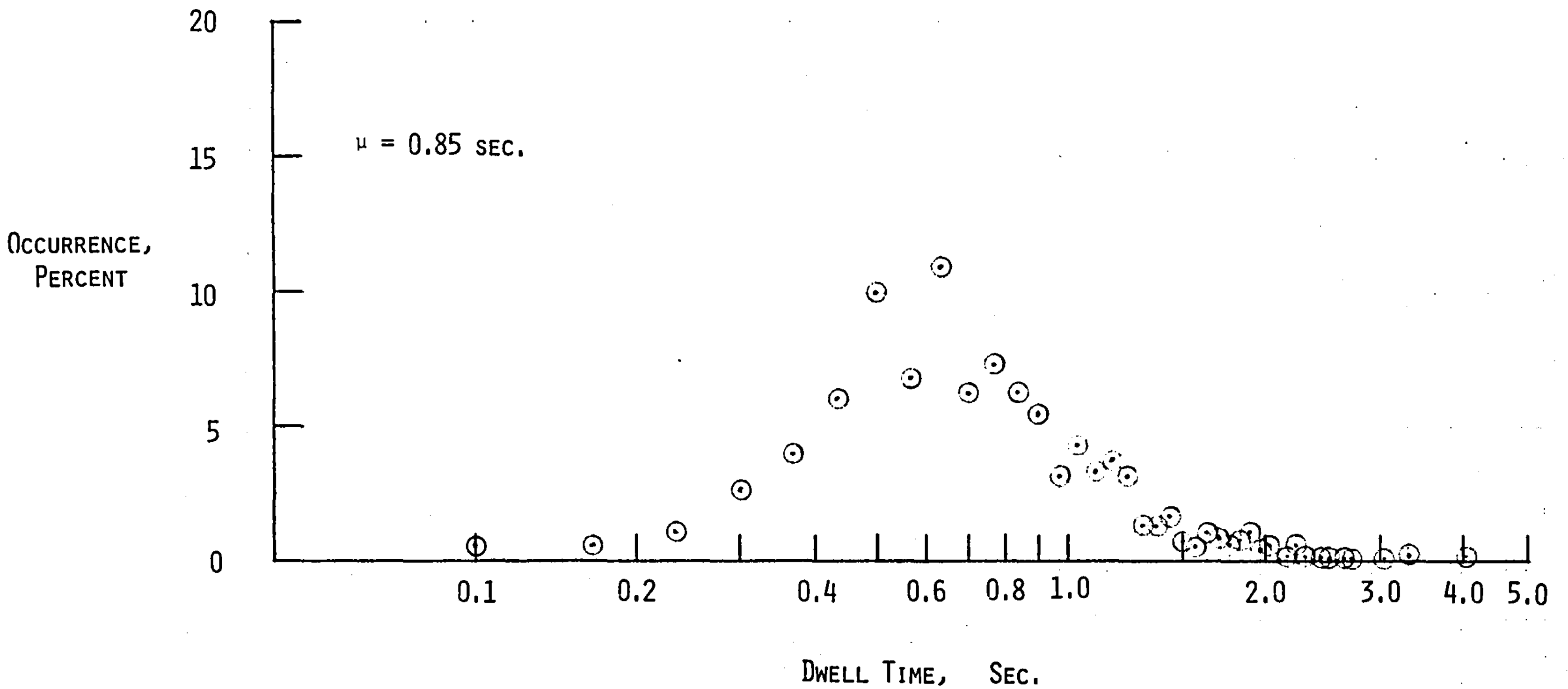

Figure 17.- Dwell histogram of 3-digit, 7-segment, 0.5 inch LED meter with 2.5 updates per second for subject four.

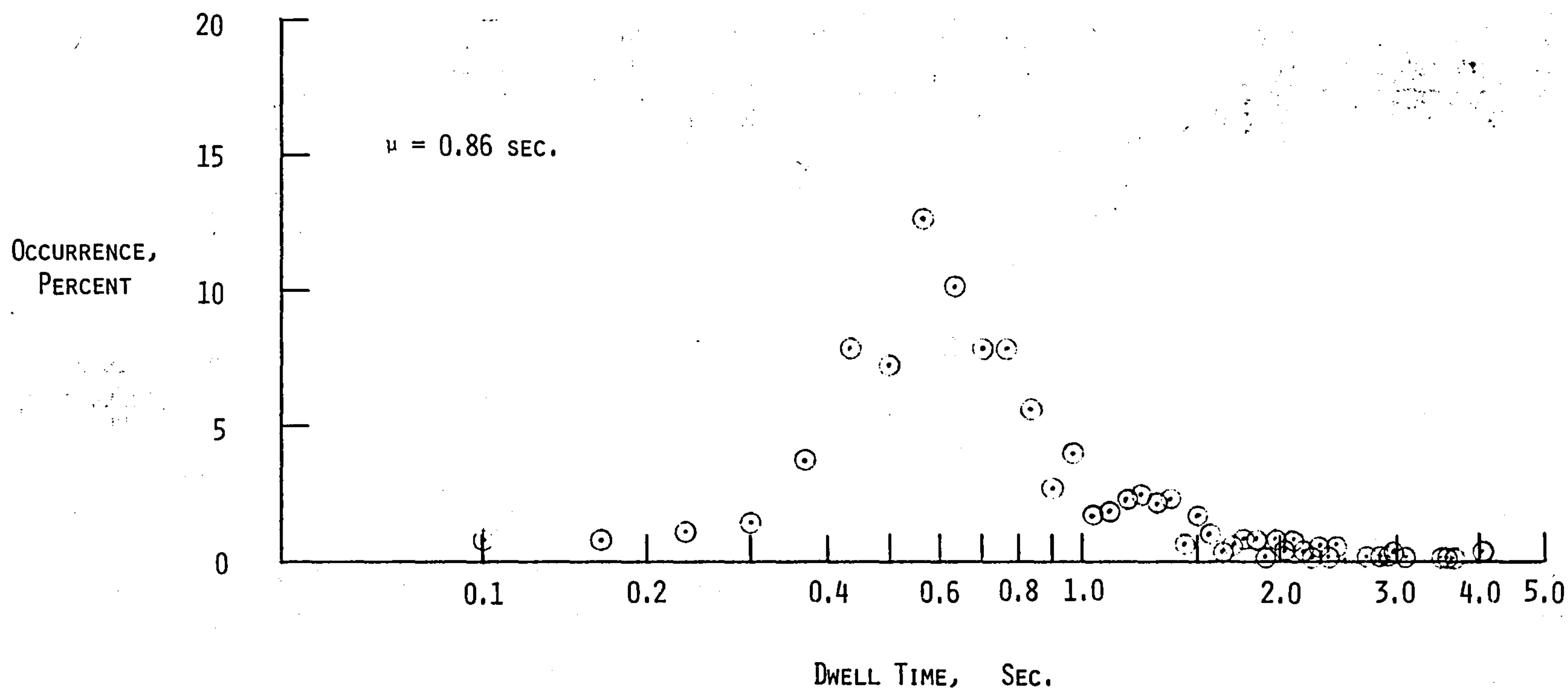

Figure 18.- Dwell histogram of 3-digit, 7-segment, 0.28 inch LED meter for subject four.

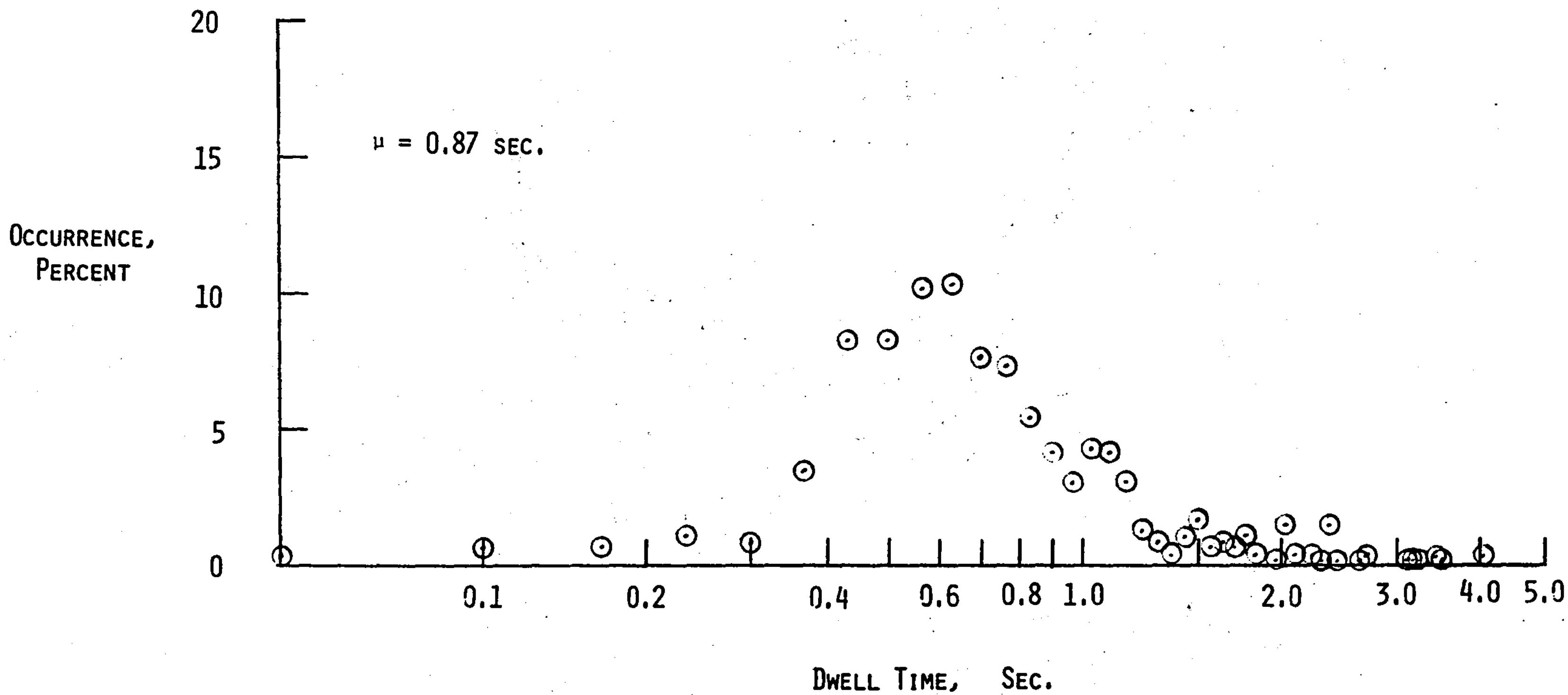

Figure 19.- Dwell histogram of 3-digit, 14-segment, 0.28 inch LED meter for subject four.

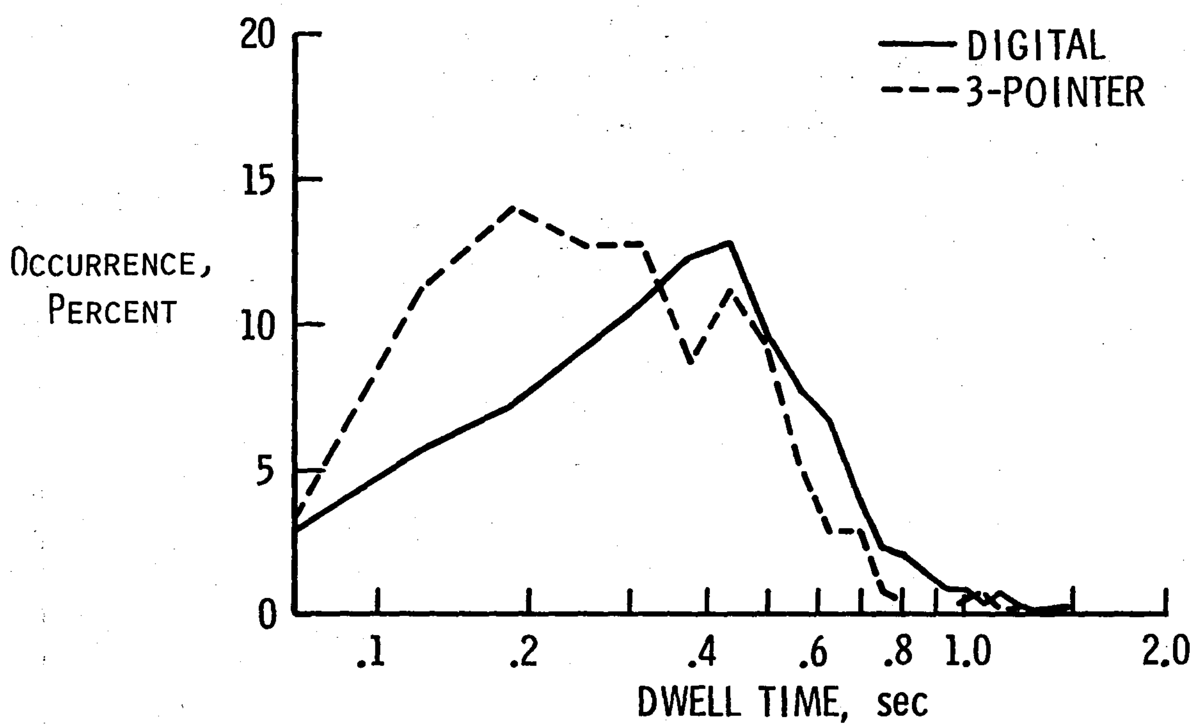

Figure 20.- Dwell histograms of CRT, digital altimeter and a three-pointer altimeter.

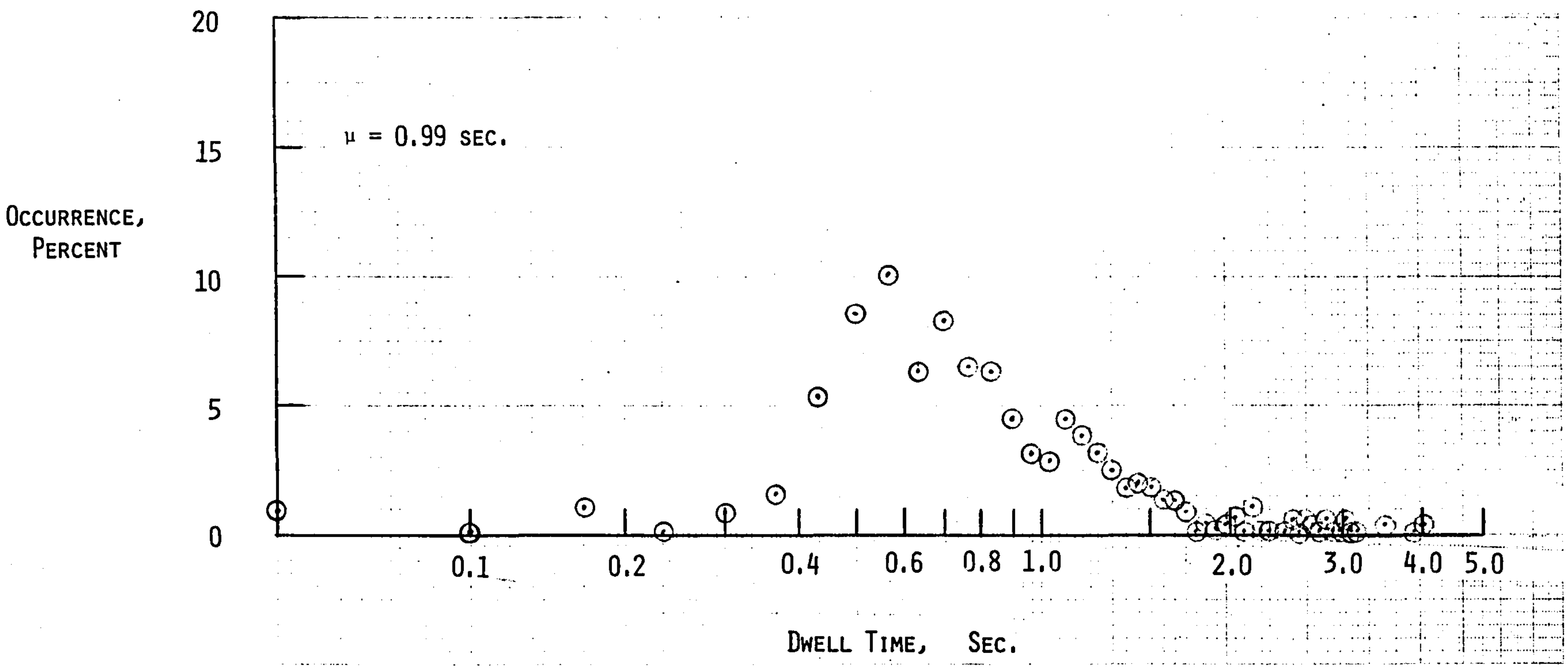

Figure 21.- Dwell histogram of 4-digit, 0.28 inch CRT meter for subject four.

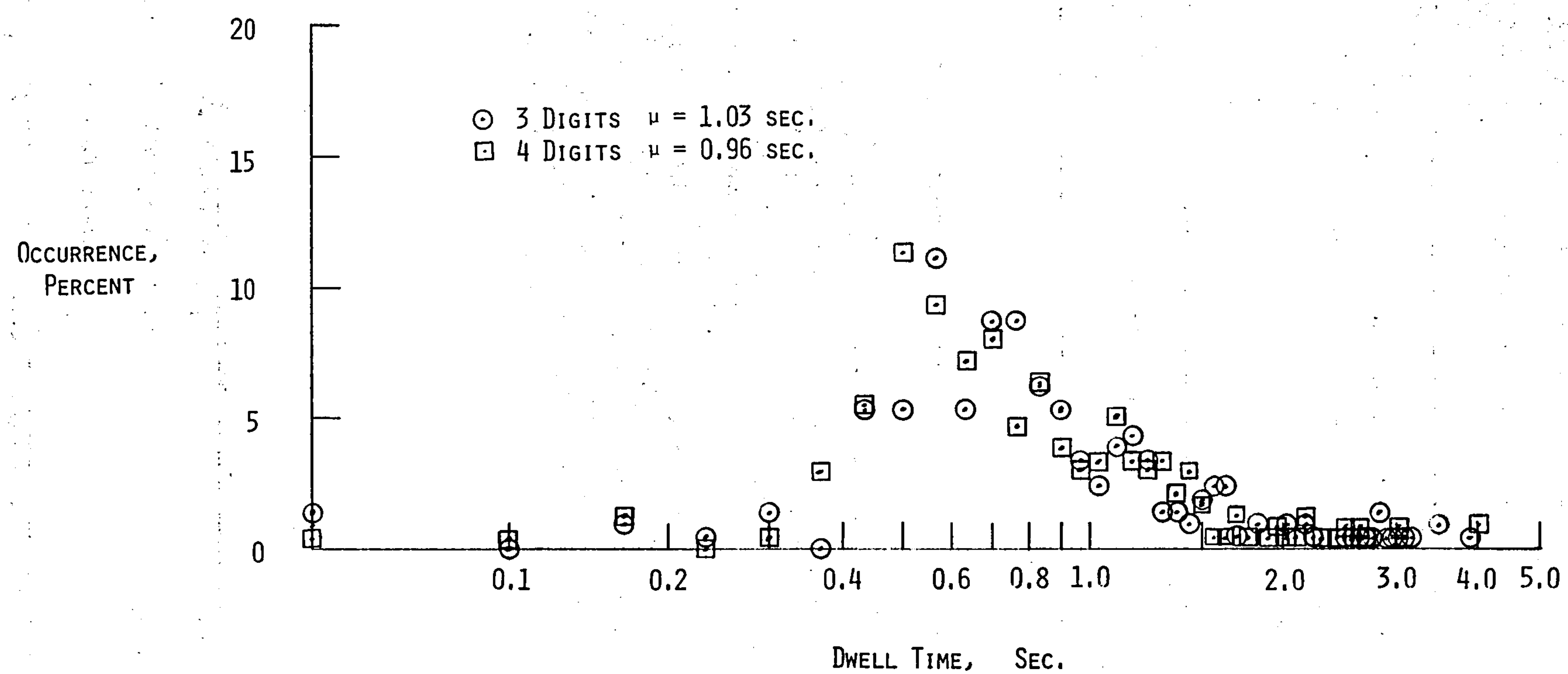

Figure 22.- Dwell histograms of 3- and 4-digit, 0.28 inch CRT meter for subject four.

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15. Supplementary Notes

16. Abstract

A series of exploratory tests were conducted to investigate the effects of advanced display formats and display media on pilot scanning behavior using Langley's oculometer, a desktop flight simulator, a conventional electro-mechanical meter, and various digital displays. The primary task was for the test subject to maintain level flight, on a specific course heading, during moderate turbulence. A secondary task of manually controlling the readout of a display was used to examine the effects of the display format on a subject's scan behavior. Secondary task scan parameters that were evaluated were average dwell time, dwell time histograms, and number of dwells per meter change. The round dial meter demonstrated shorter dwell times and fewer dwells per meter change than the digital displays. The following factors affected digital display scanning behavior: (1) the number of digits; (2) the update rate of the digits; (3) the display media; and (4) the character font. The size of the digits used in these tests (0.28 to 0.50 inches) did not affect scan behavior measures.

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