HOW A PILOT LOOKS AT ALTITUDE

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SUMMARY

Altitude information is very important to pilots. Although on the instrument landing approach, pilots only look at the altimeter 3% to 6% of the time, they obtain relative altitude information from glideslope and command bar needles. One pilot questionnaire survey has indicated that altimeters are misread by almost all pilots. Commercial pilot eye scanning data previously collected were reanalyzed to evaluate how pilots used the drum pointer altimeter. The results of these tests showed that the pilots seldom used the drum window apparently because it was difficult to read as indicated by average drum window dwell times of .6 seconds. It is suggested that pilot scanning data be collected for other types of altimeters in order to find those with good scanning characteristics.

INTRODUCTION

Altitude is one of the prime bits of information needed by a pilot during any phase of flight. Misreading of the altimeter can result in incidents and accidents. Consequently, a number of altimeter designs have been tried over the years. The tests conducted and the reports written on the subject are numerous; in fact, a number of summary reports have been written such as references 1 and 2. In 1975, A. N. Du Zeu (ref. 3) wrote that "the altimeter is one of the most important aircraft instruments and is likely to remain so for many years to come. It is pertinent, therefore, to attempt to forecast what the future holds for this instrument." In summarizing he wrote "no great change is foreseen in display presentation of altimeters, the counter pointer type will become universal except for low performance, low altitude aircraft. Solid state displays are likely to supplant mechanical displays, but still with an imitation of mechanical displays. It is possible that the advent of CRT presentation will result in presentations of optimum displays for each phase of flight, but still there is no sign of an acceptable completely new presentation on the horizon." Even though no completely new presentation is forecast, the current altimeter designs are not totally adequate as evidenced by the number of accidents, near accidents, and incidents due to pilots misreading altimeters.

This paper will discuss an analysis of pilot scanning characteristics of a drum pointer altimeter. Correlations will be made to past research on altimeters in an effort to understand how a pilot uses an altimeter. Also, suggestions to help improve the readability of the altimeters thereby reducing the number of misreads will be discussed.

EQUIPMENT AND TEST PROCEDURE

The tests were performed in a Boeing 737 simulator at Piedmont Airline's Training Facility. The simulator is FAA certified and used for initial and recurrent training. The only change in the instrument panel was the incorporation of an oculometer optical head which was mounted below the Automatic Direction Finder (ADF) behind the instrument panel. A TV camera was mounted behind the pilot to view the instrument panel and a TV monitor was located behind the pilot's seat to allow the test conductor to observe the pilot lookpoints superimposed in the instrument panel scene.

The oculometer has two primary subsystems: the electro-optical system and the signal processing unit. The electro-optical system mounted in the instrument panel generates a beam of infrared light which is directed through a beam splitting mirror toward the subject's eye. Reflections from the eye are directed back through the beam-splitter to an infrared-sensitive TV camera. The high reflectivity of the human retina for infrared leads to a backlighting of the pupil, so that the camera sees the pupil of the eye as a bright, circular area (fig. 1). The camera also sees a small bright spot due to a reflection from the corneal surface. The relative positions of the center of the pupil and the corneal reflection depend on the angle of rotation of the eyeball with respect to the infrared beam. The signal processing unit uses the signal from the TV camera to compute this angle of rotation and the coordinates of the lookpoint on the instrument panel. The output of the signal processor is a set of calibrated analog signals representing the subject's lookpoint coordinates and pupil diameter. A complete description of the oculometer and test situation can be found in reference 4.

All landing approaches were started at 19 km (12 miles) from runway threshold and approximately 415 m (1360 ft) above ground level. The first 6 km (4 miles) were used by the pilot to stabilize the aircraft on the correct flight path and to check the oculometer calibration. At 13 km (8 miles) data recording was started and continued through capture and descent down the 3° glideslope, touchdown and rollout or until the approach was aborted as a result of the pilot choosing to go around.

All airline pilots used in the program were qualified Boeing 737 pilots who fly regularly for a scheduled airline. The pilots were asked to assume that they were flying an aircraft full of passengers, and if they would normally elect to go around, they should do so. All tests were conducted using the same co-pilot. The co-pilot functioned in the same manner as he would in a normal approach and provided all required call outs.

REVIEW OF PILOT OPINION AND SELECTED ALTIMETER RESEARCH

If altimeter display improvements are to be accomplished and if optimum altimeter displays are to be developed for future flight systems, it becomes imperative that we understand the problems with existing altimeters and how a pilot obtains and perceives altitude information.

Drum Pointer Altimeter Misreads

A survey was conducted by Jim Anderson, National Airline Control Safety Chairman, through the Airline Pilots Association to ascertain the percentage of National Airline pilots who have misread or observed another pilot misread the drum pointer altimeter used in National Airline's B727 aircraft. The results of the survey indicated that of the 169 pilots who responded, 137 stated that they had misread the altimeter and 134 stated that they had observed another pilot misread the altimeter (85% of each group stated that such observations had been made on more than one occasion). The survey results also indicate that a surprisingly large number of misreads (50) happen during the approach phase. Several comments of pilots relating to the drum pointer altimeter are:

1. "This altimeter takes more concentration than should be necessary to read accurately."

2. "The small drum window is a complication on the instrument and (is) quite small, often requiring a 'double look' and diverting attention from the needle. Other instruments require only a single point of visual attention to comprehend and do not divert, slow, or complicate a smoothly flowing scan."

3. "Misreads seemed to always occur at the lower altitude when attention is split between more activities."

4. "The more stressful situations produced more misreads."

5. "A quick glance after (being distracted) can usually induce a reading of 1,000 ft. off if the barrel drum is halfway between thousands."

Pilot Opinion of Altitude Importance

Pilots normally rate the altimeter as the third most looked at instrument in the aircraft (with the Flight Director being first and the airspeed indicator second). In fact, when asked, some pilots stated they spent 20 to 25% of their time on the altimeter. Studies conducted using these same pilots (ref. 4) indicate that for all test conditions they actually spent an average of between 3 to 6% of their time looking at the altimeters. The discrepancy between pilot opinion and actual time spent on the altimeter may not be as bad as it seems at first glance. Indications are that while the pilot may in fact be concerned about his altitude 25% of the time, it does not equate to spending that much time looking at the altimeter. On the straight and level portion of the approach, once having established his altitude, the pilot can use either the horizontal command bar of the Flight Director to indicate position with respect to desired altitude or other cues which indicate that a change in altitude is taking place. Upon starting the descent, additional instruments also provide altitude information. To quote a NASA test pilot, "On the glideslope the altimeter is all but relegated to a back up mode. My sources of information are first the raw glideslope data, second, command bars, and third, where present, co-pilot call outs." While the first two do not give absolute altitude information they do tell the pilot where he is with respect to his desired altitude at that point in his approach. Therefore, while a pilot may in fact spend up to 25% of his time concerned with altitude information, it is not necessary, however, that he spend all of that time looking at the altimeter.

Altimeter Research

A number of different altimeters are used in current commercial aircraft such as the three pointer, counter pointer, drum pointer, and counter drum pointer (fig. 2). The altimeter used in the current study was a drum pointer (fig. 2b). The pointer indicates altitude over a 30.5 m (1000 ft) range while the drum indicates thousands and tens of thousands of feet. One of the most comprehensive studies of time required to read the various types of altimeters (fig. 2) is reported in reference 5. In these tests, the subjects were required to read altimeter settings while engaged in a central tracking task. At random times, the experimenter would open a shutter which was covering the altimeter. The subject would read the altimeter, operate a hand switch to close the shutter and then report the altitude to the nearest 30.5 m (100 ft.) Measurements were taken of the altimeter exposure time and the accuracy of reporting the altitude. Eighteen pilots participated in the study. A total of 15 altimeter exposure trials were performed on each of the four types of altimeters (similar to those of fig. 2). The results for the drum pointer altimeter (equivalent to the one used in the airline pilot study) showed a mean exposure time of 1.38 seconds with a probability of an error of 2.4%. In those tests, the pilot was presented with a random selection of altitudes so that no history of altitude profile could be maintained; consequently, the subject pilots were required to read the entire altimeter each time it was shown.

RESULTS AND DISCUSSION

In an actual flight situation, altimeter readings are not presented to pilots in a random fashion. In fact, the pilot has a continuing altitude profile which provides a running time history; consequently, he has a prior knowledge of what to expect when he looks at the altimeter and therefore, does not have to read the entire altimeter each time he looks at the instrument. In fact, both reference 4 and reference 6 indicate that pilots when flying simulated approaches have an altimeter mean dwell time of only between .3 to .4 seconds as opposed to the 1.38 seconds found in reference 5. In addition, observation of the real time TV tapes, taken during the airline pilot study (ref. 4), shows that the pilot looked at the left side of the altimeter even though the needle was pointing to the right side. This observation coupled with the large standard deviation of mean dwell time found in the data led to a reanalysis of the altimeter data in terms of dwell times for the left side, right side, and altimeter drum window. For the above analysis, the altimeter was divided into three areas: the left side, the right side, and the altitude drum window. The left and right side divided the altimeter in half from top to bottom with no overlap. The drum window, however, overlapped a very small part of the left side and part of the right side (fig. 3). Figure 4 presents a combined dwell time histogram of the frequency distribution of individual dwells on the total altimeter. These data were taken from seven pilots who performed a total of 108 simulated ILS approaches from 13 km (8 miles) out to 30.5 (100 ft) above the runway. The abscissa is dwell time in seconds plotted on a log scale; the ordinate is percent of the total number of looks at the altimeter. The curve shows a mode at about .25 seconds with a median at .275 seconds and mean of .32 seconds. The next figure (fig. 5) presents a break out of the dwells on the left and right sides of the altimeter. This shows a characteristic difference in the dwells on the right and left sides. The left side dwells show a distribution with two peaks, one at about .1 seconds and a second at about .4 seconds. Reference 7 refers to a bimodal dwell distribution as being a characteristic of a type II instrument and defined the peaks occurring at these same dwell times as glance (.1 sec) and read (.4 sec) dwells. For the short dwell times the pilot gets only minimal information such as the direction of needle orientation. The longer dwell times are associated with reading the needle value. During the approximately 180 seconds required for an approach the needle is on the left side for only 40 or 50 seconds (on the average 25% of the time). Yet, the pilot spends approximately 48% of the time in the altimeter on the left side. It is hypothesized that the pilot can determine right side needle position and/or rate parafoveally while fixated on the left side of the altimeter. The right side of the altimeter shows a totally different shape with a single mode at .25 seconds. Reference 7 refers to a single peaked dwell distribution as a type one instrument with the pilot reading only the value to which the needle was pointing.

Of particular interest, on the right side of the altimeter, is the window which contains the drum. The data were analyzed for dwell times in the area of the drum window (fig. 3) plus ½ of a visual degree (¼ inch) surrounding the window. When the pilot looks in the drum area and the needle is overlapping the drum area, it is difficult to determine which piece of information he is reading. Figure 6 gives the dwell time histogram for the drum window area. These data show a broad peak between .1 to .25 seconds. This broad peak could be a summation of a distribution having a peak at about .1 seconds (glances) and one having a peak at .25 seconds. Reference 8 presents the dwell time histogram of subjects during text reading. The text reading data also peak at .25 seconds and have a shape that appears to be log normally distributed. To obtain an estimate of what dwell distribution remains when the text reading (in this case assumed to be needle position reading) is removed, the distribution of reference 8 was subtracted from that of figure 6. The resulting curves are plotted in figure 7. The middle curve is the one subtracted (ref. 8) and the remaining distribution forms the left and right curves. The one to the left is almost identical in distribution to the glances of reference 7 and is probably associated with needle direction estimation. The distribution on the right appears to be log normally distributed with a peak between .5 and .6 seconds. There are two possibilities to explain the distribution. In follow-on work, Dr. R. Harris (co-author of this paper) using the general aviation data reported in reference 7, found similar distributions at this peak dwell time to be associated with a control input. These data were analyzed for associated control inputs (ref. 9) by establishing a control input criterion based on amplitude and rate. When this criterion was met, the instrument at which the subject was looking and the dwell time for that look were determined. These data, however, were not found to be associated with control input. In fact, no altimeter looks occurred within .75 seconds of a control input. The second possible explanation of the dwell distribution peaking at .5 to .6 seconds is that these are the dwells in which the pilot was reading the altitude digits in the drum window. If these are associated with the pilot reads of the drum, then two implications can be drawn. First, the number of times that the altitude window is actually read is very small (approximately 3.0% of all altimeter dwells). Second, the peak occurring at .5 to .6 seconds is a display design concern since this is almost twice as long as text reading.

The longer time could either be because of digit size (the digits are the minimum size recommended in ref. 10) or it could be that reading the drum requires the pilot to interpolate between the 305 m (1000 ft) digits showing (see fig. 2b) or a combination of both factors. In any case, numbers presented on a counter which steps between thousands of feet altitude should reduce the total read time, as the pilot has only one set of digits to evaluate. This is what apparently helped reduce the reading times (reported in ref. 5) of the drum pointer from 1.38 sec. to .8 sec. for counter pointer altimeter. It would seem logical to make the counter digits as large as possible and place them on the left of the altimeter. This is the location where the pilots look most often.

CONCLUDING REMARKS

While the drum pointer altimeter may not be the best available, all altimeters share to some degree the same problems. Additional research in exactly how and why pilots glance, read, and scan altimeters should lead to better instrument design and consequently enhance safety in both commercial and general aviation aircraft.

While each pilot has an individual scan pattern which changes with instrument layout, aircraft, and flight conditions the basic time required to extract the desired components of information should be fairly constant across conditions for an instrument like the altimeter.

The results presented here indicate that:

1. Drum pointer altimeter misreads by pilots are fairly common.

2. It requires several fixations within the drum pointer altimeter to get all the information available.

3. The pilot can pick up relative needle position (right or left) in a quick glance (.1 sec.).

4. The total time spent looking at the altimeter drum is very small, 3% of the dwells within the altimeter and it requires .5 to .6 seconds to read it.

5. Additional scan research with tests specifically designed to look at altimeter design and use is needed to properly develop and evaluate future altimeters.

At this point, several improvements are indicated; first, to increase the size of the drum numbers, second, use a counter or counter/drum combination and third, place it where the pilot looks most often (on the left side of the altimeter). Some of these improvements have already been incorporated in some of the newer altimeters. Research using these newer altimeters is needed to determine if in fact they do allow the pilots to extract the needed information quickly and accurately.

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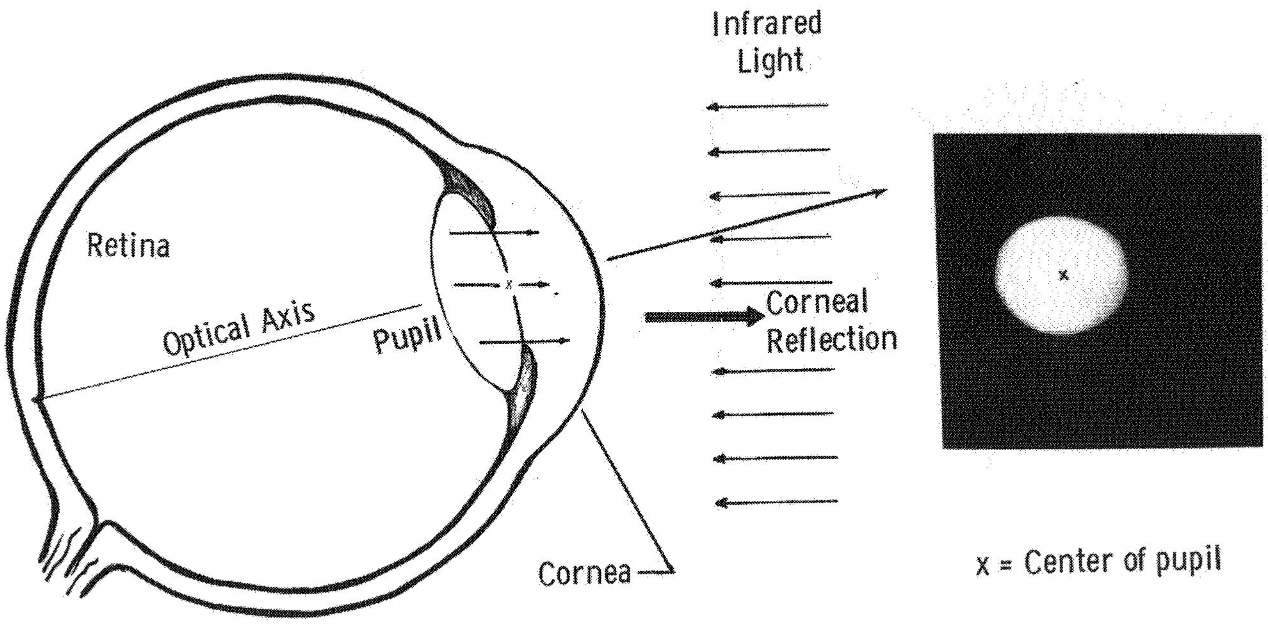

Figure 1.- Basic sensing principle.

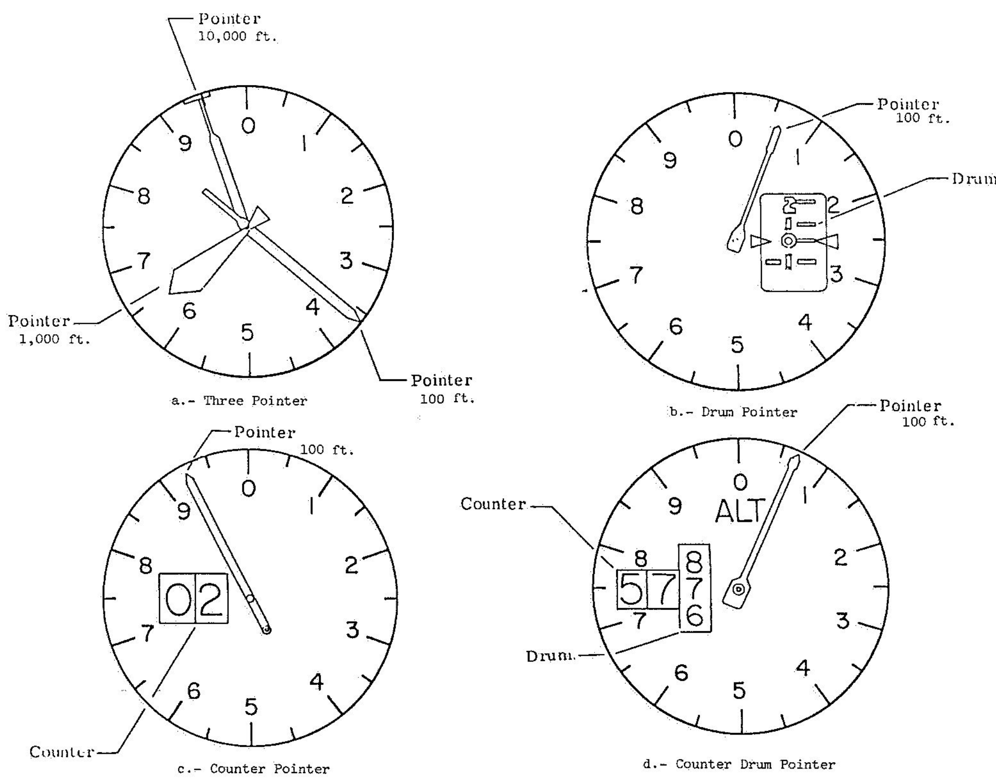

Figure 2.- Four types of altimeters. (Note: 1 ft = 0.3048 m.)

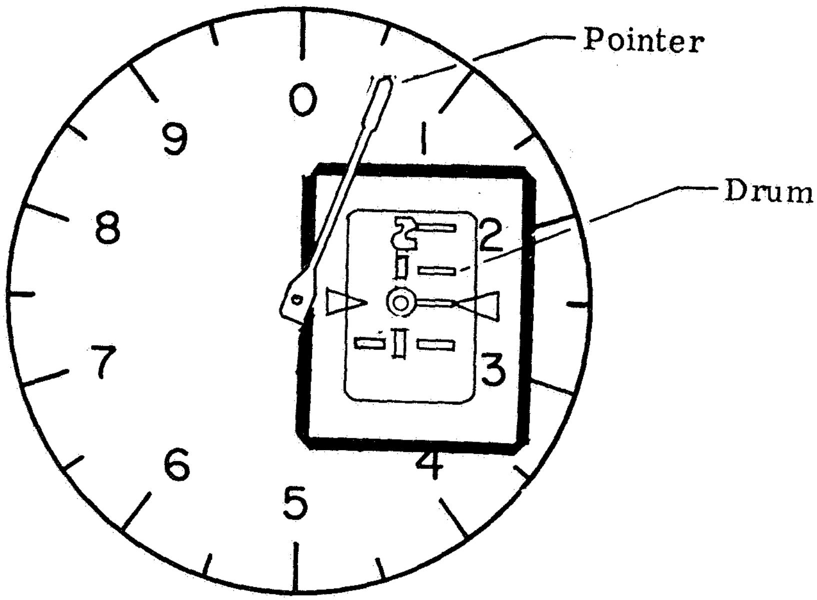

Figure 3.- Drum pointer altimeter showing drum window area used for analysis.

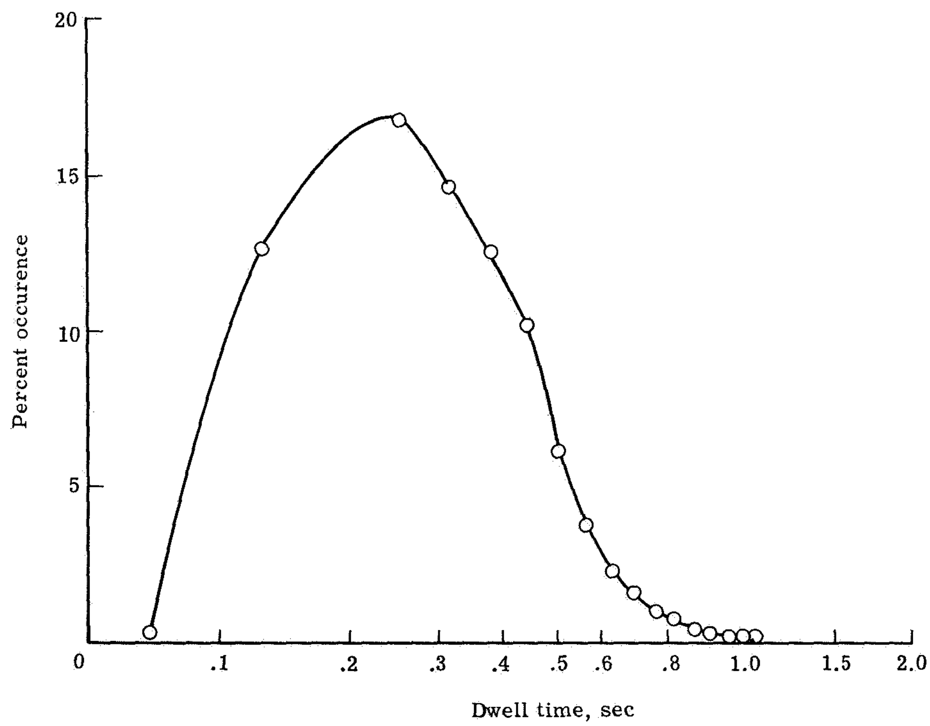

Figure 4.- Dwell time for total altimeter.

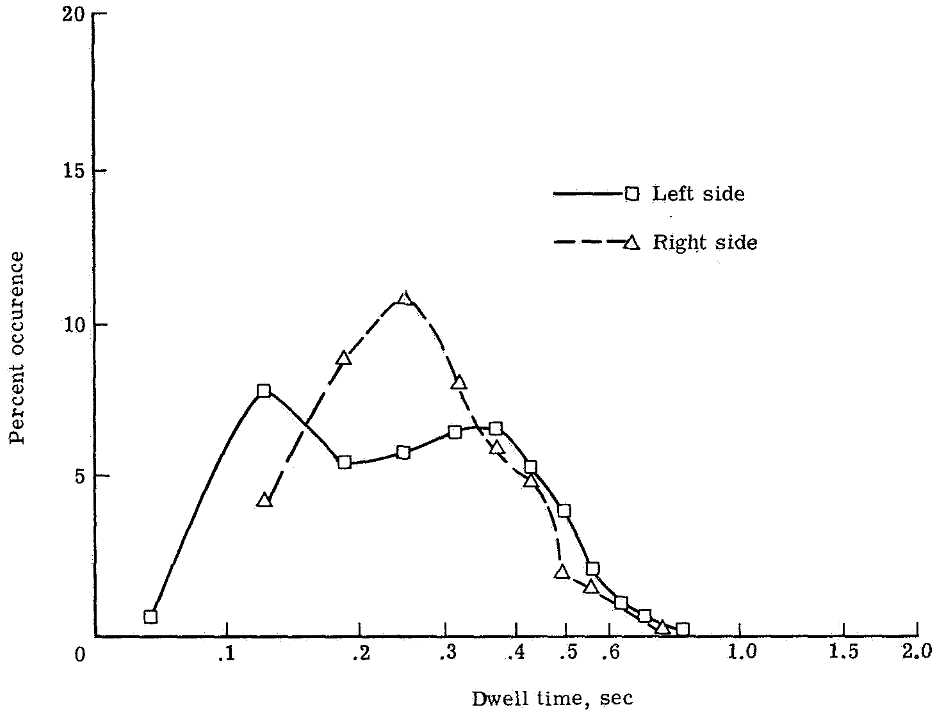

Figure 5.- Dwell time for right and left side of altimeter.

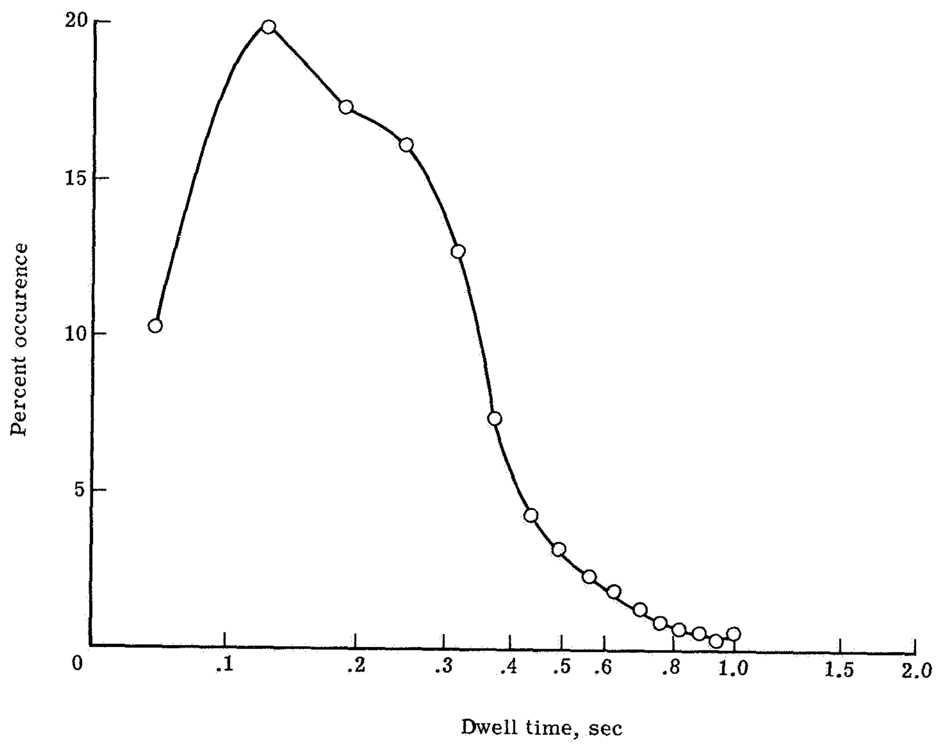

Figure 6.- Dwell time for altimeter drum area.

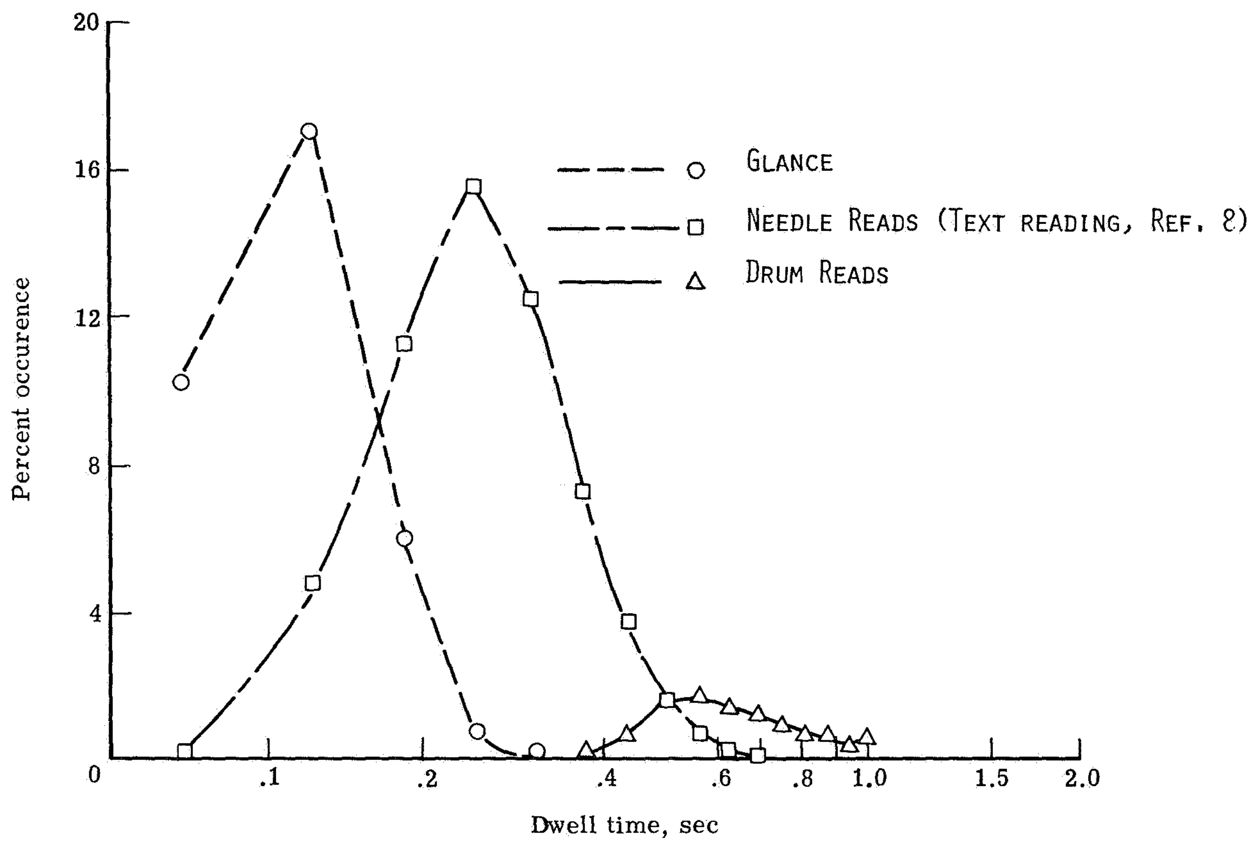

Figure 7.- Dwell time histogram of altimeter drum area showing distributions of looks.