PRELIMINARY REPORT ON AIRLINE PILOT SCAN PATTERNS DURING SIMULATED ILS APPROACHES

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SUMMARY

A series of ILS approaches using seven airline-rated Boeing 737 pilots in an FAA qualified simulator have been conducted. The test matrix included both manual and coupled approaches with and without atmospheric turbulence in Category II weather. A nonintrusive oculometer system was used to track the pilot's eye-point-of-regard throughout the approach. The results indicate that, in general, the pilots use a different scan technique for the manual and coupled conditions; however, the introduction of atmospheric turbulence does not greatly affect the scan behavior in either case. A comparison is made between the objective measures of the instrument scan (oculometer data) and the pilots' opinions of their instrument use. The data show a high degree of consistency among pilots for both the quantitative data and the qualitative data (pilots' opinions). However, there is a slightly lower agreement between the quantitative and qualitative measures.

INTRODUCTION

The scanning patterns used by pilots during various phases of flight have been of extreme interest for a number of years. A number of techniques have been developed to measure subject lookpoint; however, each has either intruded on the pilot or been difficult to correlate with the state of the aircraft. For this study a nonintrusive real-time oculometer system, which allows the subject 0.03 m^3 (a cubic foot) of head motion, was used.

The purpose of this study was twofold. The first objective was the measurement of the pilots' scan patterns to provide a better understanding of how airline pilots use the existing flight instruments and to provide a data base for ILS approaches against which advanced flight displays can be compared. The second objective was to determine to what degree pilots can describe their behavior and to compare these descriptions with the quantitative data of eye-movement recordings.

The study used airline pilots flying a FAA certified Boeing 737 flight simulator at Winston-Salem, North Carolina. Both manual and coupled (automatic without auto throttle) ILS approaches from approximately 13 km (8 miles) out to a 30 m (100 ft) decision height were investigated. The data obtained give information on the pilots' scan patterns while monitoring the automatic controls and while manually flying the aircraft during which control input decisions must be made to carry out the ILS approach. Control inputs and aircraft parameters were recorded to obtain the strategy of the individual pilots during the two modes of operation, but these data have not been analyzed.

ABBREVIATIONS

ADF	automatic direction finder (also called RMI (radio magnetic indicator))
AS	airspeed indicator
BA	barometric altimeter
FAA	Federal Aviation Administration
FD	flight director (also called ADI (attitude direction indicator with command bars))
HSI	horizontal situation indicator (also called CI (course indicator))
ILS	instrument landing system
RA	radar altimeter
SEG()	flight segment as defined in figure 5
T	in oculometer tracking region
n/T	out of oculometer tracking region
VSI	vertical speed indicator

EQUIPMENT

The Boeing 737 simulator used is a FAA certified initial and recurrent training facility operated by Piedmont Airlines. The only changes to the system were the incorporation of the oculometer optical head which was mounted below the ADF behind the instrument panel (fig. 1) and the addition of TV cameras behind the pilot (fig. 2) to monitor the instrument panel and a TV monitor located behind the pilot's seat to allow the test conductor to monitor the pilot lookpoints during the tests.

A modified Honeywell Mark 3 oculometer was used for the study. The oculometer has two primary subsystems: the electro-optical head and the signal processing unit. The electro-optical system 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 by 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. 3). It also sees a small bright spot due to reflection at 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, for instance, an instrument panel. The output of the signal processor is a set of calibrated digital or analog signals representing the subject's lookpoint coordinates and pupil diameter. The modification to the system consists primarily in a redesign of the electro-optical head resulting in a unit one-fourth the original size and simplification of the operating system.

Several constants were set in the aircraft program as follows: (1) the simulated aircraft weight was 42 640 kg (94 000 lbm) throughout all approaches; (2) the visual scene was set for Category II conditions (30 m (100 ft) ceiling, 366 m (1200 ft) runway visual range); (3) there were zero wind conditions; (4) turbulence when used was the maximum available on the simulator (pilots rated this turbulence as moderate); (5) at no time were emergency conditions imposed on the pilots. It should be noted that the airplane was not equipped with autothrottle; therefore, in the coupled mode the pilot was required to control airspeed.

Thirty-two channels of data were recorded. The data included oculometer information, aircraft state variables, pilot inputs, and simulator motion inputs. The data were recorded at a rate of 32 times a second and are in a format that can be handled by a Control Data Corporation 6600 computer.

The oculometer was capable of tracking lookpoints within the envelope shown in figure 1. The engine management percent times are estimated by determining the time the subject spent looking to the right of the area covered by the oculometer since the primary reason for looking to the center console is engine management.

PROCEDURES AND SUBJECTS

The test conditions, as given in the following table, were designed to investigate the pilot's scan during operations as a monitor in the coupled approaches and as a controller in the manually controlled approaches.

Condition	Approach	Turbulence	Category
1	Manual	No	II
2	Coupled	No	II
3	Manual	Yes	II
4	Coupled	Yes	II

The test conditions also included the effect of atmospheric turbulence on the scanning behavior for both modes of operation. Approximately four runs for each condition were flown by each of the seven pilots. The order of runs was randomized based on a random number table. All tests were conducted in simulated Category II weather. The airport simulated was Smith-Reynolds at Winston-Salem, North Carolina. A Vital II out-of-the-window system was used to provide the pilots the visual information needed to land.

All test runs were started at 19 km (12 miles) from runway threshold (fig. 4). 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 until touchdown or until the run had been 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 for a scheduled airline. Prior to starting the test program each pilot was given a briefing on the operation of the oculometer, as it was the only thing different in the cockpit. Also, 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. At the end of the test period, the pilots were asked to fill out a questionnaire concerning how they felt they had used the instruments.

All tests were conducted using the same instructor pilot as a copilot. The copilot functioned in the same manner as he would in a normal approach and provided all required callouts.

RESULTS AND DISCUSSIONS

The scanning patterns of pilots are expected to differ between pilots, and even from run to run for the same pilot; however, there should be a consistency in terms of the primary information scanned for a particular type of run. In order to establish this consistency, this report will deal only with the summary data obtained from three runs for each condition by all seven pilots. Data on aircraft state variables, pilot inputs, etc. are not dealt with, as additional work is needed in order to correlate the information.

Observation of the pilot scan patterns during the test indicated that the pilots used the center of the flight director as the primary lookpoint and moved from there to an instrument and then came back to the center of the flight director. Only rarely did a pilot check more than one instrument before returning to the center of the flight director. This is demonstrated in figure 5 which is a time history of one pilot's scan from approximately 213 m (700 ft) altitude down to 30 m (100 ft) altitude. Figure 5(a) shows the manual case (with no turbulence), and figure 5(b) shows the coupled case with no turbulence. The ordinate indicates the instruments at which the pilot was looking, with the flight director being broken in to its information blocks as indicated in figure 6. The abscissa indicates flight time in seconds. The sections T and n/T indicate eye tracking (upper level) and not tracking (lower level). As can be seen from the time histories the pilot changes fixations more rapidly and looks at more instruments in the coupled mode as compared with the manual mode. The majority of the out-of-track time was caused by the pilot looking at the center console engine instruments.

The bar graphs presented in figure 7 show a comparison of the percent time spent (dwell fraction) on the instruments for both the manual and coupled modes with no atmospheric turbulence. Each grouping contains the summary data (S) over the entire run and the data for each flight segment (1 to 4) defined in figure 4. The crosshatched section defines the mean percent time spent on the instrument while the open section on top defines the standard deviation. The clock, radar altimeter, and ADF are not included in this figure as they are basically not used by the pilot. Of particular interest is the comparison of percent time spent in the flight director (approximately 73 percent for the manual mode as compared with 50 percent for the coupled mode, as indicated by the crosshatched area). Therefore, for all the other instruments the percent time is down in the manual mode compared with the coupled mode. The segmented data indicate small deviations in percent time but, in general, they do not grossly deviate from the summary data. The purpose for including it here is to indicate the type of analysis or data breakdown which is possible but an extensive look at the segment data is beyond the scope of this report. The scan rate (the number of instruments fixated on per second) also reflects this. For the manual mode, it is 1.2 per second and for the coupled mode, it is up to 1.7 per second.

The area covered by the oculometer (fig. 1) did not include the center console, where the engine and fuel management instruments are located. A check of the TV film made of the subjects' eyes indicated that they spent up to 5 percent of their time in the manual mode and up to 10 percent of their time in the coupled mode checking either fuel flow or engine pressure ratio.

A comparison of the summary of percent time spent on instruments for the manual mode with no atmospheric turbulence and with turbulence is given in figure 8. A slight increase of about 3 percent in flight director percent time is noted in the summary bar with turbulence; however, changes in the other instruments, while present, are small. Additional data analysis is needed to determine the significance of the effect of turbulence on scan. The introduction of turbulence caused a slight increase in scan rate from 1.2 to 1.4 fixations per second.

The effect of turbulence in the coupled mode is shown in figure 9. In this case additional time is spent in both the flight director and the airspeed indicator with slight decreases for the BA, HSI, and VSI. However, all the changes are small. The average scan rate increased slightly as a function of turbulence from 1.7 to 1.9 fixations per second.

The standard deviations shown by the open bars above the means in figures 5 to 7 are small, particularly for the FD and AS (which account for most of the percent time on instruments), indicating that the pilots are consistent in terms of the use of these instruments.

The mean dwell time and standard deviation of mean dwell time in seconds for the manual and coupled approaches for conditions with no turbulence are given in figure 10. Of interest is the reduction in dwell time for the FD from approximately 1.6 sec in manual mode to approximately 0.8 sec in the coupled mode. However, the mean dwell time for the other instruments increased slightly in the coupled case. The standard deviations of mean dwell are large compared with the mean dwell. Additional analysis is needed to determine the dwell time distributions and correlate them to actual conditions of the aircraft and techniques of control used by the individual pilots.

The flight director was broken down into information areas as indicated in figure 6. The percent time spent in the flight director areas for the manual and coupled cases with no turbulence is presented in figure 11. It should be noted that these values are percentages of the time spent in the flight director, as indicated in figure 7, and not of total flight time. Basically, the data indicate (fig. 11) that the pilots spent a smaller percentage of their time in the center of the flight director in the coupled mode than they did in the manual mode. The rest of the time is distributed fairly evenly among the other areas for both modes, with the exception of the roll indicator. The majority of the pilots did not look at the roll indicator area at all. In this airplane the speed bug of the FD is not operative; however, the airspeed indicator (located to the left of the FD) is a bug instrument. Additional studies are needed to verify a hypothesis that the pilots are gleaning information from the airspeed indicator peripherally while still in the speed bug area. The scan rate within the flight director for the manual approach was 1.9 fixations per second as compared with 2.9 fixations per second for the coupled approach.

It is evident from the oculometer data that in terms of the percent time on instrument data (figs. 7 to 9) the ranking of instruments (the most to least percent time) changes relatively little either between pilots or between conditions. The oculometer data indicated that the FD, AS, and HSI ranked 1, 2, and 3, respectively; the VSI and BA were approximately equal for 4 and 5 rank; and the ADF and RA (not shown) ranked 6 and 7, respectively. A review of the pilot questionnaire indicated that while the pilots basically agreed with each other, their rankings did not agree with the oculometer data for the HSI, which the pilots generally ranked fifth, and for the BA, which is ranked third. It is presumed that the pilots reported those things which concerned them most and not necessarily their actual behavior. Therefore, ranking instruments strictly according to percent time spent (as measured by the oculometer) may, in fact, not reflect actual instrument priorities.

A great deal of additional analysis of the data is needed to develop a basic understanding of the strategy used in controlling or monitoring an ILS approach.

CONCLUSIONS

The results obtained from the study provide a data base on how pilots scan the existing flight instrument during simulated Category II ILS approaches. A preliminary look at the data indicates that:

1. Pilot mean percent time on the various instruments remained relatively constant throughout the approach to 30 m (100 ft).

2. The standard deviation of the percent time on instruments was relatively low.

3. Pilots spend less time in the flight director during the coupled approach than during the manual approach. Most of the difference was used on airspeed.

4. Pilots percent time on instruments varied little with the introduction of turbulence.

5. Mean dwell time on the flight director for the coupled mode was half that for the manual mode.

6. Standard deviations of dwell time are large compared with mean dwell time.

7. Pilots were consistent in ranking the instruments in terms of most to least used. However, the ranking obtained from the oculometer data in terms of percent time on instruments did not agree with pilot opinion with regard to the horizontal situation indicator and barometric altimeter.

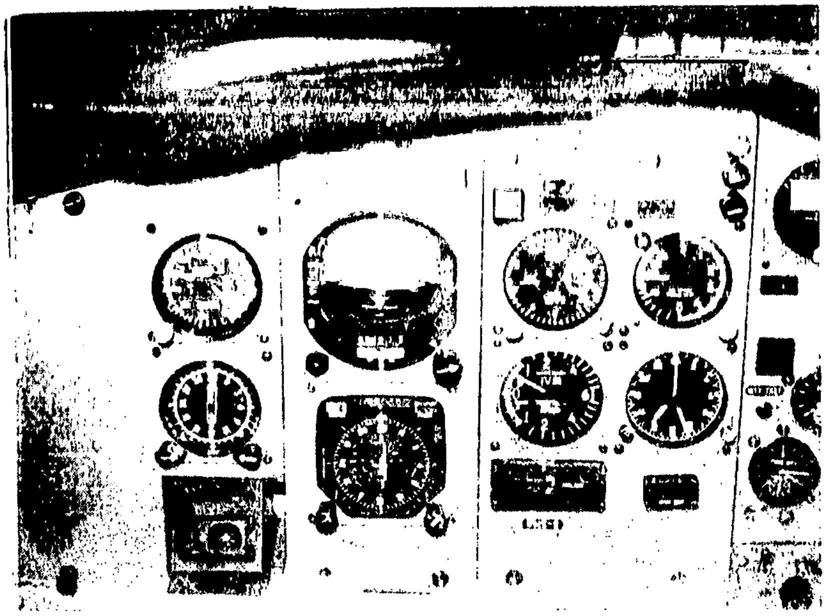


Figure 1.- Instrument panel with oculometer optical head in place.

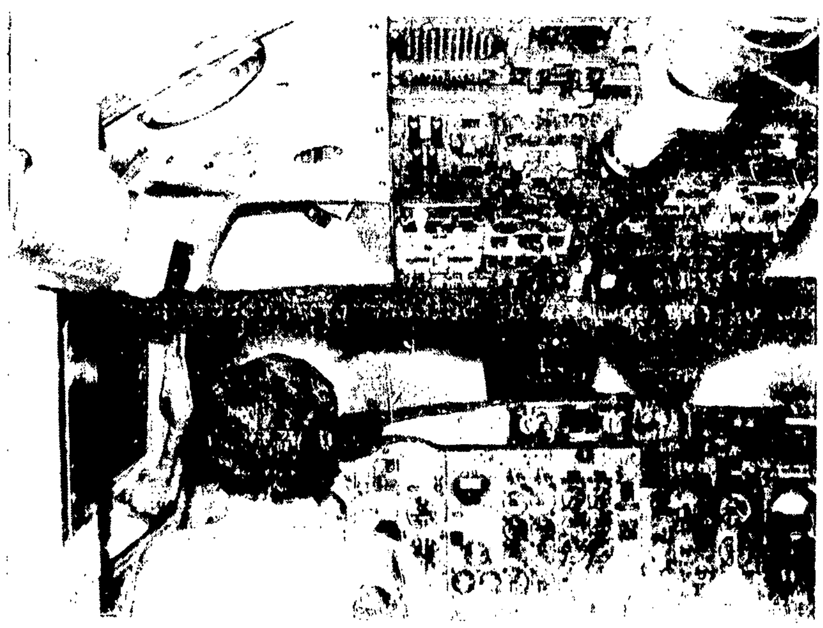


Figure 2.- Camera used to monitor pilot, instrument panel, and copilot

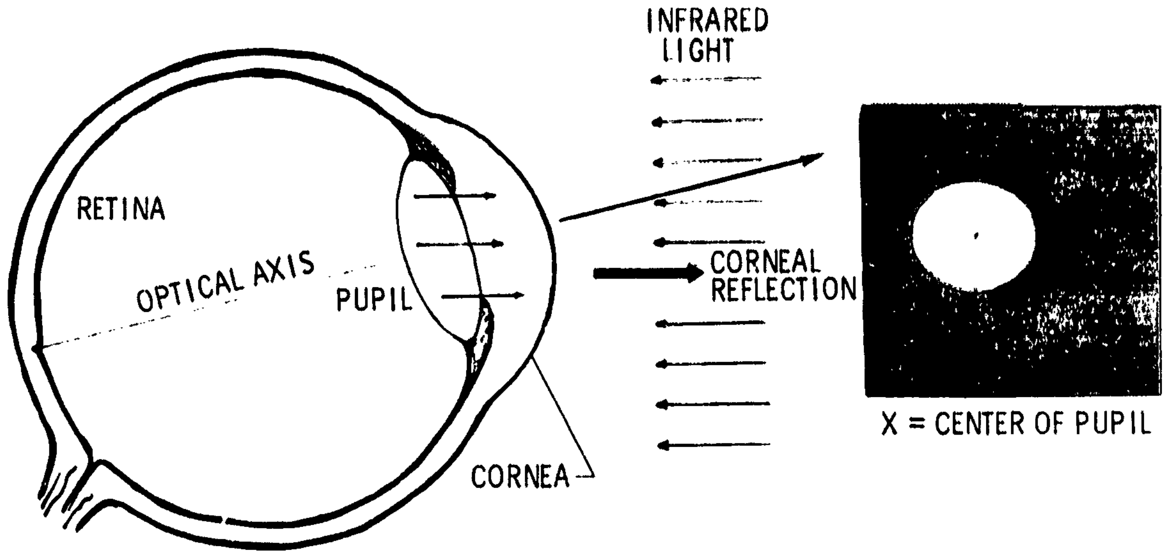


Figure 3.- Basic sensing principle.

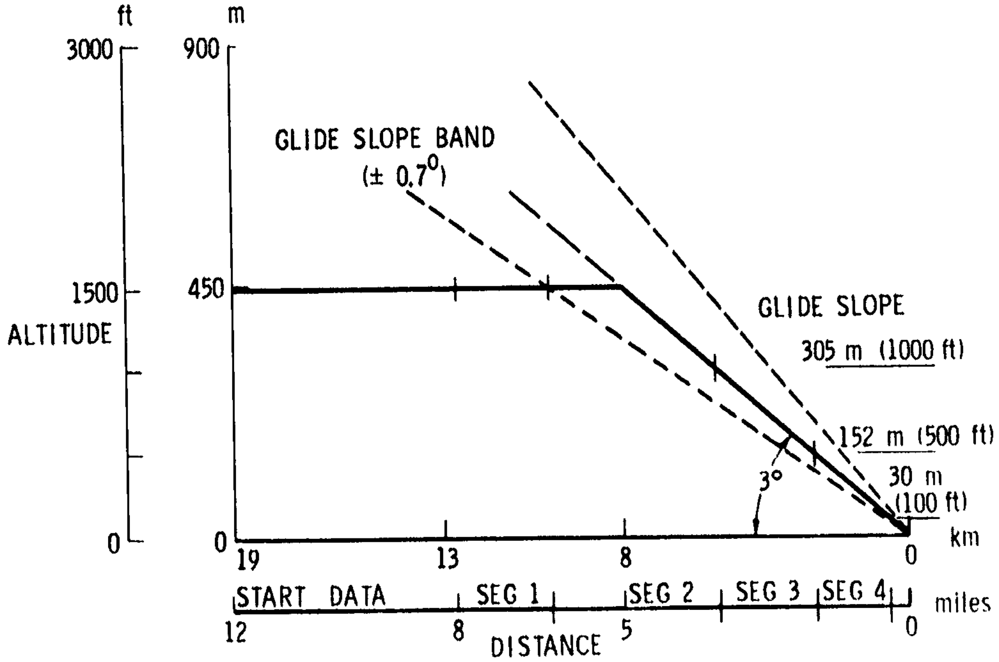
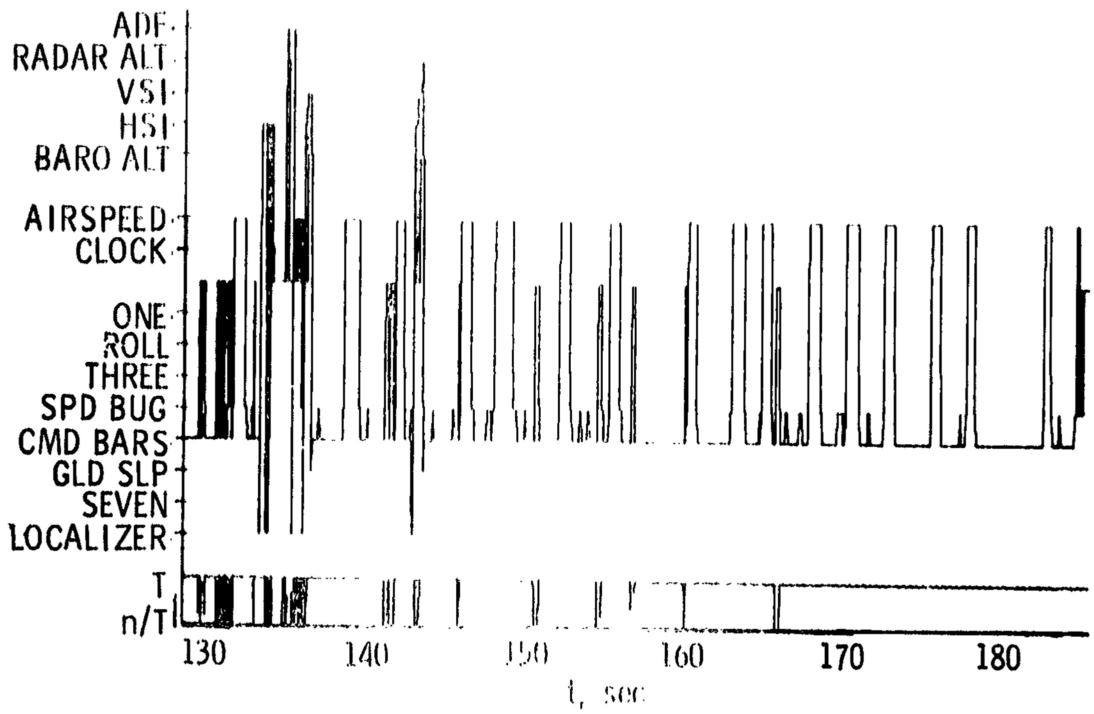
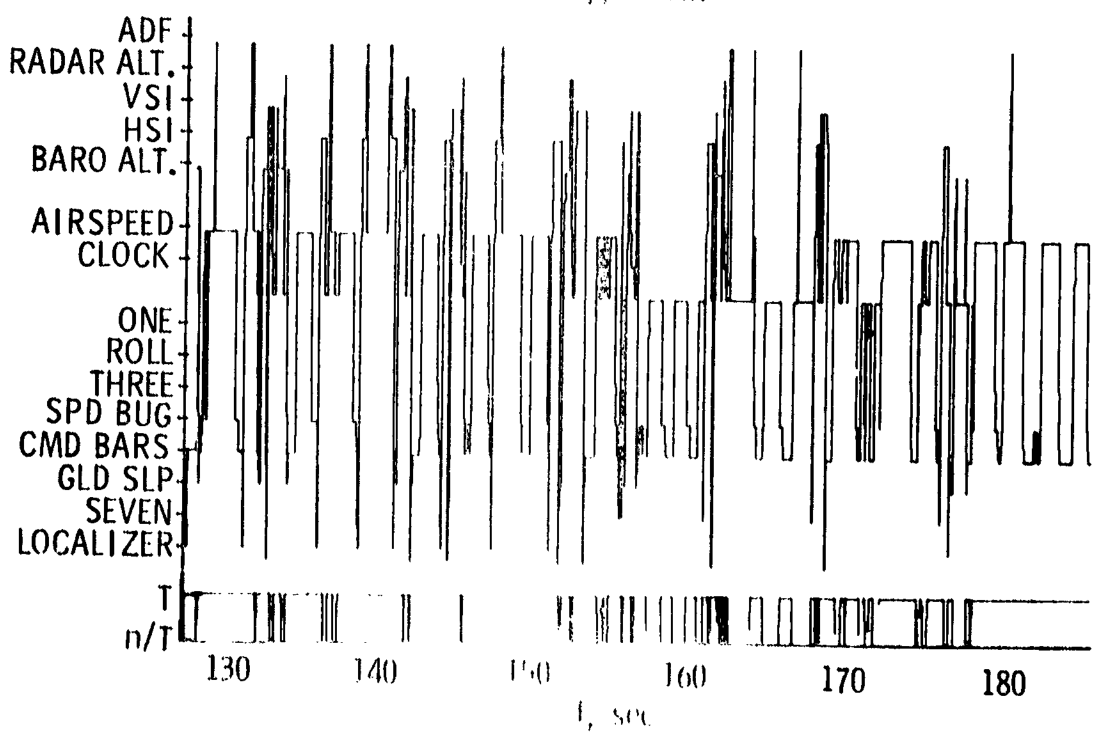


Figure 4.- Flight profile.



(a) Manual approach.



(b) Coupled approach.

Figure 5.- Time histories of one pilot's scan. 213 m (700 ft) to minimum decision altitude of 30 m (100 ft) above ground level.

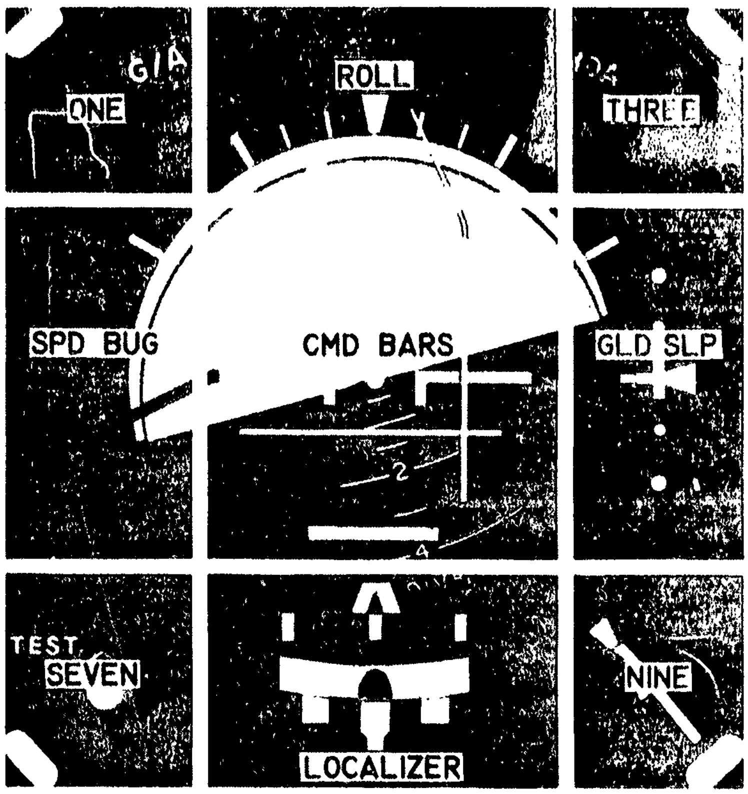
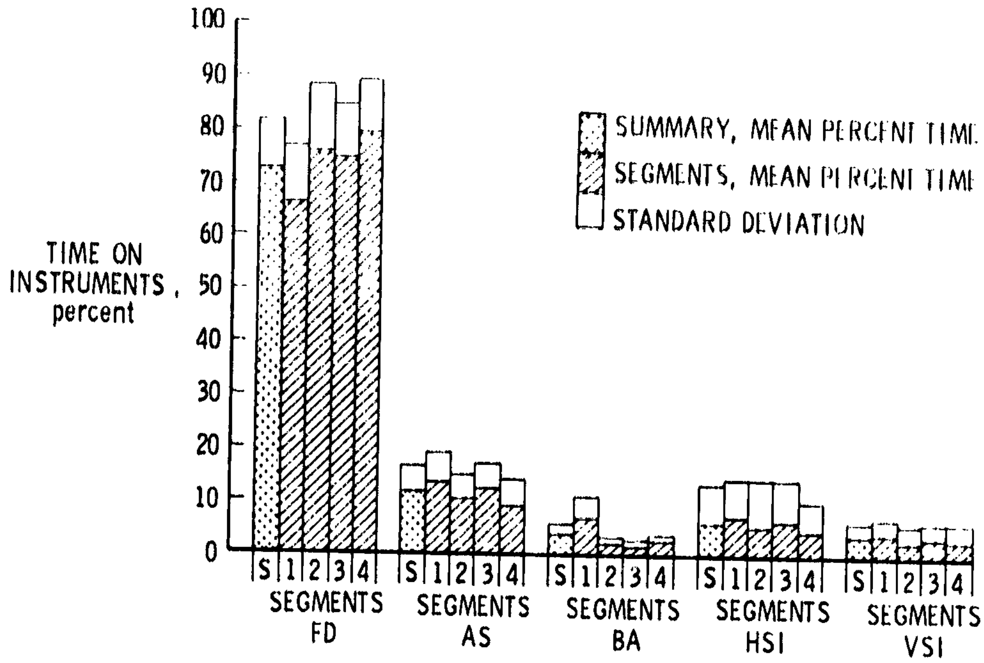
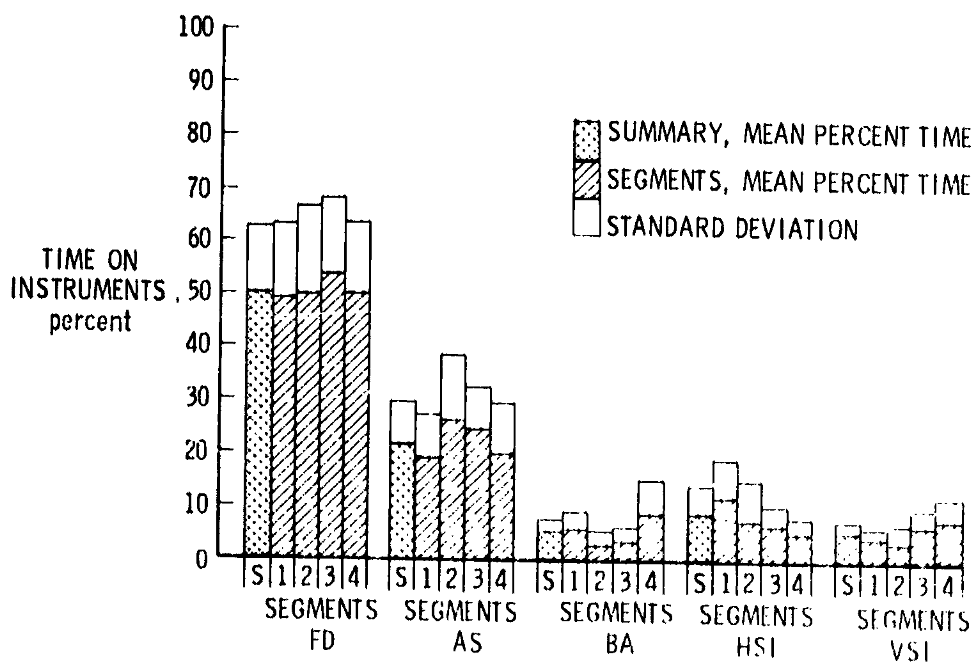


Figure 6.- Flight director breakdown.



(a) Manual approaches.



(b) Coupled approaches.

Figure 7.- Percent time on individual instruments (7 pilots, 3 runs each).

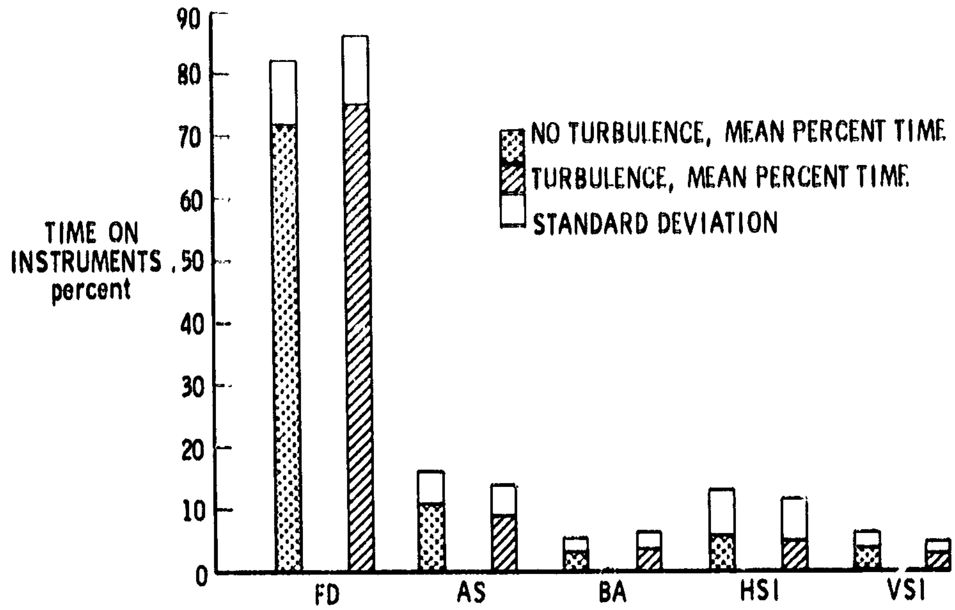


Figure 8.- Percent time on individual instruments for manual ILS approaches with and without turbulence (7 pilots, 3 runs each).

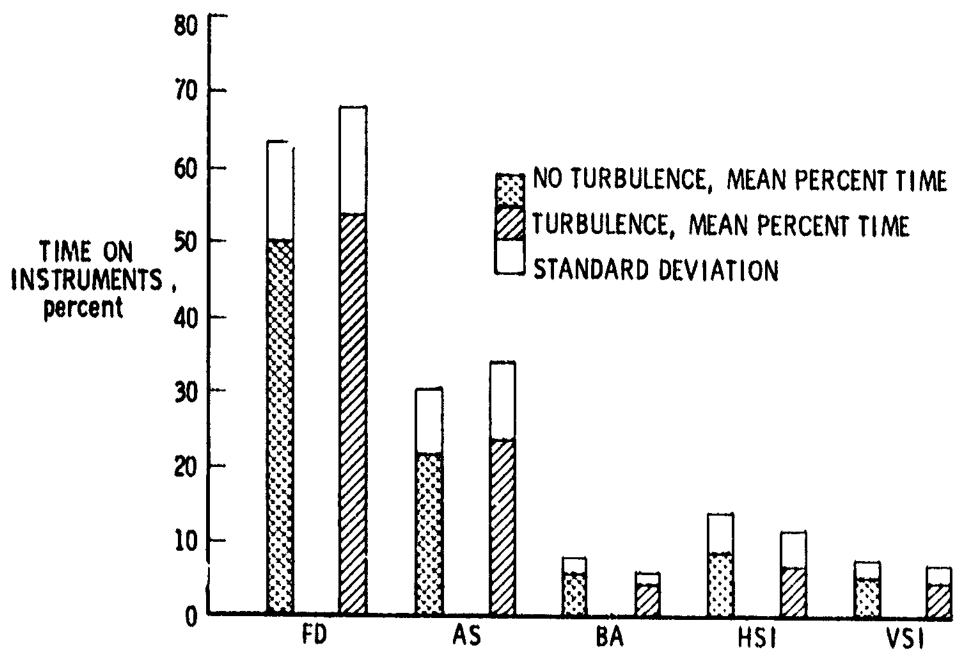


Figure 9.- Percent time on individual instruments for coupled ILS approaches with and without turbulence (7 pilots, 3 runs each).

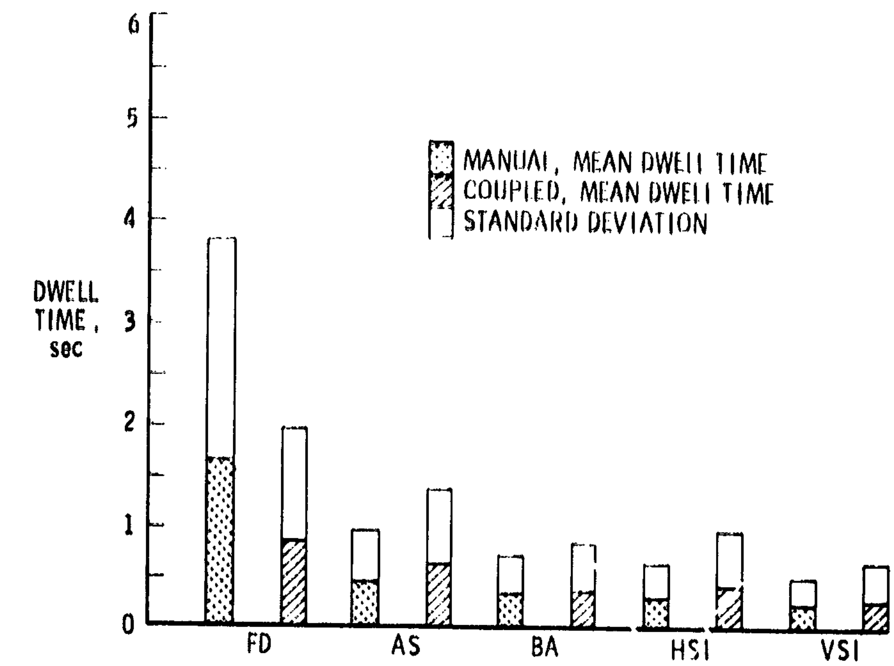


Figure 10.- Dwell time on individual instruments for manual and coupled ILS approaches (7 pilots, 3 runs each).

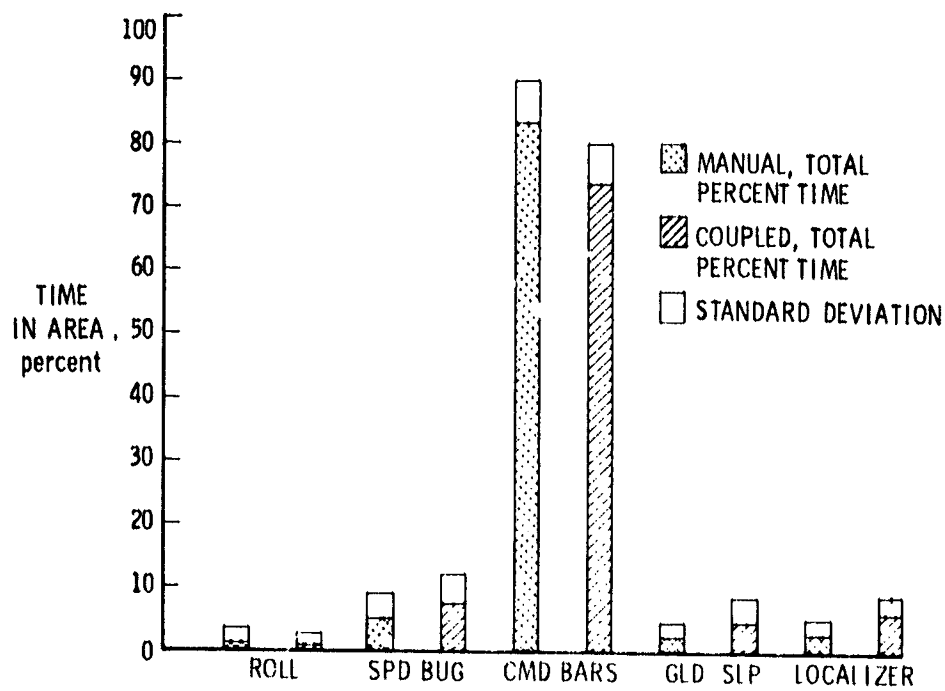


Figure 11.- Percent time on flight director areas (7 pilots, 3 runs each).