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Airline Pilot Scan Patterns During Simulated ILS Approaches

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SUMMARY

A series of instrument landing system (ILS) approaches have been conducted using seven airline-rated Boeing 737 pilots in a Federal Aviation Administration (FAA) qualified simulator. The test matrix included both manual and coupled approaches with and without atmospheric turbulence in Category II visibility conditions. A nonintrusive oculometer system was used to track the pilot eye-point-of-regard throughout the approach. The results indicate that, in general, the pilots use different scan techniques for the manual and coupled conditions and that the introduction of atmospheric turbulence does not greatly affect the scan behavior in either case.

A comparison between objective measures of the instrument scan (oculometer data) and subjective pilot opinion, ranking their use of each instrument, has been included. The pilots consistently ranked the instruments in terms of most used to least used. The ranking obtained from the oculometer data agrees with the pilot ranking for the flight director and airspeed, the most important instruments. However, the pilots apparently ranked the other instruments in terms of their concern for information rather than according to their actual scanning behavior.

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 the pilot's lookpoint; however, each has either intruded on the pilot or has been difficult to correlate with the state of the airplane (refs. 1 to 5). This study used a non-intrusive real-time oculometer system, which allows the subject a cubic foot of head motion. Appendix A, by Marion A. Wise and James D. Holt, explains the system, a Mark III oculometer developed for NASA by Honeywell Radiation Center of Lexington, Massachusetts.

The purpose of this study is twofold. First, the airline pilots' scan patterns were measured to establish an oculometer data base for instrument approaches against which advanced flight displays can be compared. The information thus obtained provides a better understanding of how the pilots use the existing flight instruments. Second, the pilots' qualitative ranking of instrument use was compared with the quantitative scan data from eye movement recordings.

The study used airline pilots flying Piedmont Airlines' FAA certified Boeing 737 flight simulator at Winston-Salem, North Carolina. Each flight test started 13 km (8 miles) from runway threshold and continued to 30-m (100-ft) decision height. All approaches were conducted in simulated Category II conditions (ref. 6). The conditions included both manual and coupled (automatic with manual throttle) approaches for both moderate and no atmospheric turbulence.

The information presented in this paper is similar to that presented in previous scan pattern reports (for example, refs. 1 to 5). It includes percent time on instruments, dwell time, and link value as a function of conditions. The control inputs by the pilots were recorded, but these data have not been analyzed for this report.

The information obtained in this study indicates how the pilots scan the existing instrument panel. It also shows how control mode (manual or coupled) and atmospheric turbulence affect the pilots' scanning behavior. Such information helps provide the necessary base for the design and evaluation of advanced display systems for future aircraft.

ABBREVIATIONS

ADF automatic direction finder (also called radio magnetic indicator (RMI))

AGL above ground level

AS Mach/airspeed indicator

BA barometric altimeter

CMD command

FAA Federal Aviation Administration

FD flight director (attitude direction indicator with command bars)

FM frequency modulation

GSI glide-slope indicator

HSI horizontal situation indicator (also called CI (course indicator))

ILS	instrument landing system
RA	radar altimeter
RVR	runway visual range
T/nT	track/no track
Seg	flight segment as defined in figure 5
TV	television
VSI	vertical speed indicator

EQUIPMENT

The Boeing 737 simulator used was an FAA certified initial and recurrent training facility operated by a scheduled United States airline. An outside view of the simulator is shown in figure 1. The only changes to the cockpit were the installation of the oculometer optical head, a TV camera, and a monitor. The optical head was mounted behind the instrument panel and looked at the pilot's eye through an opening located below the ADF (fig. 2). The TV camera was located above and behind the pilot's right shoulder (fig. 3) so that a real-time picture of the instrument panel could be obtained. The TV monitor was located behind the pilot's seat to allow the test conductor to monitor the pilot's lookpoints overlaid on the instrument panel picture during the tests. A complete description of the oculometer and data recording system is contained in appendix A.

The oculometer tracked the pilot's lookpoint within the boundaries indicated in figure 2 with an overall accuracy of approximately 0.5° of visual angle. This accuracy allowed the flight director to be divided into information areas as indicated in figure 4 for data reduction purposes. The time spent in the area of the center console not covered by the oculometer (to the right of the captain's flight panel, fig. 2) was estimated by reviewing video tapes and recording the times the pilot looked in that area. Looking at the eye picture allows the viewer to determine whether the pilot was monitoring the engine instruments or whether he had turned his head to look at the copilot or other areas of the cockpit.

PROCEDURES AND SUBJECTS

The test matrix was designed to investigate the pilot's scan during operations as a monitor in the coupled approaches (auto pilot and manually controlled throttle) and as a controller in the manually controlled approaches. The manual mode requires that the pilot actively control the airplane at all times. In the coupled mode the pilot monitors the airplane while it is controlled by the auto pilot, except for airspeed which the pilot controls with the throttle (Piedmont Airline airplanes do not have auto throttle). At minimum decision height or when the pilot has the runway in sight, he switches out the auto pilot and manually lands the airplane. The test matrix included the effect of atmospheric turbulence on the scanning behavior for both modes of operation. The four test conditions are given in table I. At least three runs for each condition were flown by each of the pilots. The order of runs was randomized based on a random number table. All tests were conducted in simulated Category II conditions (ref. 6).

The airport simulated was Smith-Reynolds at Winston-Salem, North Carolina. A Vital II out-the-window system (a computer generated night-time scene) was used to provide the pilots with the proper visual information at decision height.

All approaches were started 19 km (12 miles) from runway threshold (fig. 5). The investigators used the first 6 km (4 miles) to check the oculometer calibration while the pilot stabilized the airplane on the correct flight path. Data recording (test run) began 13 km (8 miles) from runway threshold.

Several constants were built into the airplane program: (1) the airplane weight was held at 21 000 N (94 000 lb) throughout all approaches; (2) the visual scene was set for Category II conditions (30-m (100-ft) ceiling, 365-m (1200-ft) RVR); (3) wind conditions were zero; (4) when used, turbulence level was set at the maximum available on the simulator (pilots rated it as moderate); (5) at no time were emergency conditions imposed on the pilots; and (6) the initial airspeed at 13 km (8 miles) was approximately 150 knots with gear up and flaps at 15°. The final approach speed was 128 knots with gear down and flaps at 40°.

All airline pilots used in the program were currently qualified Boeing 737 pilots who flew for a scheduled airline. Before the pilots started the test program, they were briefed on the operation of the oculometer. The pilots were also asked to assume that they were flying an airplane full of passengers; therefore, if they would normally elect to go-around, they should do so. At the end of the test period, the pilots filled out a questionnaire concerning how they felt they had used the major flight instruments (fig. 2), controls used, and so forth. A copy of the questionnaire is contained in appendix B.

The same instructor pilot acted as copilot for all tests. The copilot functioned as he would in a normal approach and provided all required call-outs.

RESULTS AND DISCUSSION

Performance

The scanning behavior was expected to differ between pilots and even slightly 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 includes only summary data obtained from three runs for each condition by all seven pilots. The pilots usually made four runs, and the first three were used. Because of equipment problems, either simulator or oculometer, or the pilot's decision to execute a go-around, the fourth run was used in several cases.

The pilots flew all of their approaches within acceptable boundaries of glide-slope, localizer, and airspeed error. An indication of the errors involved in airplane position relative to the ILS beam position for the glide slope for all four test conditions is given in figure 6. The figure presents the mean glide-slope error and average standard deviation of glide-slope error for all seven pilots for three runs each for three segments of the approach. The segment labeled 2.5 includes only the section from the ideal glide-slope intercept down to 305-m (1000-ft) glide-slope altitude. Segments 3 and 4 are the same as those indicated in figure 5. The mean and standard deviations of each condition were taken, including each data point, and were computed for three runs each for all seven pilots at each condition. The resulting data for each pilot were then averaged with the data for other pilots to obtain the data used in figure 6. The mean and standard deviation of airplane position in relation to the localizer beam is presented in figure 7. The data were derived in the same manner as for figure 6 and are presented in the same format.

The final approach airspeed was set at 128 knots as indicated earlier. The average airspeed flown by five of the pilots is presented in figure 8 for all four test conditions. (The airspeed data for two of the pilots were lost during the recording process.) As can be seen in figure 8, the pilots during segments 3 and 4 held the airspeed close to 128 knots with the exception of the manual turbulence case where the average airspeed was 132 knots. This increase is expected because the pilots indicated that they added 5 knots to the nominal approach speed as a function of the turbulence.

Scan Time Histories

Observation of the pilot scan patterns during these tests indicated that, as reported for tests in reference 4, the pilots used the center of the FD[1] as the primary lookpoint and moved their lookpoint from the FD to an instrument and then came back to the center of the FD. Only rarely did a pilot check more than one instrument before returning his attention to the center of the FD. Typical scan time histories of the same pilot for manual (fig. 9(a)) and coupled (fig. 9(b)) cases with no turbulence show this lookpoint transition from FD to other instruments and back to FD. The ordinate indicates the instruments at which the pilot was looking with the FD broken into information blocks as indicated in figure 4. The abscissa indicates flight time in seconds. The T/nT trace indicates eye tracking (upper level) and not-tracking (lower level). Most of the not-tracking time occurred when the pilot looked at the engine instruments located in the center console or when the pilot blinked (verified by checking real-time video tapes). As the time histories show, the pilot changed fixations more often (transitions) and looked at more instruments when he was flying in the coupled mode than in the manual mode.

Percent Time on Instruments

The area covered by the oculometer (fig. 2) did not include the center console where the engine and fuel management instruments were located. However, a check of the TV tape made of the subjects' eyes indicated that they spent, overall, 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. The percentage of time on instruments is based on oculometer track time, not on total run time. The oculometer track time averaged 92 percent of run time for the manual and 88 percent for the coupled mode.

The bar graphs presented in figure 10 compare the percent time spent looking at the individual instruments for both the manual and coupled modes with no atmospheric turbulence. Each grouping contains the summary data (sum) over the entire run and the data for each of the four flight segments as defined by figure 5. The crosshatched section defines the mean percent time spent on the instrument while the open section on top defines the standard deviations. The clock, RA, and ADF are not included in this figure since the clock was not used at all, the RA was used less than 2 percent of the time, and the ADF is not a flight-critical instrument for approaches of this kind. The percent time spent on the FD was approximately 73 percent for the manual mode in comparison with 52 percent for the coupled mode. For all the other instruments, however, the percent time was down in the manual mode in comparison with the coupled mode. The reduced

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[1]This instrument is also called an attitude direction indicator (ADI). However, it is labeled and defined as a flight director (FD) in the Boeing 737 operations manual (ref. 7); therefore, that term is used in this report.

percent time spent on the FD in the coupled mode gave the pilot more time to look at the other instruments. The scan rate (the number of instruments fixated on per second) increased from 1.2 per second for the manual mode to 1.7 per second for the coupled mode.

A comparison of the percent time spent on instruments for the manual mode with and without atmospheric turbulence is given in figure 11. A slight increase (3 percent) in FD percent time is noted in the summary bar with turbulence with a trade-off primarily from percent time on airspeed; changes in the other instruments, while present, were small. The introduction of turbulence caused a slight increase in scan rate from 1.2 to 1.4 fixations per second for the manual mode.

The effect of turbulence in the coupled mode is shown in figure 12. In this case, additional time was spent in both the FD and AS with slight decreases in the BA, HSI, and VSI. However, all the changes were small. The average scan rate increased slightly as a function of turbulence from 1.7 to 1.9 fixations per second.

Percent time from segment to segment varied somewhat for all conditions (figs. 10 to 12), but these variations were generally small except for the manual conditions where the pilots spend approximately 6.5 percent of their time on the BA in segment 1 and less than 2 percent for the other three segments. For the coupled condition the pilots tended to spend twice as much time in the BA for both segments 1 and 4 as for segments 2 and 3. Pilots attribute this to the maintenance of a constant altitude in segment 1 profile while in segment 4 they were approaching the ground.

The standard deviation shown in figures 10 to 12 is moderate, particularly for the FD and AS (the FD and AS account for most of the percent time on instruments) indicating that the pilots are relatively consistent in their percent time uses of these instruments.

Dwell Times

Dwell time is defined as the period of time the subject's lookpoint is continuously found to be within the boundary of one instrument. Two statistics obtained for each run were the dwell time mean and the dwell time standard deviation. The averages of these two quantities are given in figure 13 for the manual and coupled approaches with no turbulence. A reduction of dwell time mean on the FD is noted when the pilot changes from the manual mode (1.6 sec) to the coupled mode (0.8 sec). The dwell time mean for the other instruments increased slightly in the coupled case. When questioned about the change, the pilots indicated that although they had not necessarily been aware of the change, they could attribute it to the difference in strategy used. For the manual mode the pilots believed they were required "to keep a mental picture of where they are and where they are going which is best obtained from the FD." Any transitions from the FD require that they reform the image upon returning to the FD. Consequently, they kept transitions to a minimum. The same strategy was not used, however, when they were flying in the coupled mode; then the pilot stated that he is essentially verifying needle positions to assure that the automatic systems are operating correctly and, therefore, he is not required to keep this precise mental picture. An example of the dwell times for one pilot for one run (manual, no turbulence) is given in table II. The table gives the number of times the pilot looked at various instruments for time periods of differing lengths. For instance, the pilot's lookpoint stayed on the FD eight times for more than 0.26 sec but less than 0.51 sec and seven times for more than 4 sec. Data were recorded at a rate of 32 times per second; therefore, a count (one data point) equals 0.031 sec. The lower limit of 0.26 sec includes eight counts (0.25 sec) while nine counts (0.28 sec) fall in the 0.26 to 0.51 time period. Table II also contains the same information for a coupled approach (no turbulence) for the same pilot.

The dwell time standard deviations have approximately the same value as the dwell time means (fig. 13). These large average dwell time standard deviations are due to a nonnormal dwell time distribution within the runs (table II) and to the variability from run to run and pilot to pilot. In order to assess the relative magnitude of each factor, the following analysis was made for the two dwell time parameters (dwell time mean and dwell time standard deviation for each run) of the manual-with-no-turbulence cases. First, the mean and standard deviation of the AS, FD, and BA dwell times were calculated. Figure 14 shows the average and standard deviation of the dwell time mean for each pilot and for all pilots. The standard deviation of dwell time means for all pilots taken together is larger than that for the individual pilots. This difference should be expected because of the large variations between the dwell time means for the individual pilots. Each pilot, however, has a low standard deviation of dwell time mean, indicating that the dwell time mean varies little from run to run for a pilot. Figure 15 shows the mean and standard deviation of dwell time means averaged for all pilots for the run order. This figure shows that there is no apparent variation in the means due to learning or fatigue. Figure 16 shows the average and standard deviation of the dwell time standard deviation for each pilot and for all pilots taken together. There is a large variation of the dwell time standard deviation from pilot to pilot, especially with the flight director. However, the fairly low standard deviation of this parameter for each pilot indicates a consistency of the dwell time standard deviation for each pilot. Figure 17 shows the average and standard deviation of the dwell time standard deviation for all pilots in each repetition. Basically, no changes are present in this parameter with the repetitions that would indicate a learning or fatigue effect on the dwell time standard deviation. Therefore, it appears that the main contributor to the large dwell time standard deviation is the type of dwell distribution within each run for each pilot.

The effect of turbulence on dwell time in the manual mode is shown in figure 18. Note that the summary bars for the FD are about the same for both conditions; however, there is less variation in the segments for the turbulence case than for the no-turbulence case. Additional analysis of these conditions is required to determine the reason for this difference. Figure 19 shows the effect of turbulence for the coupled mode. Little difference is noted in dwell time mean between the two conditions.

Link Values

The average two-way link values between the instruments, the percentage of links (or transitions between instrument pairs) with respect to the total number of links between instruments, is given in table III. The table gives the values for the overall flight profile and for the four segments of the profile (fig. 5) for all four test conditions. Two-way link values are given as the pilots usually scanned from the FD to some instrument and back to the FD.

A graphical display of the summary link values is presented in figures 20 and 21. Each instrument is identified and positioned according to its location in the airplane instrument panel. The number at the top of each instrument is the value for the percent time on that particular instrument (based on total instrument time), and the numbers at the bottom are the dwell time means in seconds. The number between instruments is the percent of total transitions made between the respective instruments. Figures 20(a) and 20(b) are for the manual and coupled approaches with no turbulence. Figures 21(a) and 21(b) are for the manual and coupled approaches with turbulence. For comparison purposes, figure 22 shows the link values taken from reference 4 which were obtained for four pilots flying a manual ILS approach in a DC-8 simulator from the outer marker 9.2 km (5.7 miles) to the middle marker 760.0 m (2500 ft) from threshold in the presence of vertical gust and glide-slope bends. These conditions compare closest to the manual-with-turbulence case flown in the current tests. In fact, the percent time spent on the FD, BA, and VSI compares closely with a trade-off in percent time between the AS and HSI. However, the link values do not show close agreement.

Flight Director Scan

The FD was broken down into information areas as indicated in figure 4. The FD percent time in each area for the manual and coupled cases with no turbulence is presented in figure 23. These percentage values are based on the accumulated time spent looking at the FD and not the total flight time. Basically, the data indicate (fig. 23) that the pilots spent 8 percent less time in the center of the FD in the coupled mode than in the manual mode. The majority of the pilots did not look at the roll index area at all. Since all approaches were flown straight in and required no precision roll maneuvers, the roll information available in the center of the FD was probably adequate for roll control information.

Similar comparisons are given in figures 24 and 25 for the manual case and the coupled case, respectively, both with and without turbulence. In both cases, the time spent in the center of the FD decreased slightly with turbulence and was shifted to area four. (In the airplane and in the simulator, the speed bug on the FD is marked out.) It is the opinion of the pilots that they can match the pointer and speed bug in the AS indicator peripherally while still in area four of the flight director which would explain going to area four.

When the pilot acts as a system monitor, his scan rate within the FD is higher by approximately 1 fixation per second than when he is flying the airplane manually. The scan rate for the manual approach is 1.9 fixations per second compared to 2.9 fixations per second for the coupled approach with no turbulence. The introduction of turbulence caused an increase of scan rate for both conditions of 0.4 fixation per second. Thus, with turbulence the scan rate was 2.3 fixations per second for the manual approach and 3.3 fixations per second for the coupled approach.

Pilot Opinion of Instrument Use

At the conclusion of his test runs each pilot was asked to fill out a questionnaire (appendix B). Questions 1 and 2 ask the pilot to number in order (rank) the most used (#1) to least used (#7) instrument during the coupled and manual approaches for segments 1 to 4. The mean ranking given the instruments by six of the seven pilots is presented in table IV along with the standard deviation. Table IV(b) contains the ordering of the instruments from most used (#1) to least used (#7) ranked according to the percent time spent on each instrument as measured by the oculometer during each segment by the same six pilots used in table IV(a).

Tables V(a) and V(b) contain the order of instrument use (most to least) for the pilot rating and the oculometer rating, respectively, based on the mean ratings contained in tables IV(a) and IV(b). The ordering of instruments based on the pilot opinion (table V(a)) is the same for both the manual and coupled modes for all segments with two exceptions. The exceptions are that (1) in segment 4 of the coupled mode, the AS and BA share an equal rank, which is not true for the manual mode, and (2) the RA has a sixth rank in segment 2 of the manual mode with the ADF being seventh, while for the coupled mode these are reversed. The same consistency can be observed for the oculometer rankings with regard to the FD and AS but not for the remaining instrument (table V(b)). The greatest difference between the two rankings (pilot opinion and oculometer) is in terms of the BA. According to pilot opinion, the BA is ranked third. However, the oculometer data ranks the BA fourth (segments 1 and 2) and fifth (segments 3 and 4) for the manual mode. In the coupled mode the BA is ranked fourth for segment 1, sixth for segment 2, fifth for segment 3, and equal with the HSI for the third ranking in segment 4. These differences, while they exist, are associated with the instruments which take only a small part of the overall time the pilots spend looking at instruments (average 15 percent for manual and 25 percent for coupled). Also, it is unlikely that the pilots can estimate these small differences accurately because eye movements are difficult to bring under the precise control necessary to answer the questions. The rankings more likely represent a combination of those instruments which are examined a good deal (FD and AS which show good agreement) and the pilots' subjective opinion about the importance of the various kinds of information needed. For example, if the pilot is concerned with altitude, he might check that instrument early in the sequence to be sure he is on target; he may then make only a few quick checks during the course of the approach. In the meantime, he knows that if he holds the airplane on the glide slope by means of the command bars, glide slope, and other parameters, coupled with the copilot's call-outs of altitude, the altitude will remain under control. Therefore, his comments about the barometric altimeter probably represent a combination of the time he spends looking at the instrument and his concern during landing. Evidence for this interpretation is available from the pilots' comments and the data presented in reference 8.

While the ranking of the two most used instruments show one-to-one agreement, the instruments used least were ranked in terms of those things which concern the pilots most and not on the actual percent time spent on the instruments. The other questions of interest to this report are summarized on the questionnaire in appendix B.

CONCLUSIONS

The results obtained from the study provide a data base for studying how pilots scan the existing flight instruments during simulated instrument landing system (ILS) approaches with Category II visibility conditions. A preliminary look at the data indicates that:

1. The pilots' scan behavior differed for the coupled and the manual approaches. Indications of this are:

a. The pilots spend less time in the flight director during the coupled approach than during the manual approach (52 percent for the coupled condition in comparison to 73 percent for the manual condition with no turbulence).

b. The dwell time mean on the flight director for the coupled condition was approximately half that for the manual condition (0.8 sec for coupled in comparison to 1.6 sec for the manual).

c. The large dwell time standard deviations were caused primarily by the type of dwell distribution within each run.

d. The scan rate increases for the coupled in comparison to the manual condition (2.9 fixations per second for coupled in comparison to 1.9 fixations per second for manual).

2. Pilot mean percent time on the various instruments remained relatively constant for all flight segments of the approach to 30 m (100 ft) and the standard deviation of the percent time on instruments was relatively low.

3. The percent time spent on instruments varied little with the introduction of moderate turbulence, and only a slight increase in scan rate (0.2 fixation per second for both manual and coupled conditions) was found.

4. Pilots consistently ranked the instruments in terms of the most used to the least used. The ranking obtained from the oculometer agrees with the pilot ranking for the most used instruments (flight director and airspeed). However, the ranking based on percent time (oculometer data) did not give good agreement on the remaining instruments. The percent time on these instruments is low; therefore, the pilots may have ranked the instruments in terms of their concern for information rather than according to their actual scanning behavior.

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APPENDIX A

DESCRIPTION OF AIRLINE SIMULATION AND EQUIPMENT

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Introduction

The simulation facility used for this experiment was an FAA certified Boeing 737 initial and recurrent training simulator operated by a regularly scheduled United States airline. Instrumentation of the simulator and installation of the oculometer was a joint effort accomplished by the staff of the Piedmont Airlines simulator facility and the NASA Langley Research Center personnel.

Simulator Description

The Boeing 737 training simulator is equipped with instrumentation like that used on airplanes flown by a scheduled airline (fig. A1). The simulator consists of a motion-base platform which contains the instruments and controls for the captain's and first officer's stations (fig. A2) and space for the check pilot and the test conductor. Airplane motions are simulated by a system of three linear hydraulic actuators (fig. A3). On the motion-base platform, a computer-generated night-time out-of-the-window scene is presented to each pilot on duplicate color TV monitors and virtual image lens systems (fig. A4). The entire simulator system is controlled by a computer to provide both visual and motion cues.

For this experiment, two closed-circuit TV cameras in the simulator cockpit monitored the captain's instrument panel and the activities of the first officer. Silicon matrix vidicon tubes were used in these cameras to obtain good picture quality under the low ambient light conditions desired by some pilots. The instrument panel video signal was mixed with processed oculometer signals for recording, while the TV picture of the first officer was used only as an indication of his obvious activities such as reaching for controls and looking out the window or at the captain. A small TV monitor (fig. A5) with the instrument panel/oculometer picture was positioned behind the pilot for viewing by the check pilot and the test conductor. An instrumentation package (to be described) for measuring motions of the simulator was located near the pilot's station.

Oculometer

This basic oculometer system has been used in several experiments at the Langley Research Center. (See ref. 9.) The principle of operation of the oculometer is that by illuminating the eye with an infrared source, an image of the pupil and of the cornea reflection may be formed. With this method, the relative position of the eye details is sufficient to determine the angle of gaze with respect to the axis of the illumination source. A system of servoed mirrors tracks movements of the pilot's head within a 0.3-m (1-ft) space, while a remote focusing servo allows head movements in the fore and aft direction. A measure of the diameter of the pupil is a by-product of the calculations required to determine the fixation point on the instrument panel. A digital minicomputer is used for all calculations and control of the moving mirrors. The oculometer is capable of tracking in a $\pm 30^{\circ}$ horizontal and 30° to -10° vertical eye angle with respect to the tracking mirror position.

For this experiment, a recently developed reduced-size electro-optical sensing unit (E-O head) was used (figs. A6 and A7). The small E-O head permitted locating it in an unused area of the instrument panel in order not to obstruct the pilot's view of the cockpit controls and the instruments, nor to require the pilot to restrict his head movements. Amplifiers for the servoed mirrors were located inside the hollow nose section of the simulator. Locating these amplifiers near the mirror servos was necessary to retain the high-frequency response necessary to track pilot head movements and to ensure positive reacquisition of the eye signal after loss of track due to blinks or large head movements.

The oculometer minicomputer and its interface and video equipment were housed in a relay rack near the simulator motion base (fig. A8). The oculometer interface equipment consists of two printed circuit boards housed in the minicomputer enclosure, a digital-to-analog, analog-to-digital conversion unit, and a signal conditioning unit for the moving mirrors and focus servo. A standard teletypewriter and a small digital cassette were used to communicate with the minicomputer and to load the computer program into memory.

Oculometer video equipment consists of a camera control unit for the cockpit-mounted electro-optical head and a video processing unit to generate synchronizing pulses for the minicomputer.

Oculometer Calibration

The minicomputer program contains subroutines for selecting zeros and scale factors, for correcting nonlinearities in the eye geometry, and for correcting differences in axis systems between the fixation plane, usually the instrument panel, and the axis of the oculometer E-O head.

A three-point calibration was used to establish an initial null and the output scale factors. The null calibration point for this procedure needed to be near the oculometer infrared source for best results. The X and Y calibration points selected were the course selector knob on the horizontal situation indicator and the 200-knot point on the airspeed indicator, respectively, as shown in figure A9. The procedure consisted of instructing the pilot to look at the null, X, and Y calibration points in turn while the oculometer operator actuated appropriate switches on the computer to capture the raw signals. Coefficients were calculated for terms in the calibration routine to produce output scale factors requested by the operator.

After the three-point calibration, the linearization process was initiated. Predominant fixation points on the instrument panel were previously selected and their coordinates on the instrument panel entered into the minicomputer with the center of the plane being the center of the flight director (fig. A9). As the pilot looked at each point in turn, the oculometer operator actuated a switch which entered the uncorrected coordinates of the point into the computer memory. After all the 28 points had been "captured," the operator switched the computer to the linearize routine, where the uncorrected coordinates were adjusted to fit the actual coordinates of the points as previously entered into the memory. Further information on oculometer calibration and linearization is contained in reference 10.

An external analog device was used to make small corrections to the video recording system to establish zero output in X and Y when the pilot was looking at the exact center of the instrument panel's flight director. The external device was necessary for three reasons: (1) the null point used in the three-point calibration to establish initial zero must be at or near the infrared source; (2) the linearization program works to minimize the total error for all the points used in the linearization; thus, the program does not optimize the area of most concern to the operator; and (3) errors from unknown sources cause small shifts in oculometer output voltages and require some means of correction. The procedure used was to instruct the pilot to concentrate on the exact center of the flight director while the oculometer operator centered two meter-movements (an X and a Y) by turning bias potentiometers on the device.

Monitoring Equipment

The oculometer system used in this experiment contained considerable peripheral equipment not essential to the operation of the oculometer, but useful for monitoring, verifying proper operation, and combining video and analog signals for viewing and later analysis.

A scan converter using a storage type cathode-ray tube combined the X and Y eye direction signals of the oculometer with the video signal from the instrument panel scene. The X and Y signals caused a white dot to move over the scene as the pilot scanned the instruments. The storage feature allowed the eye movements to be displayed for a period of time after they had occurred. It was also helpful in making adjustments to the equipment (fig. A10). TV special effects generation equipment designed for this system allowed further combination so that the oculometer video signal showed the pupil and the reflection from the cornea to be positioned above the instrument panel scene. The resultant video signal enabled a viewer to observe the central area of the captain's instrument panel as the simulated flight progressed, the pilot's fixation point, and the details of his eye as viewed by the oculometer. The oculometer video signal could be positioned over any desired portion of the instrument panel and did not interfere with the observer's view of the instruments (fig. A11).

Oculometer signals were also displayed on an X-Y oscilloscope with a transparency of the instrument panel attached to the face of the cathode-ray tube. This display allowed observers to view the entire area within range of the oculometer although movements of the instruments were not shown as on the TV generated display (fig. A12). This display was used to provide better accuracy of lookpoint during calibration.

The data collected from this experiment were recorded on two 14-channel FM tape recorders (fig. A13) running at 9.53 cm/sec $\left(3\frac{3}{4}\text{ in/sec}\right)$. Time correlation was achieved by recording a standard time code on one channel of each recorder. The following signals were recorded:

A. Oculometer
   1. Fixation point X
   2. Fixation point Y
   3. In track
   4. Pupil diameter
   5. Mirror X
   6. Mirror Y

B. Pilot response
   1. Control column
   2. Control wheel
   3. Rudder pedals
   4. Throttle
   5. Pitch trim

C. Pilot stimulus
   1. Flight director
      a. Pitch attitude
      b. Roll attitude
      c. Pitch command bar

d. Roll command bar
e. Glide-slope deviation
f. Localizer deviation

2. Altimeter
3. Airspeed indicator
4. Instantaneous vertical velocity
5. Heading
6. Sideslip
7. Left motion actuator
8. Right motion actuator
9. Angular rates p, q, and r
10. Normal accelerations x, y, and z

The six oculometer signals were outputted by the oculometer through internal digital-to-analog converters to the recorders. Most of the data from the simulator were scaled and converted to analog form by the simulator digital computer before they were recorded. Exceptions to this practice were the pitch and roll command bar signals and the motion base angular rates and normal accelerations.

The command bar signals are computed externally to the simulator digital program by flight hardware pitch and roll navigational computers. Because the output signals from these navigational computers are low in level and sensitive to loading, specially designed differential amplifiers were used to interface the command bar signals to the instrumentation tape recorders.

All the signals just listed and signals from two of the linear hydraulic actuators were recorded in the FM mode on the two 14-channel recorders.

Although positions of the hydraulic actuators producing motions were available, it was considered necessary to record actual rates and accelerations near the pilot. This eliminated the data reduction effort required to transform simulator positions into actual motion cues.

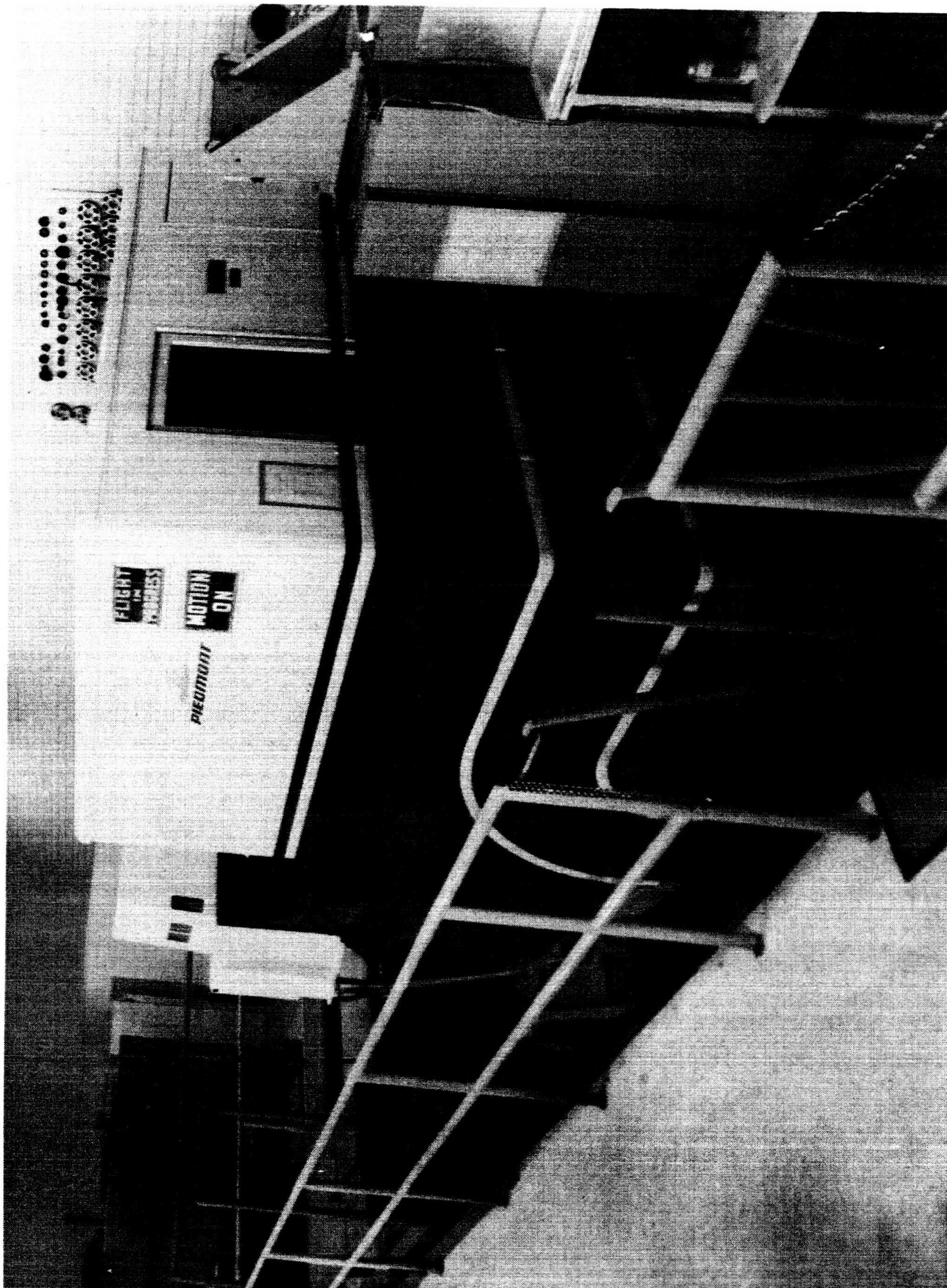
An instrumentation unit which sensed the desired motions and multiplexed them onto two channels of the instrumentation tape recorders was located under the pilot's seat. The two actuator signals were recorded on otherwise unused channels for comparison purposes.

The instrument panel scene with the oculometer data superimposed was recorded on video tape. The audio channel of the video tape recorder was used to record conversations between ground stations and the airplane, between the test conductor and operating personnel, and audio signals produced by navigational aids, such as approach markers, simulated by the simulator complex.

APPENDIX A

Observations

This experiment shows that the oculometer can be operated in the field, although the number and technical level of operating personnel required is high. As observed in previous work with the oculometer, not all individuals are good test subjects, primarily because of partial obscuration of the pupil by the lower eyelid. Further work with the oculometer computer program may help eliminate these problems. A further observation is that the task of instrumenting a simulation facility and validating the recorded data far exceeds the task of installing the oculometer. The comparative level of effort would, of course, vary widely depending upon the size and shape of the electro-optical head and the configuration of the simulator.



L-76-1788

Figure A1.- Motion-base simulator used in experiment.

L-76-1785

Figure A2.- Captain's and first officer's stations.

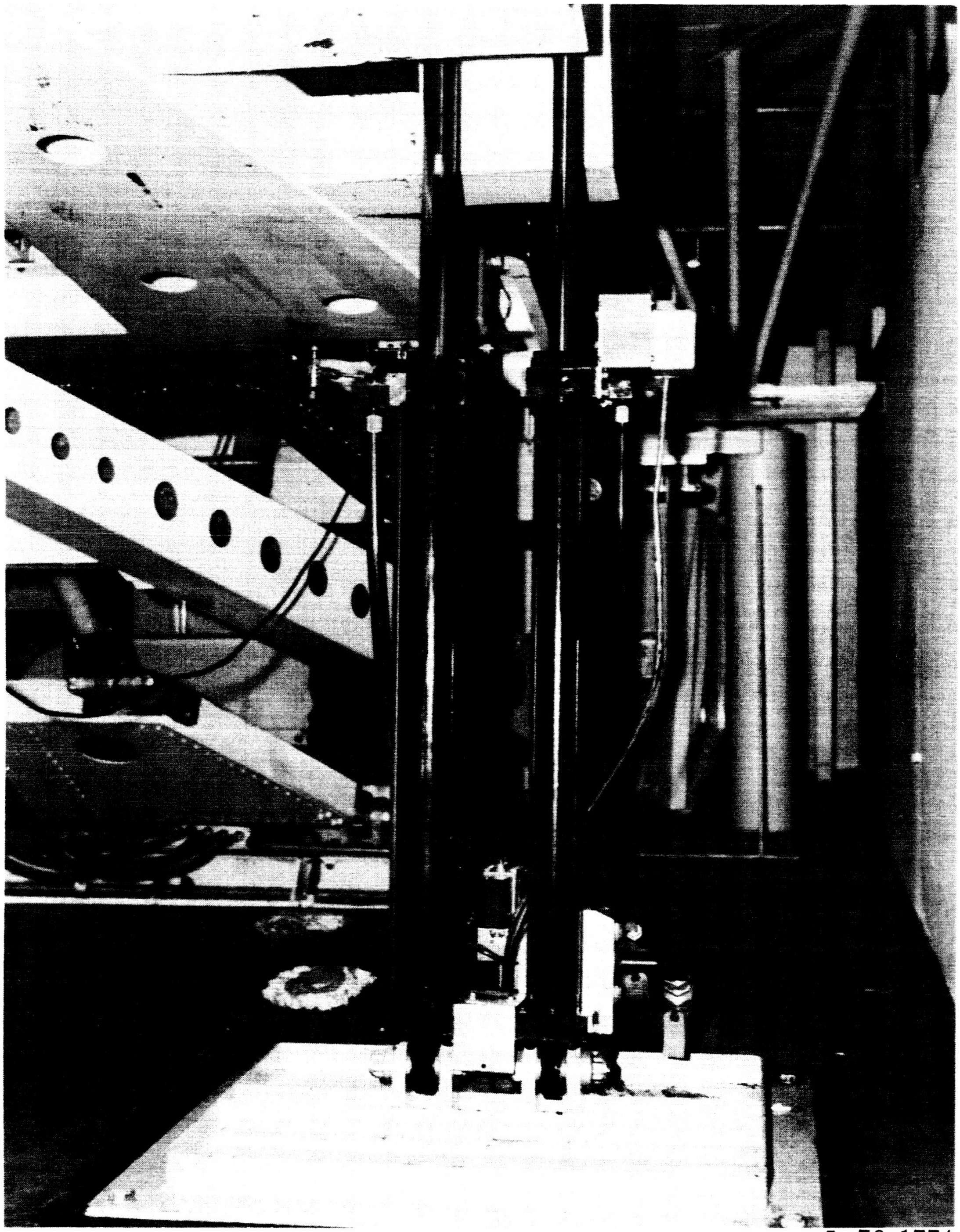


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Figure A3.- Typical linear hydraulic actuator.

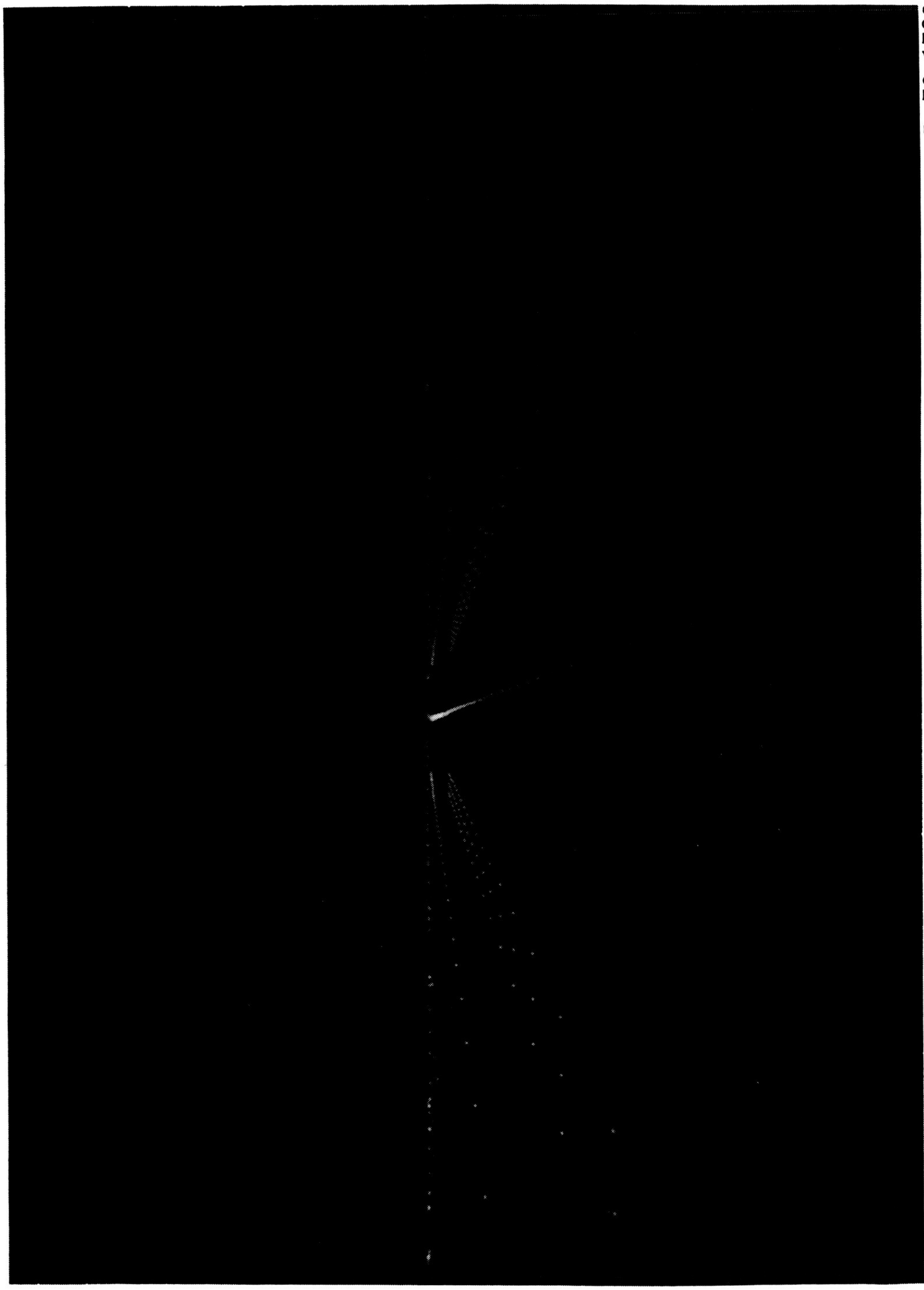

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Figure A4.- Computer-generated landing scene.

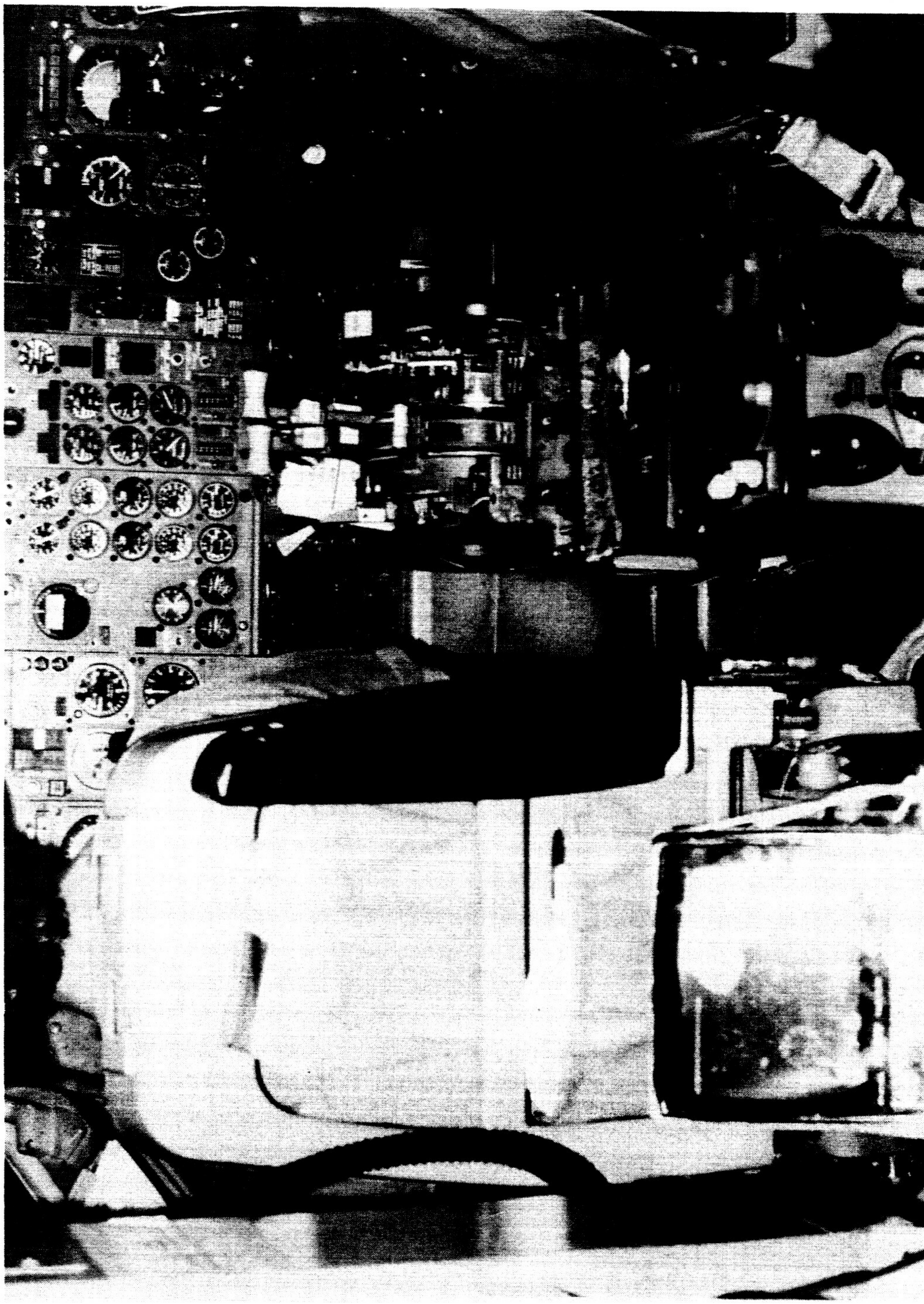

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Figure A5.- Test conductor's station showing television monitor.

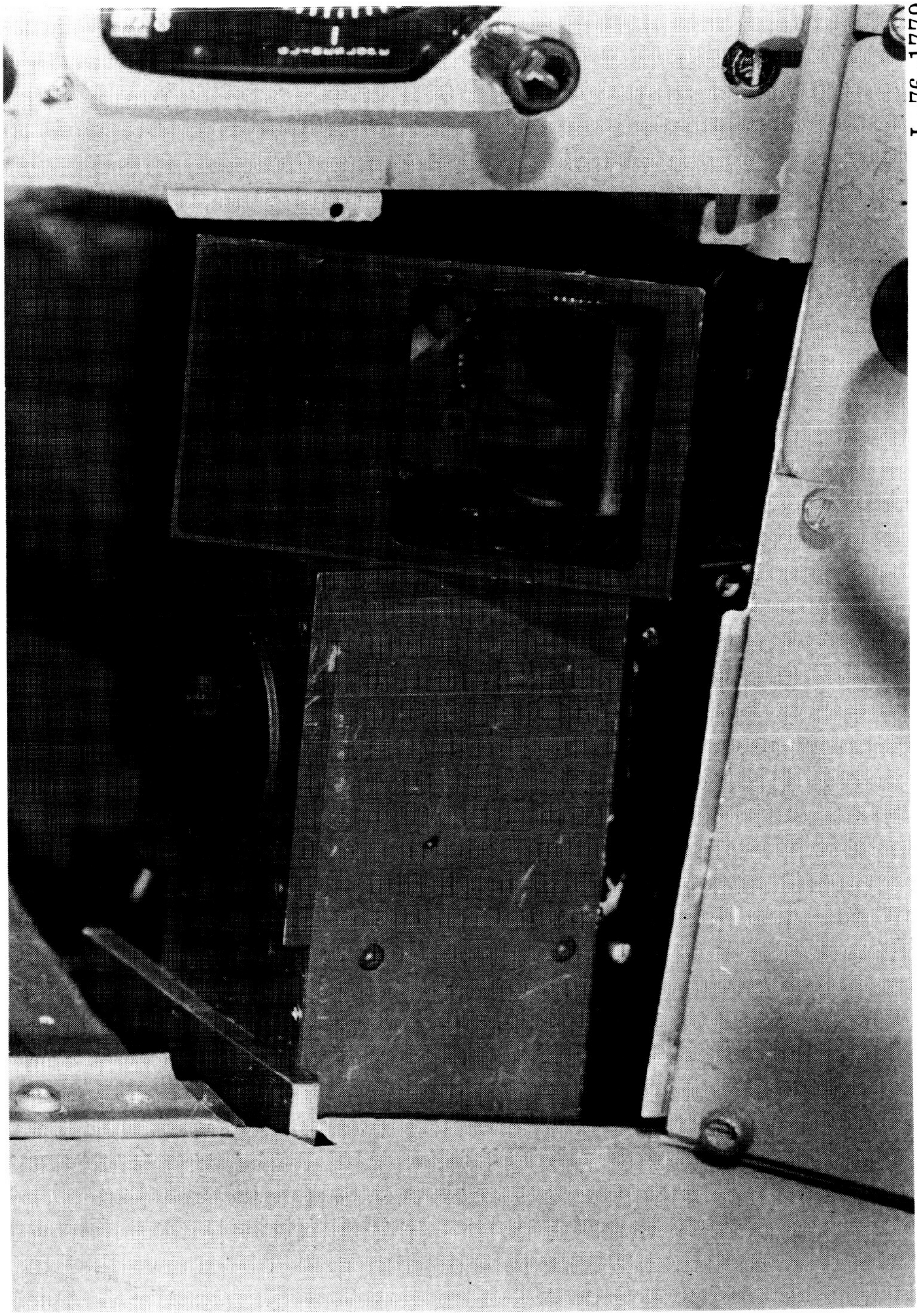

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Figure A6.- Part of electro-optical sensing unit (section of instrument panel removed).

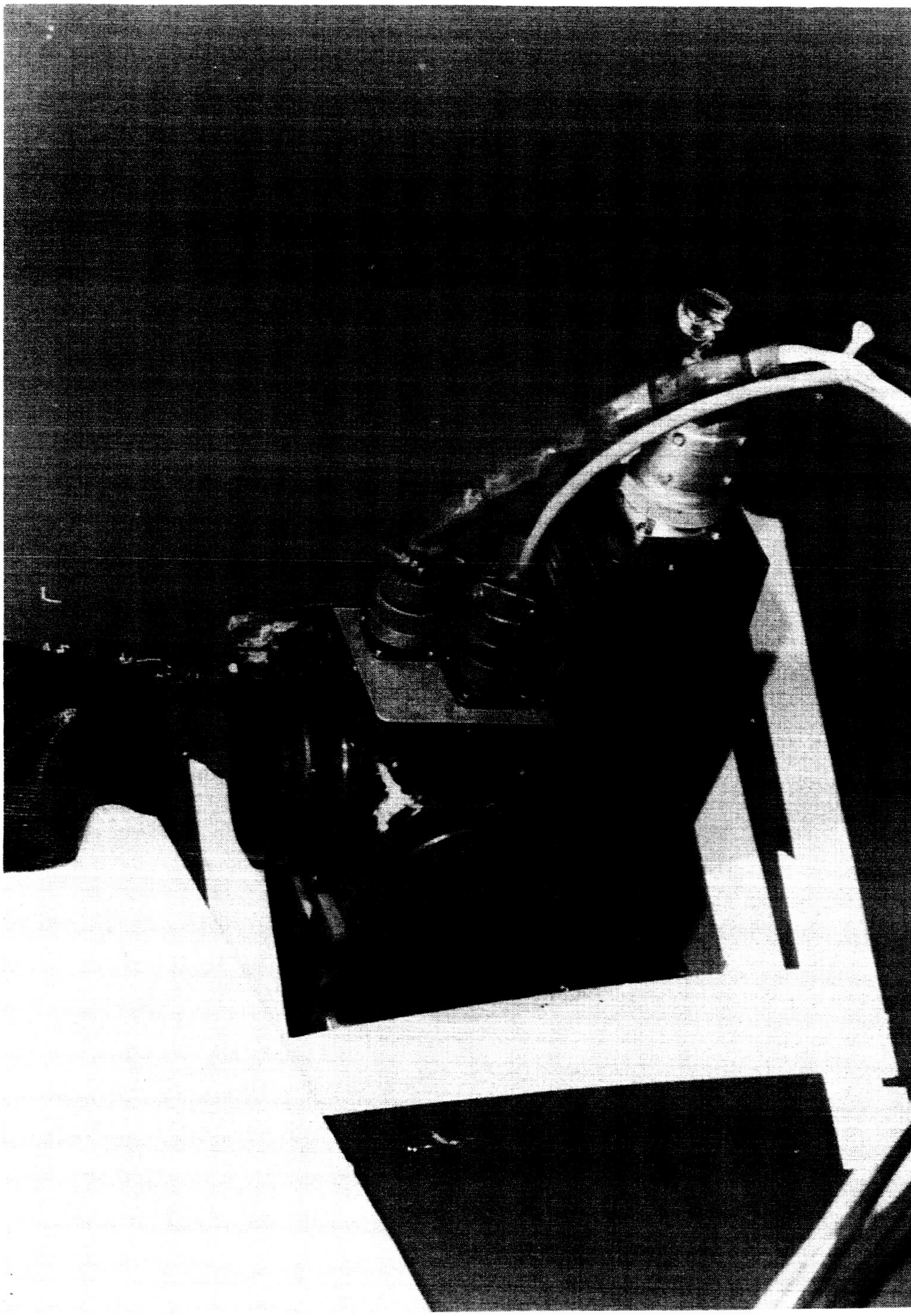

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Figure A7.- Electro-optical sensing unit protruding from exterior of simulator.

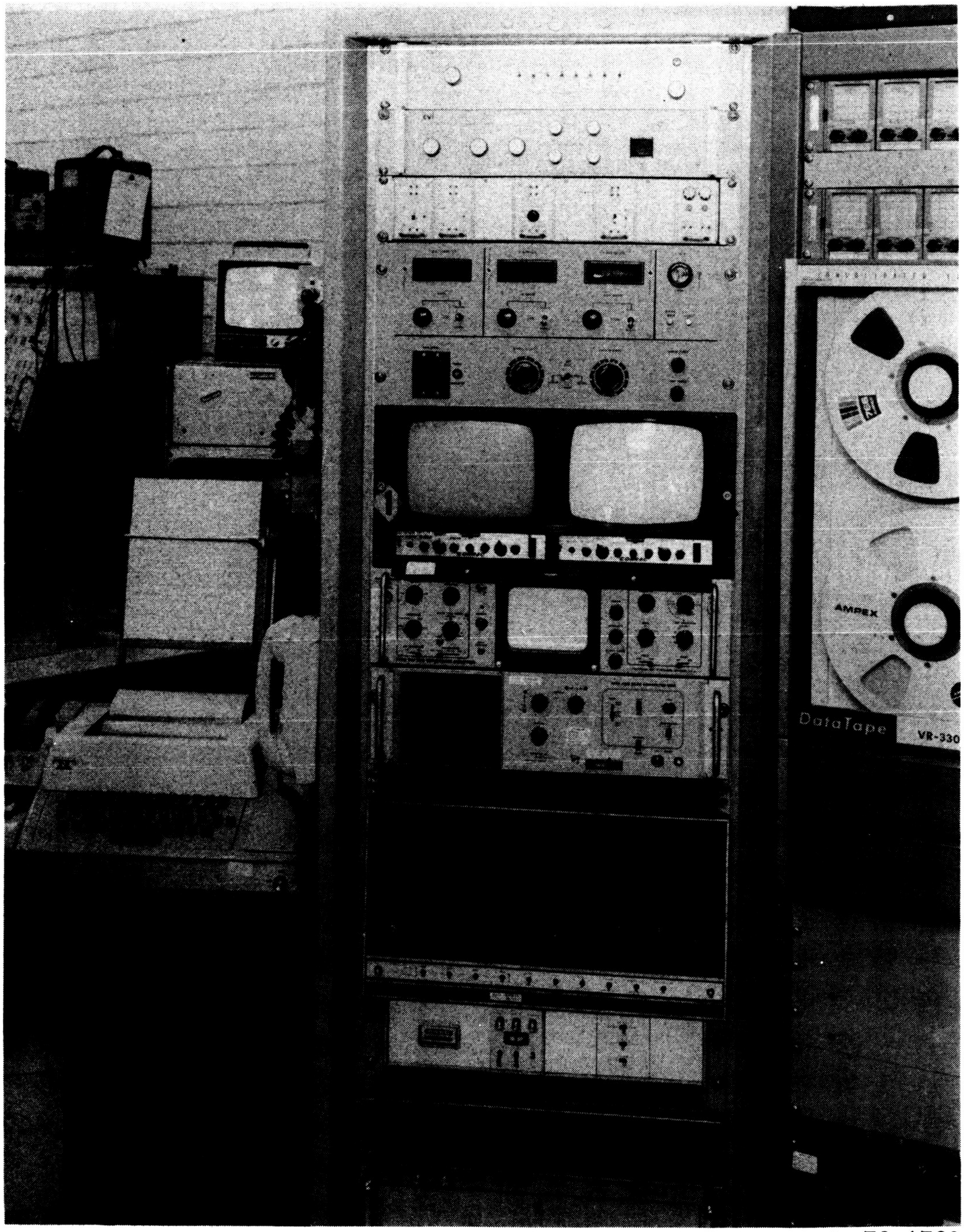

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Figure A8.- Oculometer equipment rack (center) and other electronic equipment.

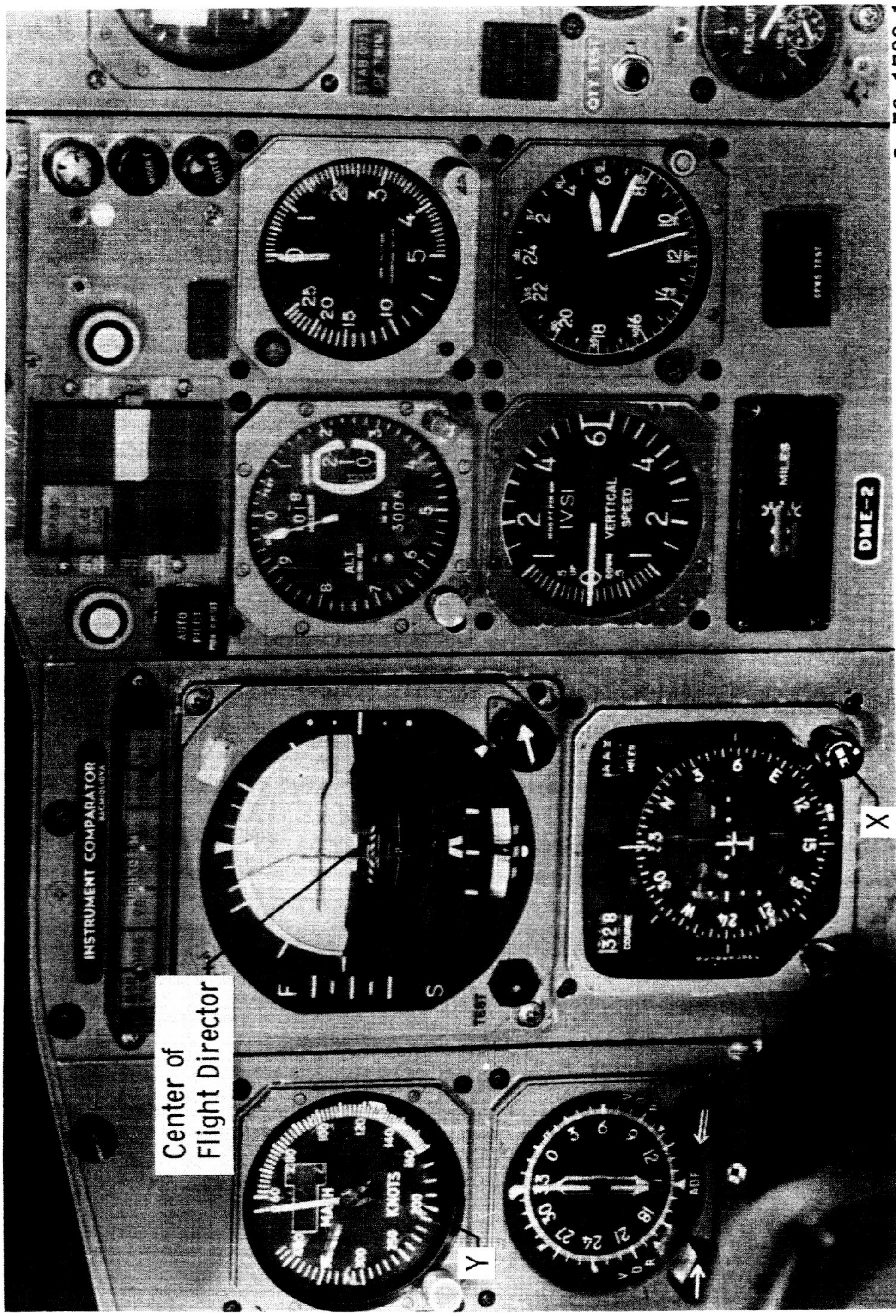

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Figure A9.- Captain's instrument panel showing points used in calibration.

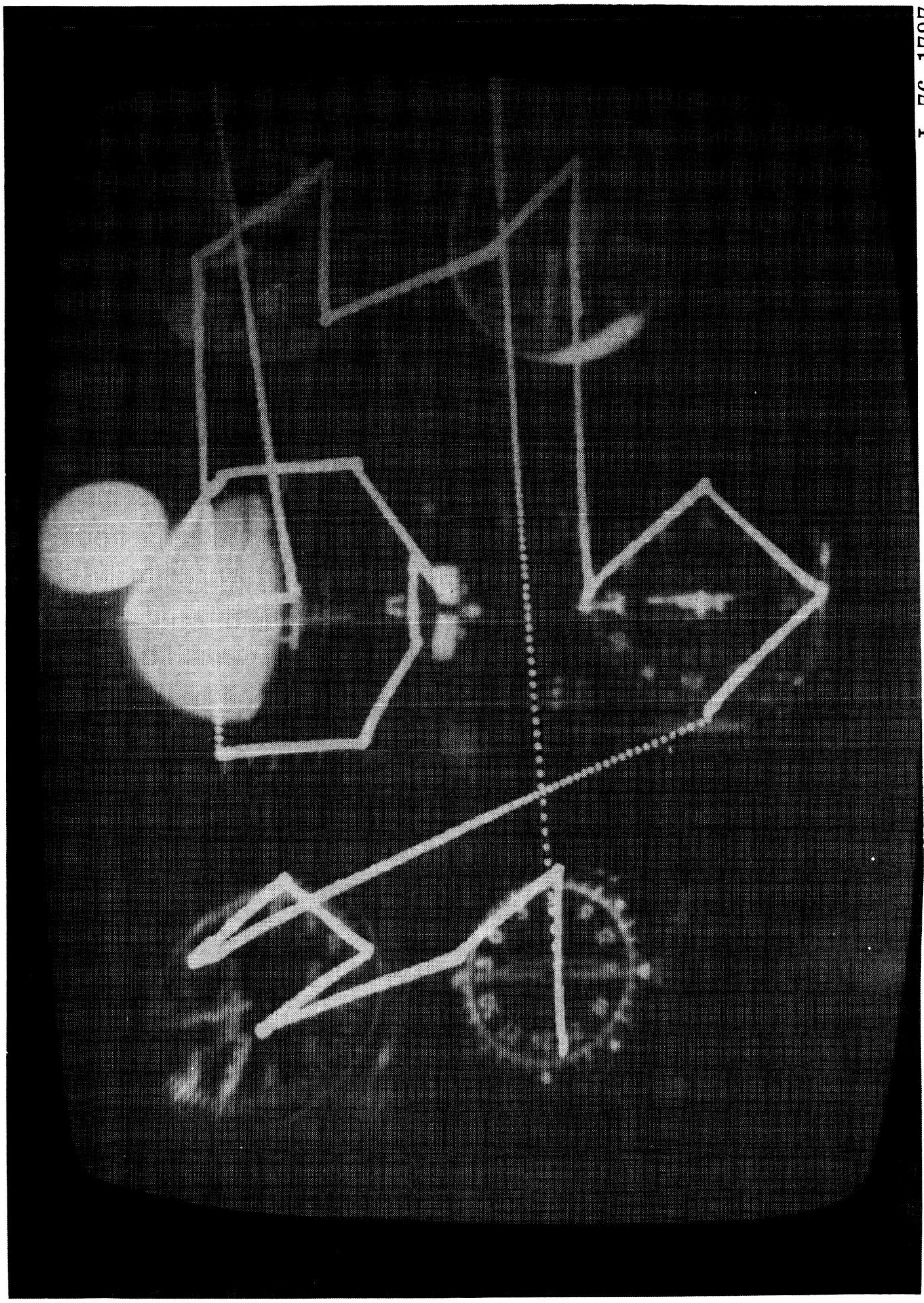

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Figure A10.- Stored output of scan converter superimposed on a video picture of the captain's instrument panel.

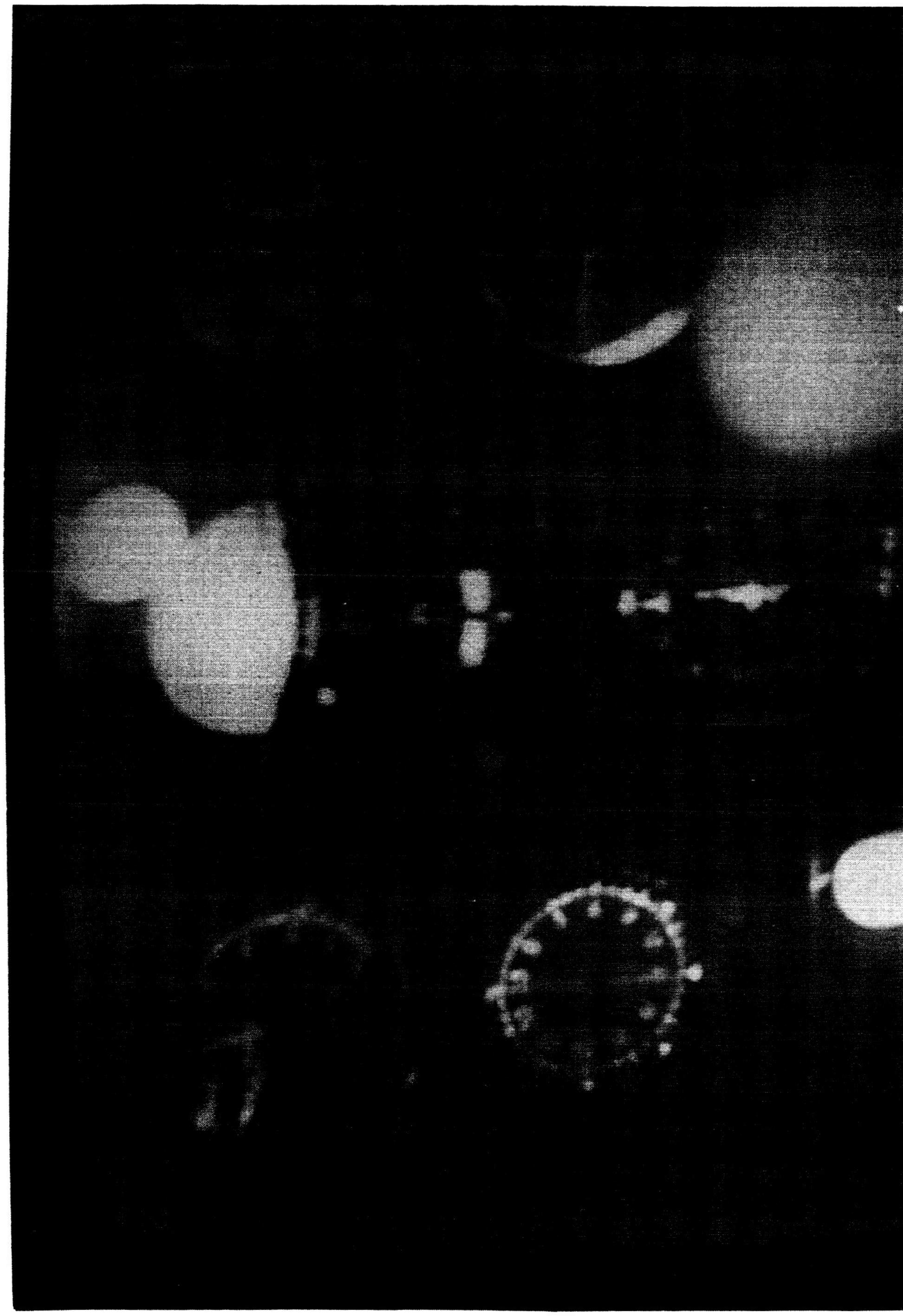

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Figure A11.- Mixed video signal showing fixation point, eye, and instrument panel.

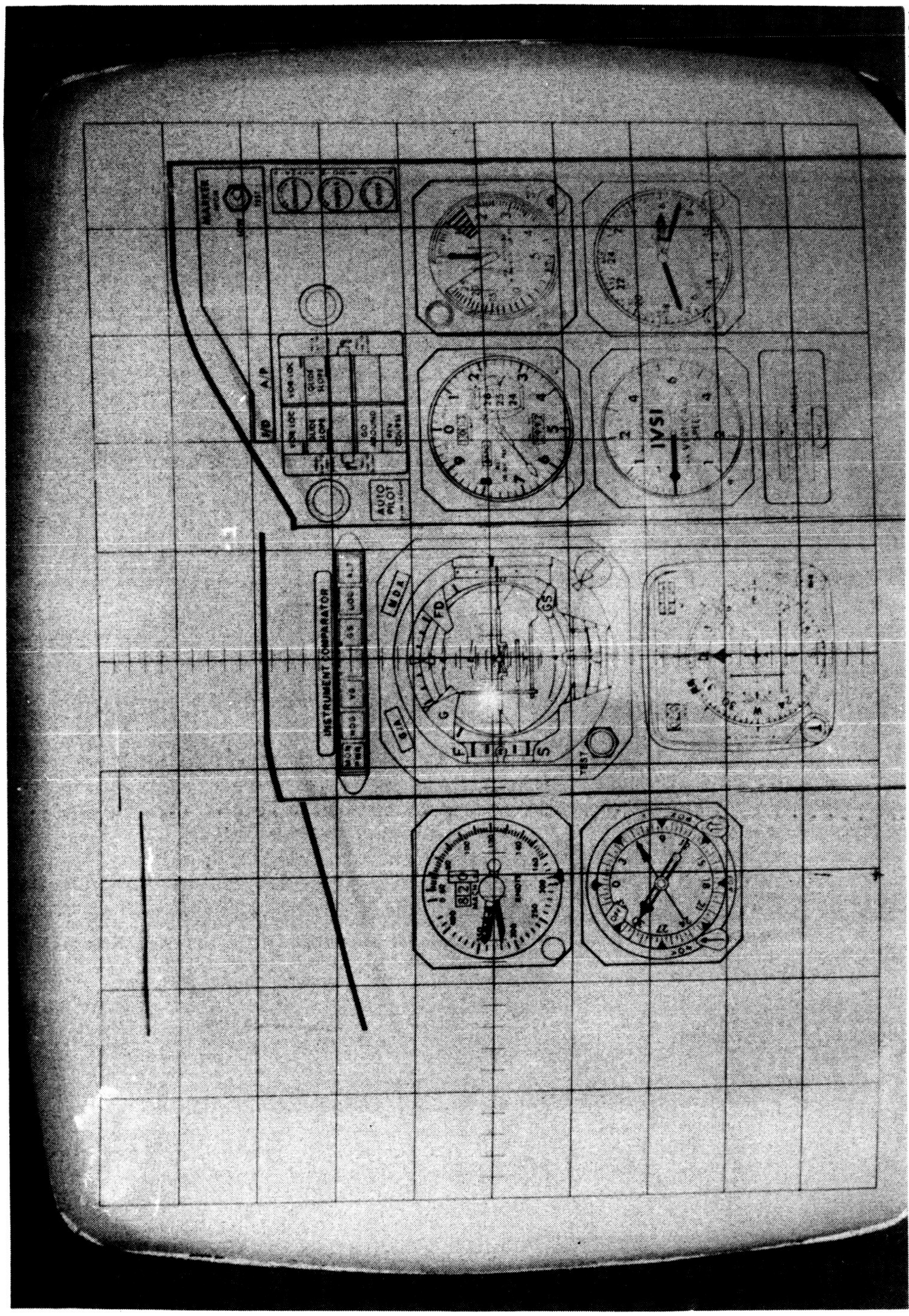

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Figure A12.- X-Y oscilloscope with fixation point and film overlay of instrument panel.

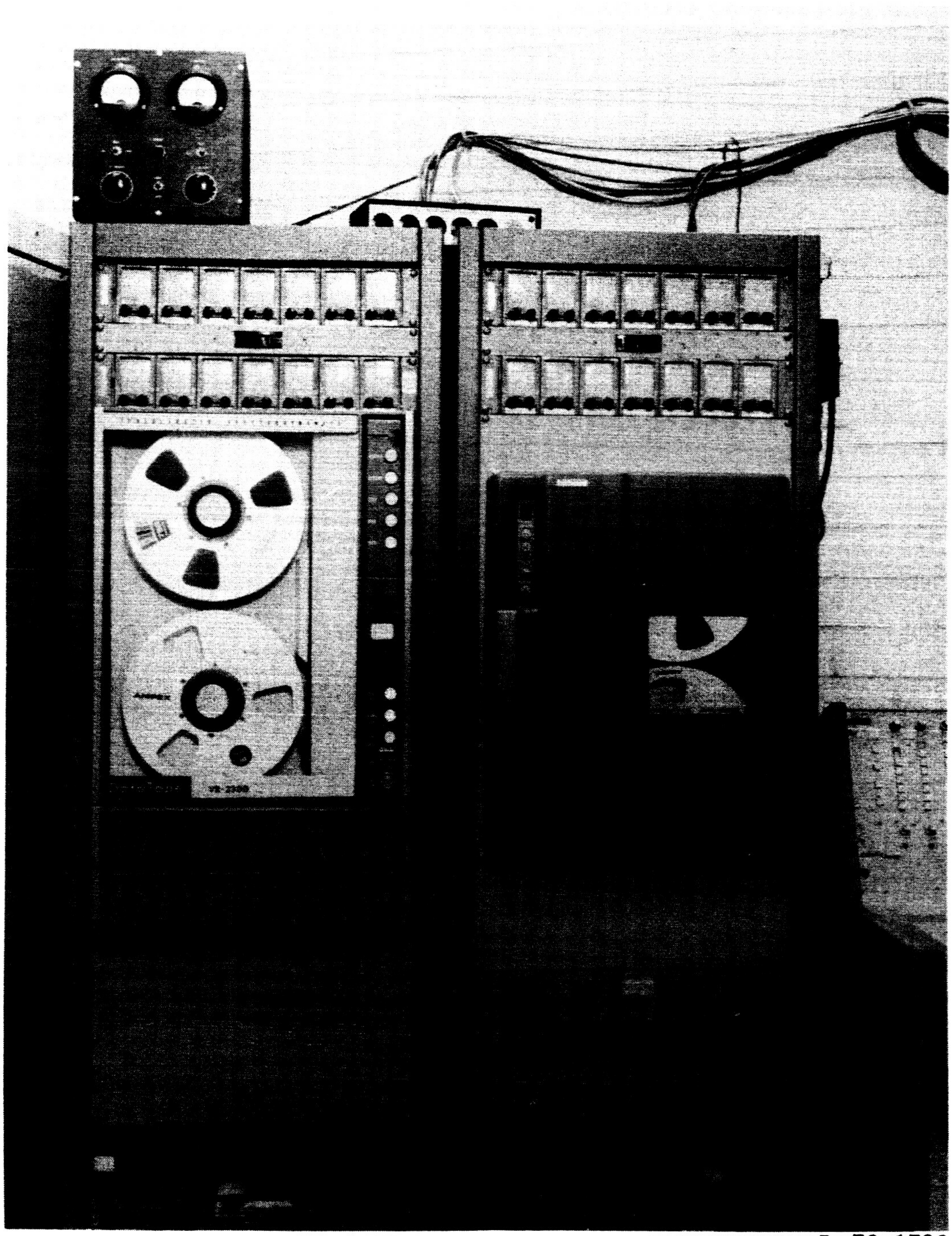

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Figure A13.- FM data tape recorders.

APPENDIX B

PILOT QUESTIONNAIRE

This questionnaire was used to gather pilot opinion during debriefing.

Pilot # ________

NASA OCULOMETER DATA

Pilot Questionnaire

Pilot Name ____________________

Date ________________________

APPENDIX B

Pilot # _____

PILOT QUESTIONNAIRE

Your answers on this questionnaire are strictly confidential and will only be used in the context of this experiment.

In this questionnaire we are trying to get an idea of your subjective impressions during your test runs. We need to know what aspects of the system need improvement as well as your estimation of how well you were flying today. Without your input our data are incomplete, so please answer carefully.

1. Number in order of most used (#1) to least used instrument during ILS coupled approach runs. (Mark X where not used at all.)

From start to glide intercept:

_____ clock
_____ airspeed
_____ flight director
_____ altimeter
_____ HSI
_____ VSI
_____ radio altimeter
_____ magnetic indicator
_____ other ______________

Flight director

_____ roll indicator
_____ command bars
_____ glide slope
_____ localizer

GS Intercept to 1000'	1000' to 500'	500' to 100'	
_____	_____	_____	clock
_____	_____	_____	airspeed
_____	_____	_____	flight director
_____	_____	_____	altimeter
_____	_____	_____	HSI
_____	_____	_____	VSI
_____	_____	_____	radio altimeter
_____	_____	_____	magnetic indicator
_____	_____	_____	other ______________

Flight director

_____	_____	_____	roll indicator
_____	_____	_____	command bars
_____	_____	_____	glide slope
_____	_____	_____	localizer

Pilot # _____

2. Number in order of most used (#1) to least used instrument in manual approach runs.

From start to glide slope intercept:

_____ clock	_____ VSI
_____ airspeed	_____ radio altimeter
_____ flight director	_____ magnetic indicator
_____ altimeter	_____ other _______________
_____ HSI	

Flight director

_____ roll indicator
_____ command bars
_____ glide slope
_____ localizer

GS Intercept to 1000'	1000' to 500'	500' to 100'	
_____	_____	_____	clock
_____	_____	_____	airspeed
_____	_____	_____	flight director
_____	_____	_____	altimeter
_____	_____	_____	HSI
_____	_____	_____	VSI
_____	_____	_____	radio altimeter
_____	_____	_____	magnetic indicator
_____	_____	_____	other _______________

Flight director

_____	_____	_____	roll indicator
_____	_____	_____	command bars
_____	_____	_____	glide slope
_____	_____	_____	localizer

Pilot # ____

3. Number in order of most used (#1) to least used controls during your approach runs.

From start to glide slope intercept:

1	elevator
2	thrust
3	aileron
4	trim
–	rudder

GS Intercept to 1000'

1	elevator
2	thrust
4	aileron
3	trim
–	rudder

1000' to 500'

1	elevator
2	thrust
3	aileron
4	trim
–	rudder

500' to 100'

1	elevator
2	thrust
3	aileron
4	trim
–	rudder

4. What cockpit tasks demanded more of your attention than you felt was necessary, as compared with normal in-flight experience?

CONTROLS

coupled approach: None

manual approach: None

INSTRUMENTS

coupled approach: None

manual approach: None

Did you fly differently as a result? No

Pilot # _____

5. Was your instrument scan any different than usual? Explain.

   No

6. How were the flight director steering commands?

   (1) 2 3 4 5 6 7 8 9
   good — bad

   Comment:

7. Was it difficult to keep the airplane in correct trim?

Lateral/Directional	_____ Yes	1 pilot Sometimes	5 pilots No
Vertical	_____ Yes	2 pilots Sometimes	4 pilots No

8. Did turbulence change your priorities in the cockpit in any way? (You looked at what instruments more or less, used what controls more or less?)

   2 pilots – no, 1 pilot – scan rate increased in turbulence, 2 pilots – look at airspeed more, 1 pilot – used elevator more and paid closer attention to pitch control and airspeed.

9. Did you notice any distractions in the cockpit? ---- Explain.

   5 pilots – no
   1 pilot – noticed oculometer once in a while

10. Are there any anomalies peculiar to the simulation which you find annoying? Do you feel these affect the way you fly the system? Explain.

    4 pilots – no
    1 pilot – simulator sensitivity greater than aircraft
    1 pilot – I do not like to fly the simulator; therefore, I do not do as well as in aircraft.

Pilot # _____

11. Under the conditions present, how would you rate your overall performance today?

I can do it better . . . (circle one)

never	seldom	sometimes	half the time	usually	almost always	always
0-5%	5-15%	15-40%	50-60%	60-85%	85-95%	95-100%
	3 pilots	1 pilot	1 pilot	1 pilot		

Were there any particular runs which deviated from your overall performance?

12. How does the workload in the simulator compare with your in-flight experience?

3 pilots – same
3 pilots – no difference

13. How did you feel before testing?

1	2	3	4	5	6	7	8	9
poorly								well

Comment:

3 pilots – 9
1 pilot – 8
2 pilots – 7

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9. Middleton, David B.; Hurt, George J., Jr.; Wise, Marion A.; and Holt, James D.: Description and Flight Tests of an Oculometer. NASA TN D-8419, 1977.

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TABLE I.- TEST CONDITIONS

[Each of the seven airline pilots flew three data approaches for each condition]

Approach	Turbulence condition	Visibility condition
Manual	No	Category II
Coupled	No	Category II
Manual	Moderate	Category II
Coupled	Moderate	Category II

TABLE II.- TYPICAL NUMBER OF PILOT DWELL TIMES IN VARIOUS INSTRUMENTS FOR TEST PERIODS

Instruments	Period, sec[a]										
	0 to 0.26	0.26 to 0.51	0.51 to 0.76	0.76 to 1.01	1.01 to 1.51	1.51 to 2.01	2.01 to 2.51	2.51 to 3.01	3.01 to 3.51	3.51 to 4.01	4.01 to over
Manual approach – no turbulence											
AS	0	12	8	1	0	0	0	0	0	0	0
FD	2	8	5	13	13	6	7	3	5	2	7
BA	7	16	9	1	0	0	0	0	0	0	0
HSI	8	2	0	0	0	0	0	0	0	0	0
VSI	12	19	1	1	1	0	0	0	0	0	0
Coupled approach – no turbulence											
AS	4	20	10	2	1	0	0	0	0	0	0
FD	13	20	16	12	13	4	5	3	1	0	2
BA	19	8	10	3	0	0	0	0	0	0	0
HSI	17	16	2	2	0	0	0	0	0	0	0
VSI	27	20	5	1	1	0	0	0	0	0	0

[a]32 counts per second; 8 counts = 0.25 sec.

TABLE III.- AVERAGE TWO-WAY LINK VALUES FOR SEVEN PILOTS

[Each pilot flew 3 runs]

Instruments	No turbulence										Turbulence									
	Manual mode					Coupled mode					Manual mode					Coupled mode				
	Sum	Segment				Sum	Segment				Sum	Segment				Sum	Segment			
		1	2	3	4		1	2	3	4		1	2	3	4		1	2	3	4
FD to AS	36	32	41	48	40	35	34	40	41	36	34	30	34	44	36	39	35	40	43	46
FD to HSI	22	19	26	30	26	16	18	16	18	14	24	14	20	28	26	13	14	16	16	10
FD to BA	12	20	06	06	10	09	11	08	08	13	13	18	06	06	08	08	10	06	04	14
FD to VSI	10	11	06	10	10	08	07	06	08	12	10	10	12	08	13	07	07	06	08	10
BA to VSI	06	05	06	00	06	07	07	04	05	12	06	10	06	00	06	05	07	04	02	07
HSI to VSI	06	05	06	08	06	05	04	06	08	06	05	04	06	06	06	05	04	04	08	04
AS to ADF	05	07	06	00	00	08	12	10	08	02	08	10	12	08	08	13	14	14	13	07
FD to ADF	01	02	00	00	00	03	04	03	04	02	02	03	03	02	03	03	04	04	04	00
HSI to ADF	01	01	03	00	00	03	04	03	02	00	01	02	03	00	00	04	04	06	04	00
BA to RA	00	00	00	00	00	02	00	00	02	06	00	00	00	00	00	01	00	00	00	02

TABLE IV.- RANKING OF INSTRUMENT USE

[Six pilots, three runs each]

(a) Pilots mean ranking of instrument use

Instrument	Ranking	Manual mode for segment –				Coupled mode for segment –			
		1	2	3	4	1	2	3	4
AS	Mean standard deviation	2.2 (0.4)	1.8 (0.4)	1.8 (0.4)	2.3 (0.8)	2.0 (0.6)	2.1 (0.7)	2.4 (1.9)	2.8 (1.7)
FD	Mean standard deviation	1 (0)	1.6 (1.4)	1.6 (1.4)	1.6 (1.4)	1.2 (0.4)	1.2 (0.4)	1.3 (0.5)	1.8 (1.4)
BA	Mean standard deviation	2.8 (0.4)	3.1 (0.5)	3.1 (0.5)	3.1 (0.8)	3.3 (0.8)	4.0 (1.6)	3.2 (1.5)	2.8 (0.4)
HSI	Mean standard deviation	5.0 (1.1)	4.9 (0.9)	5.3 (0.9)	5.9 (0.5)	4.8 (1.2)	4.8 (1.5)	5.1 (1.4)	5.6 (0.9)
VSI	Mean standard deviation	5.0 (0.9)	4.3 (0.8)	4.3 (0.8)	4.4 (0.8)	4.8 (1.3)	4.1 (1.3)	4.3 (1.3)	4.8 (0.8)
RA	Mean standard deviation	6.3 (1.2)	5.9 (1.7)	5.4 (1.8)	3.9 (1.9)	6.7 (0.8)	6.2 (1.0)	5.3 (1.3)	3.9 (2.2)
ADF	Mean standard deviation	5.7 (1.0)	6.4 (0.5)	6.6 (0.5)	6.8 (0.4)	5.3 (1.1)	5.7 (1.2)	6.4 (1.2)	6.4 (1.2)

TABLE IV.- Concluded

(b) Oculometer mean ranking based on percent time on instruments

Instrument	Ranking	Manual mode for segment –				Coupled mode for segment –			
		1	2	3	4	1	2	3	4
AS	Mean standard deviation	2.3 (0.5)	2.2 (0.4)	2.2 (0.4)	2.3 (0.5)	2.0 (0.6)	1.8 (0.4)	1.8 (0.4)	2.0 (0.4)
FD	Mean standard deviation	1 (0)	1 (0)	1 (0)	1 (0)	1.3 (0.8)	1.3 (0.8)	1.2 (0.4)	1.2 (0.4)
BA	Mean standard deviation	4.0 (1.1)	4.7 (1.2)	4.3 (0.8)	4.3 (1.2)	4.0 (0.9)	4.8 (0.8)	5.0 (0.6)	4.0 (0.9)
HSI	Mean standard deviation	3.9 (1.5)	3.7 (1.5)	3.5 (1.2)	4.2 (1.3)	3.7 (1.6)	3.8 (1.5)	3.7 (0.8)	4.0 (0.9)
VSI	Mean standard deviation	4.3 (1.2)	4.8 (0.8)	4.0 (0.6)	4.0 (1.4)	5.0 (1.1)	4.7 (1.4)	4.3 (1.5)	4.2 (1.7)
RA	Mean standard deviation	7 (0)	6.8 (0.4)	6.8 (0.4)	6.3 (1.8)	7 (0)	7 (0)	7 (0)	6.4 (0.5)
ADF	Mean standard deviation	5.5 (0.8)	4.9 (1.4)	6.2 (0.4)	5.8 (1.5)	5.2 (1.3)	4.7 (1.5)	5.2 (1.3)	6.4 (0.8)

TABLE V.- ORDER OF INSTRUMENT USE

Order	Manual mode for segment –				Coupled mode for segment –			
	1	2	3	4	1	2	3	4
(a) Based on pilot ranking								
1	FD	FD	FD	FD	FD	FD	FD	FD
2	AS	AS	AS	AS	AS	AS	AS	[a]{AS
3	BA	BA	BA	BA	BA	BA	BA	BA}
4	[a]{VSI	VSI	VSI	RA	[a]{VSI	VSI	VSI	RA
5	HSI}	HSI	HSI	VSI	HSI}	HSI	HSI	VSI
6	ADF	RA	RA	HSI	ADF	ADF	RA	HSI
7	RA	ADF	ADF	ADF	RA	RA	ADF	ADF
(b) Based on oculometer ranking								
1	FD	FD	FD	FD	FD	FD	FD	FD
2	AS	AS	AS	AS	AS	AS	AS	AS
3	HSI	HSI	HSI	VSI	HSI	HSI	HSI	[a]{BA
4	BA	BA	VSI	HSI	BA	[a]{VSI	VSI	HSI}
5	VSI	VSI	BA	BA	VSI	ADF}	BA	VSI
6	ADF	ADF	ADF	ADF	ADF	BA	ADF	[a]{RA
7	RA	RA	RA	RA	RA	RA	RA	ADF}

[a]{ } indicate equal rank.

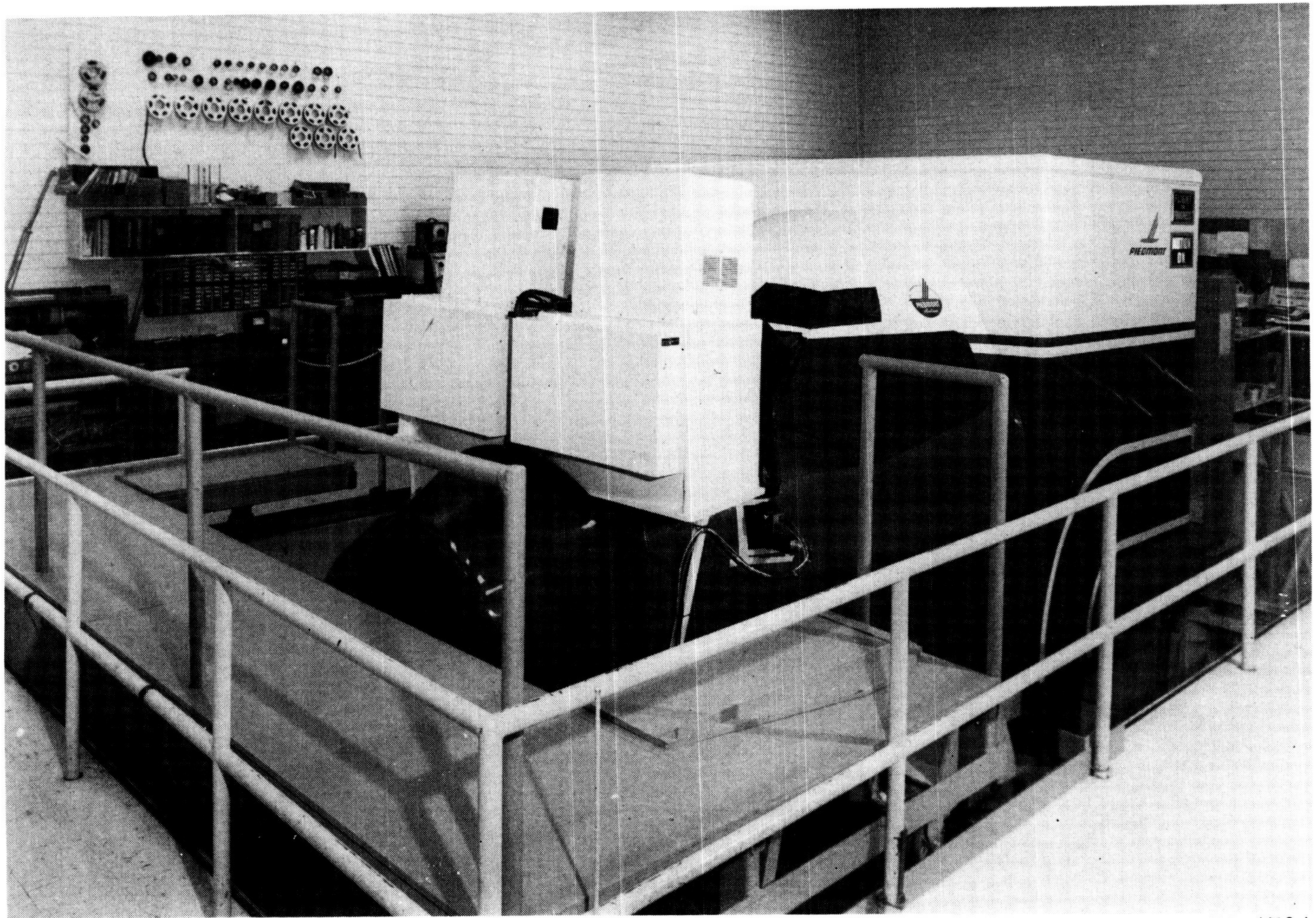

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Figure 1.- Piedmont Airline's Boeing 737 training simulator used for airline pilot studies.

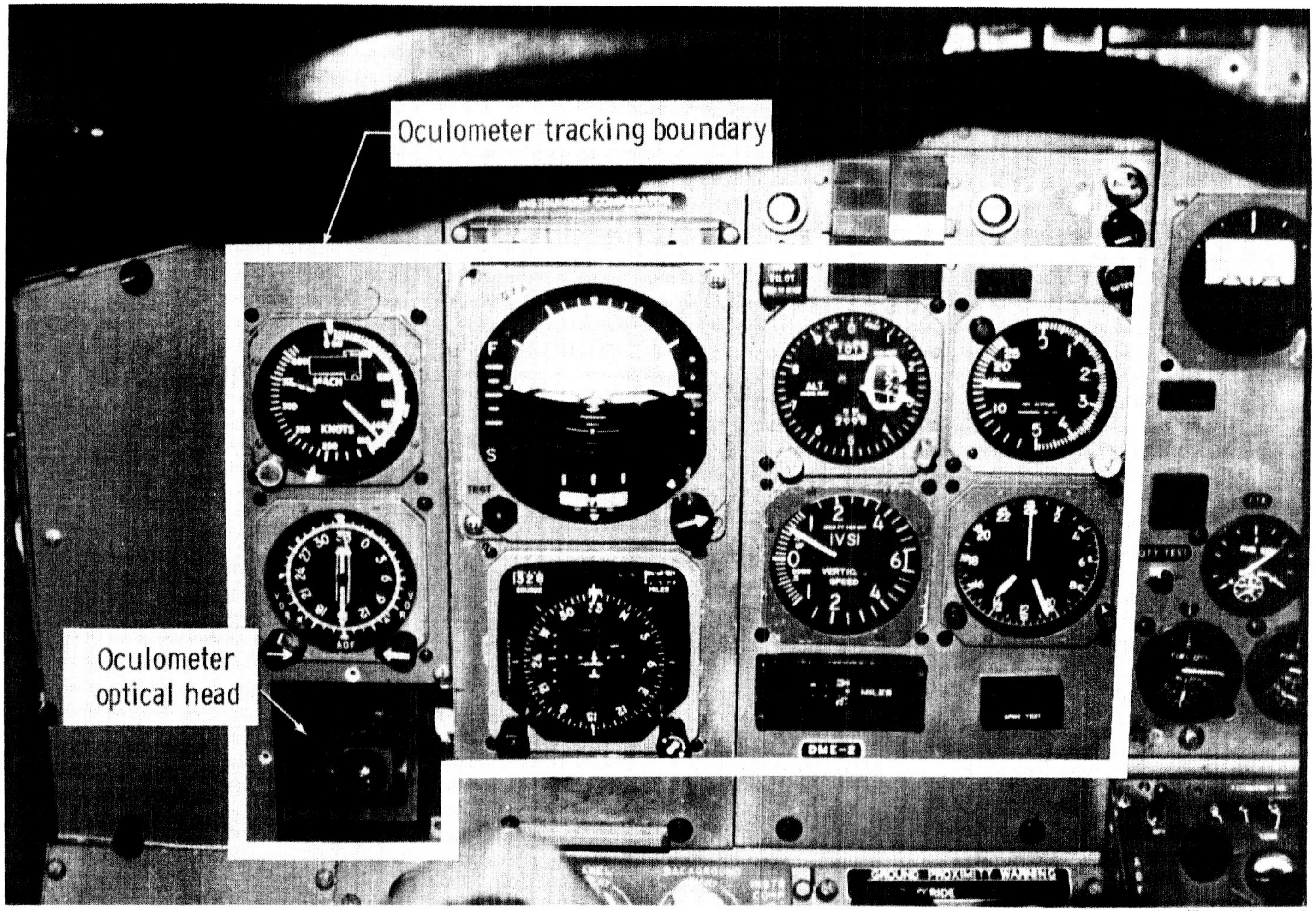

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Figure 2.- Captain's flight instrument panel.

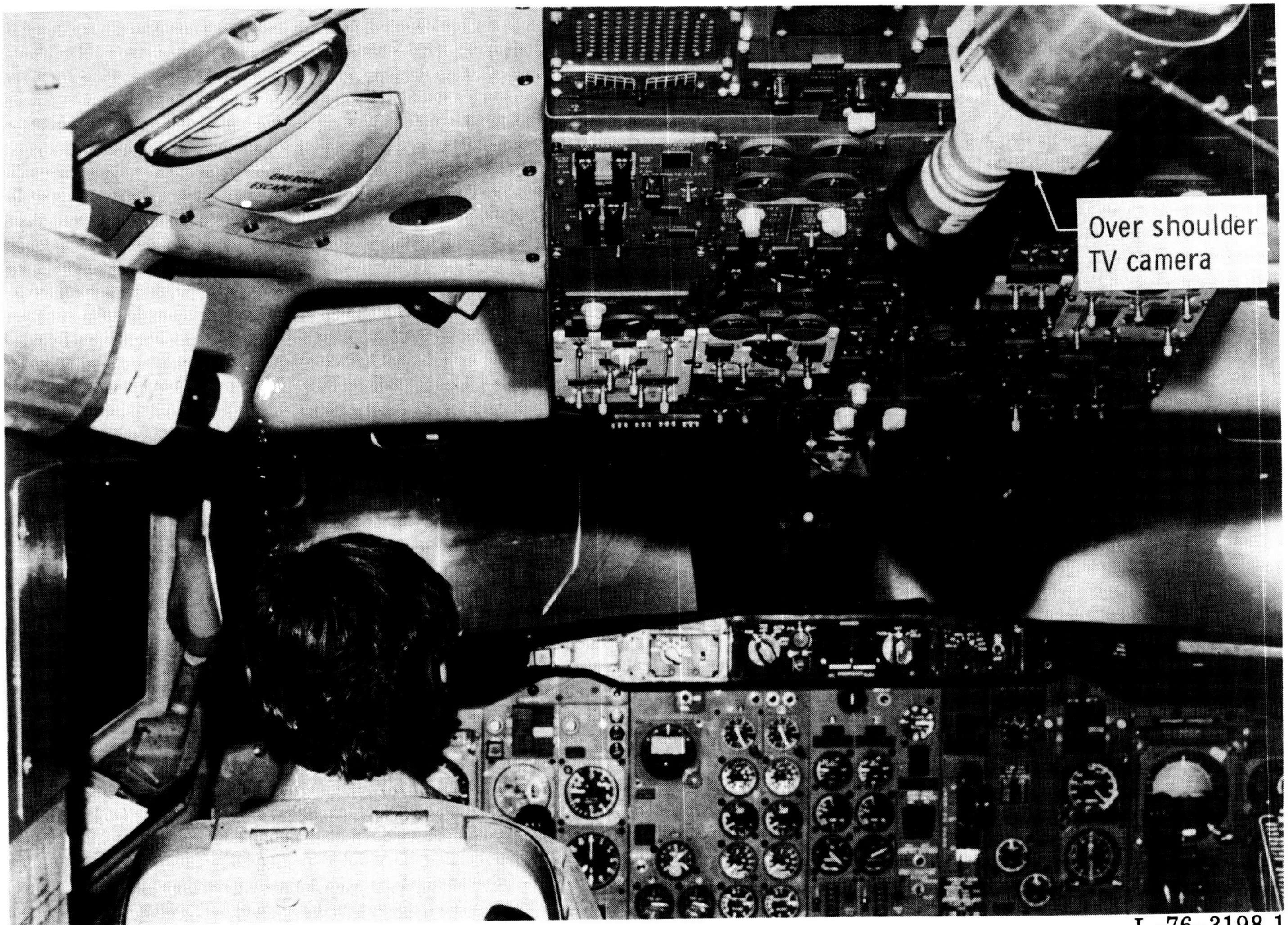

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Figure 3.- View of cockpit.

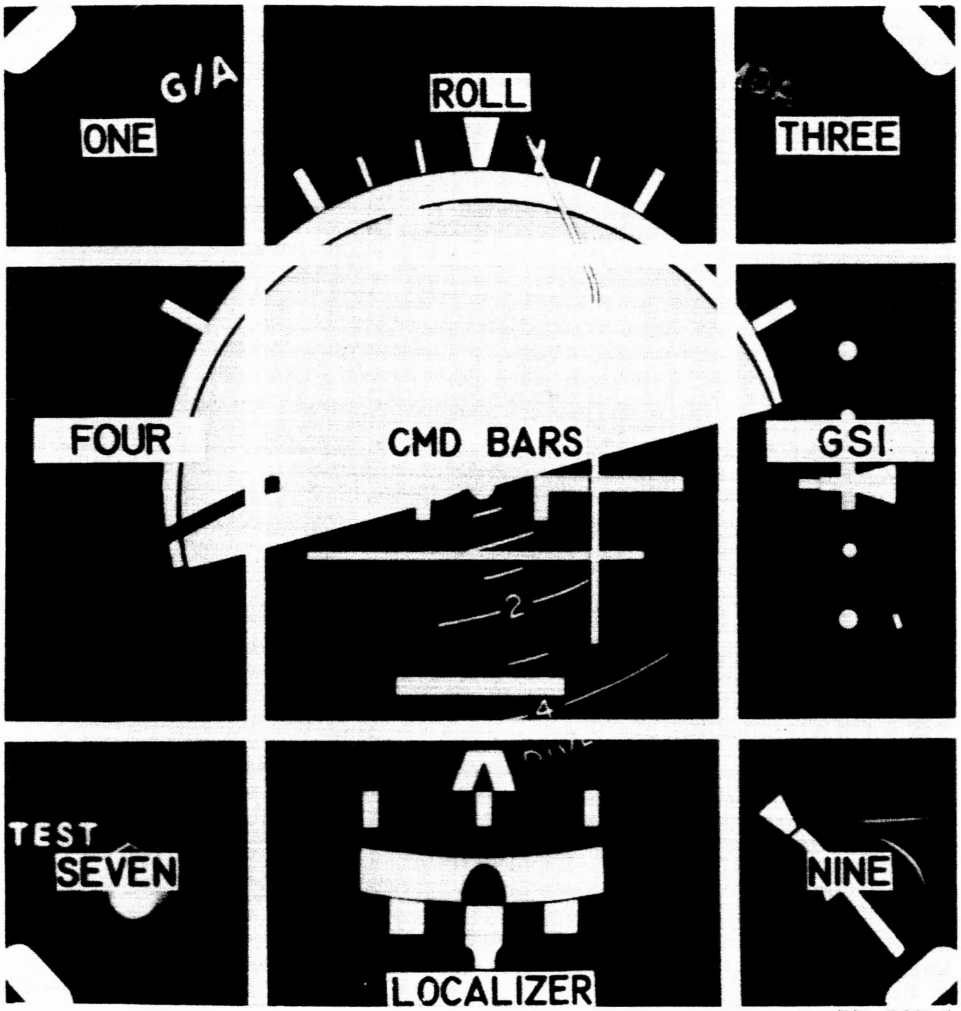

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Figure 4.- Flight director breakdown.

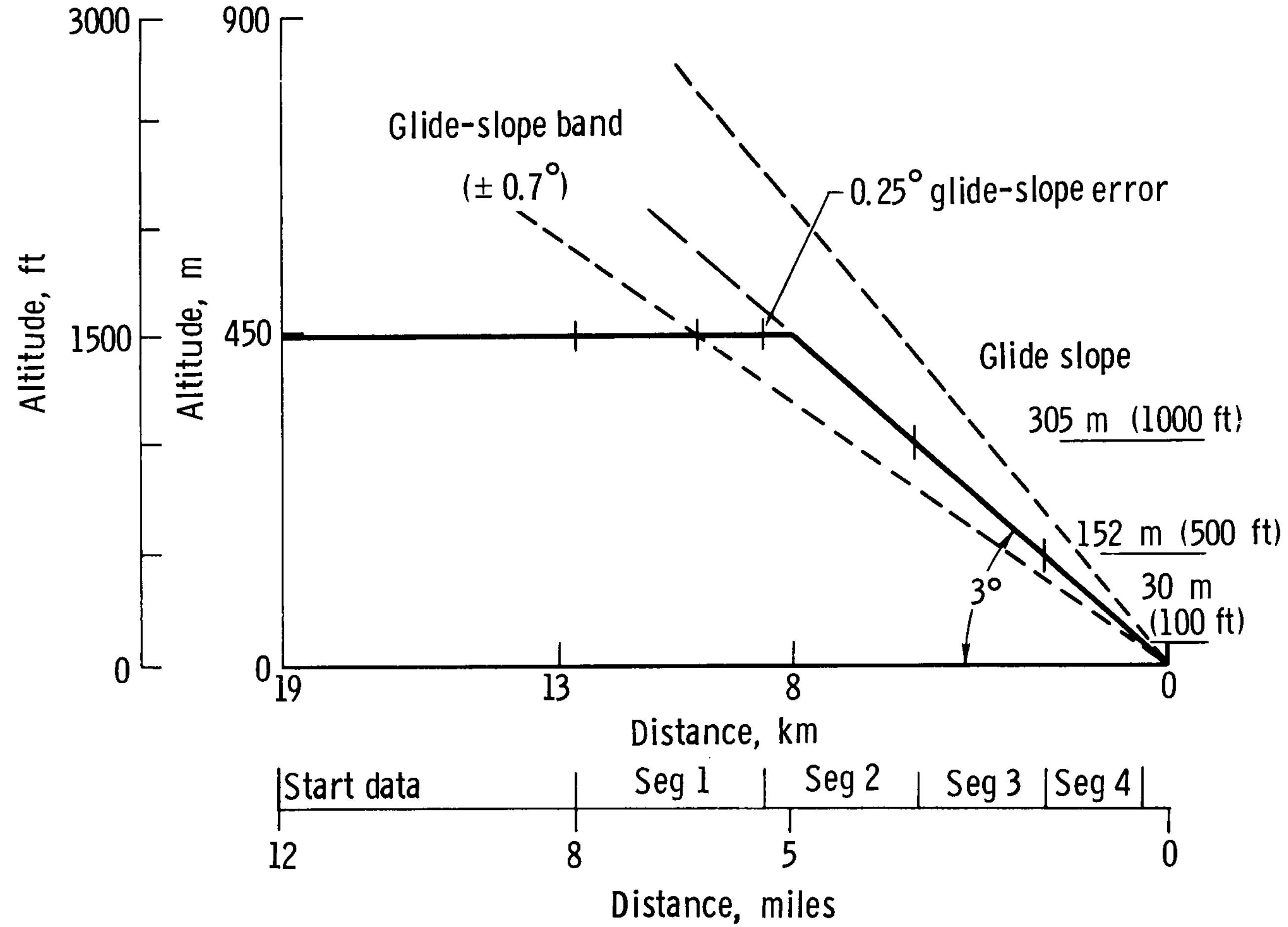


Figure 5.- Flight profile.

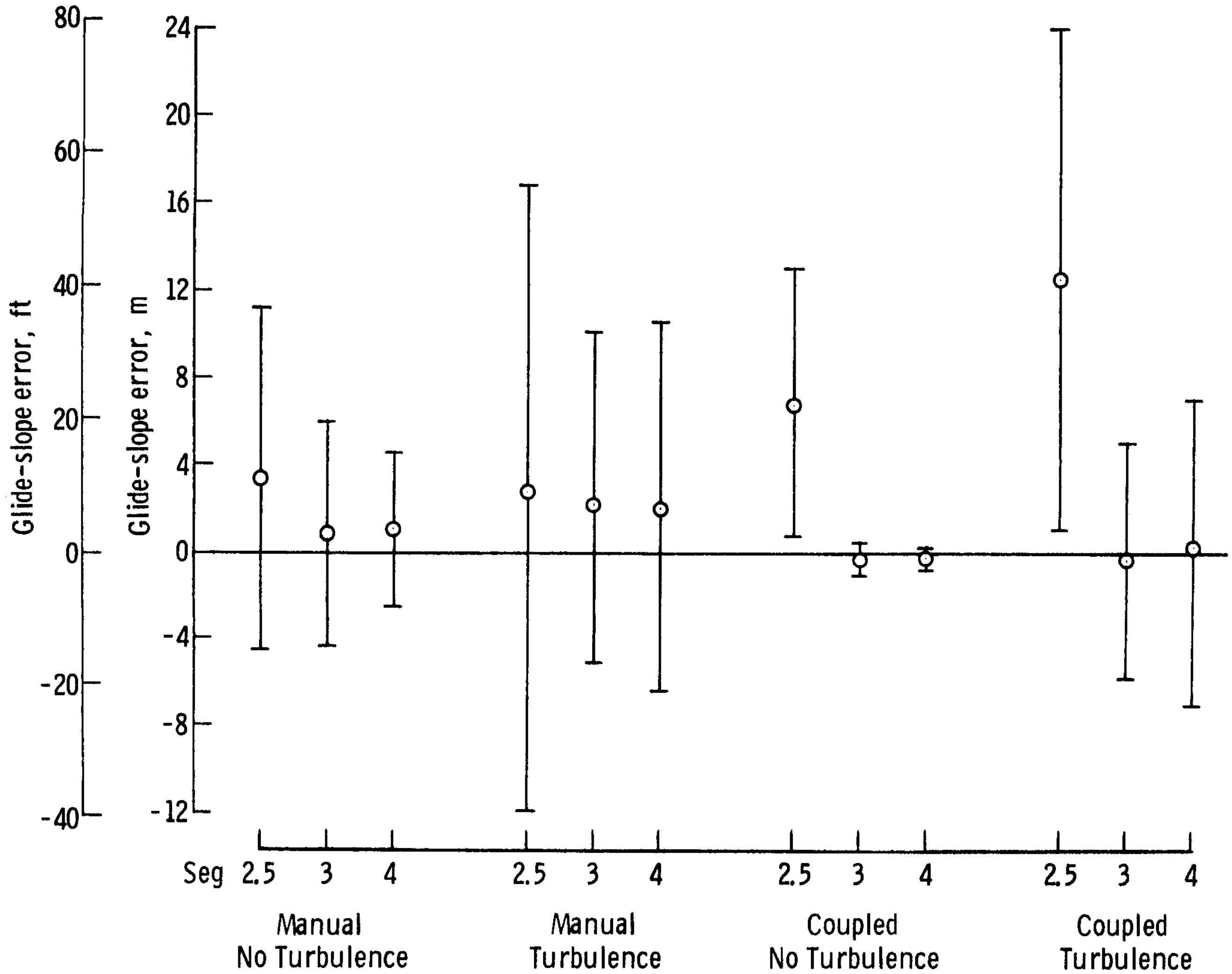


Figure 6.- Mean and standard deviation of glide-slope error; seven pilots, three runs each.

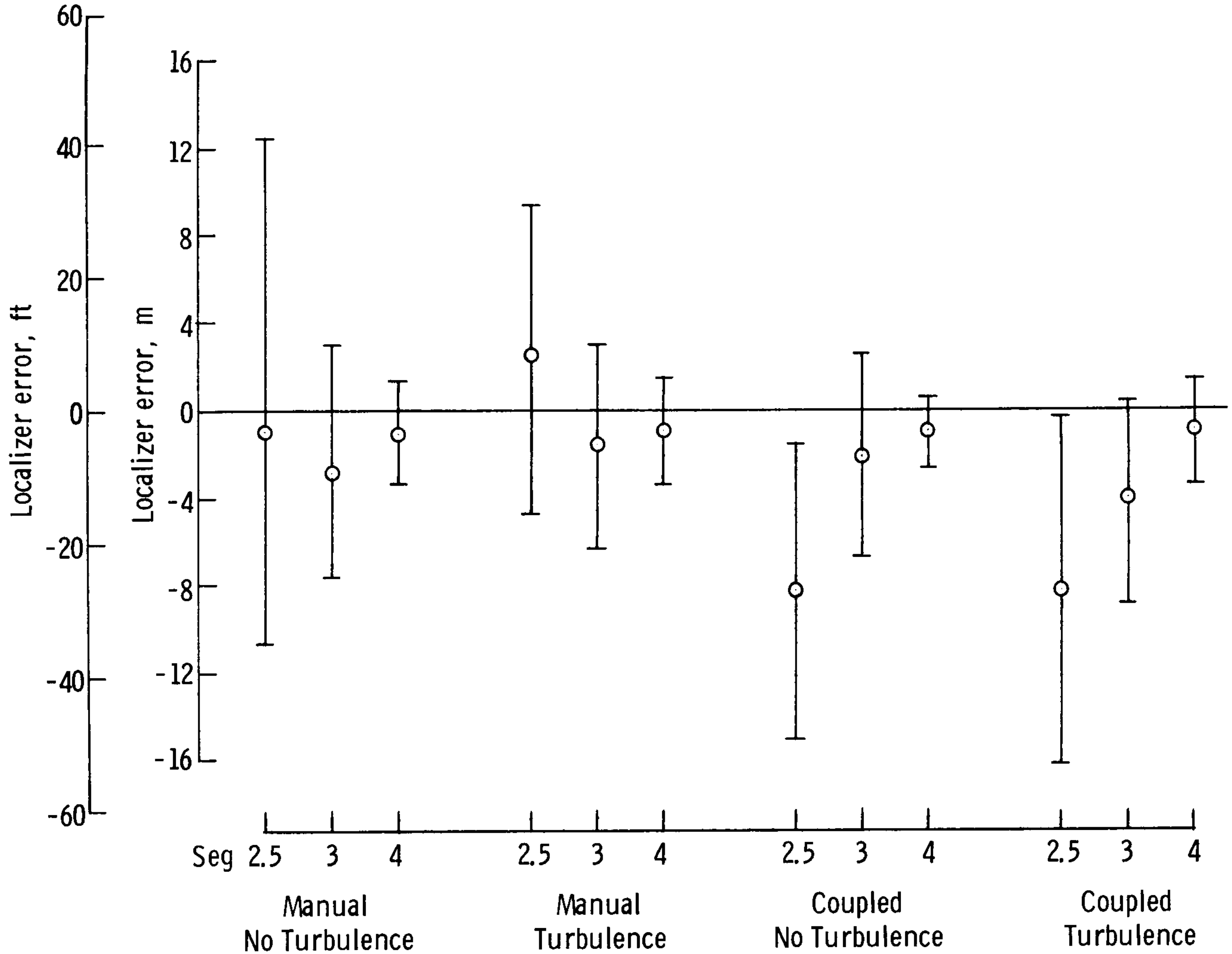


Figure 7.- Mean and standard deviation of airplane position relative to localizer beam; seven pilots, three runs each.

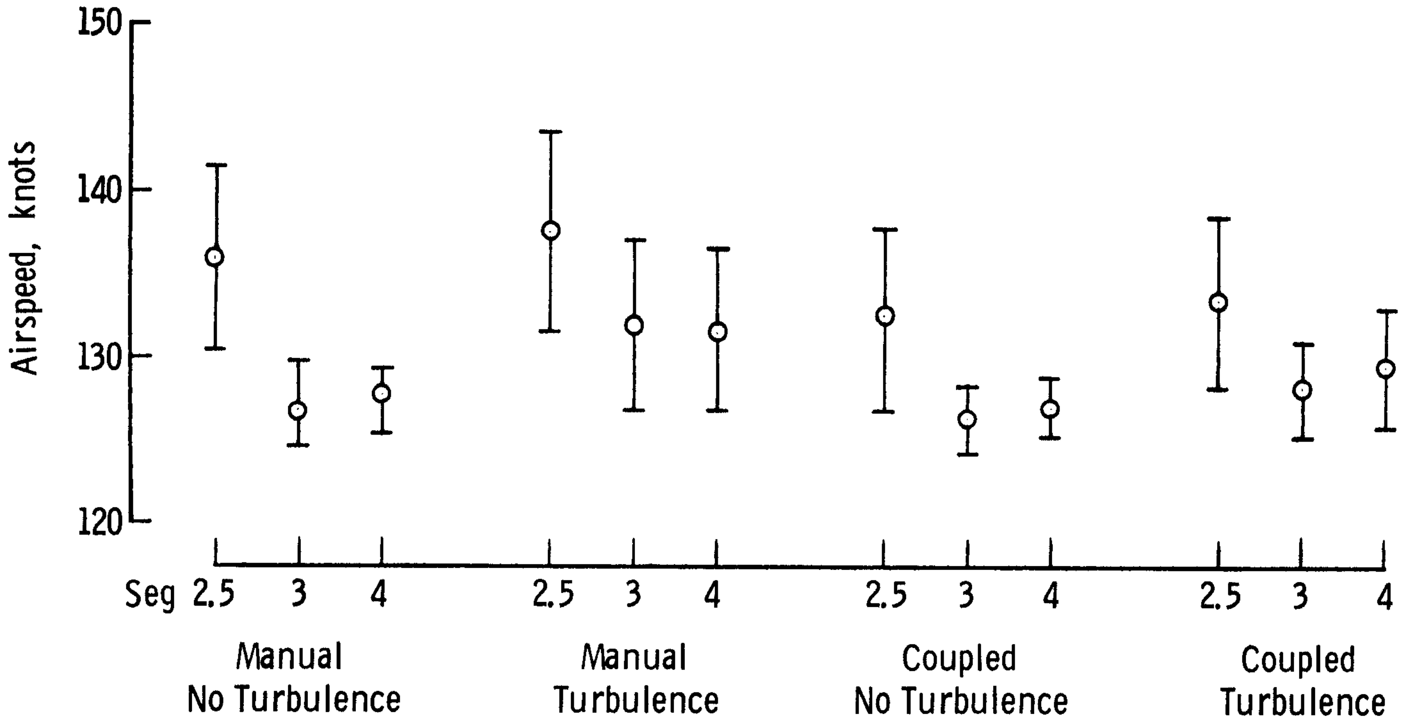
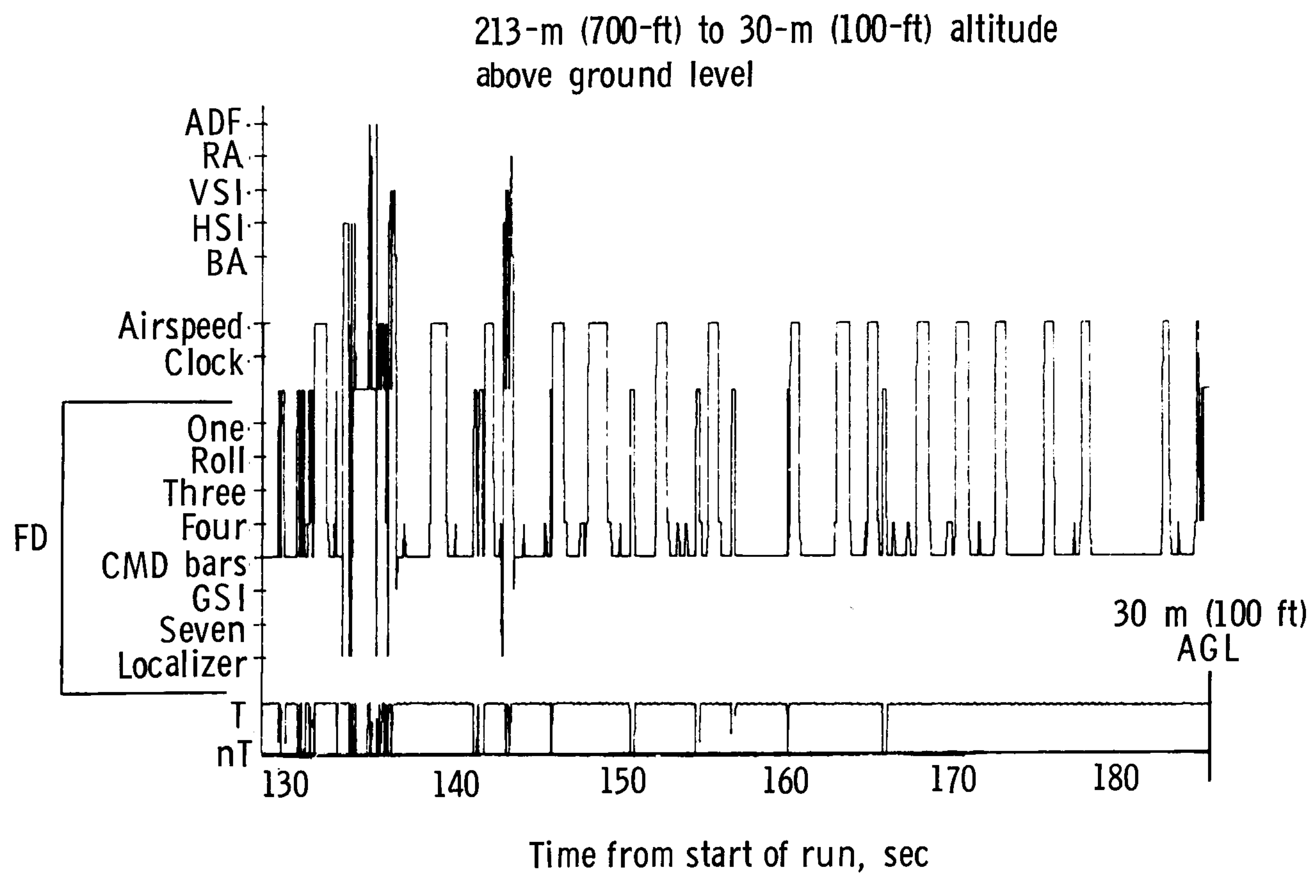
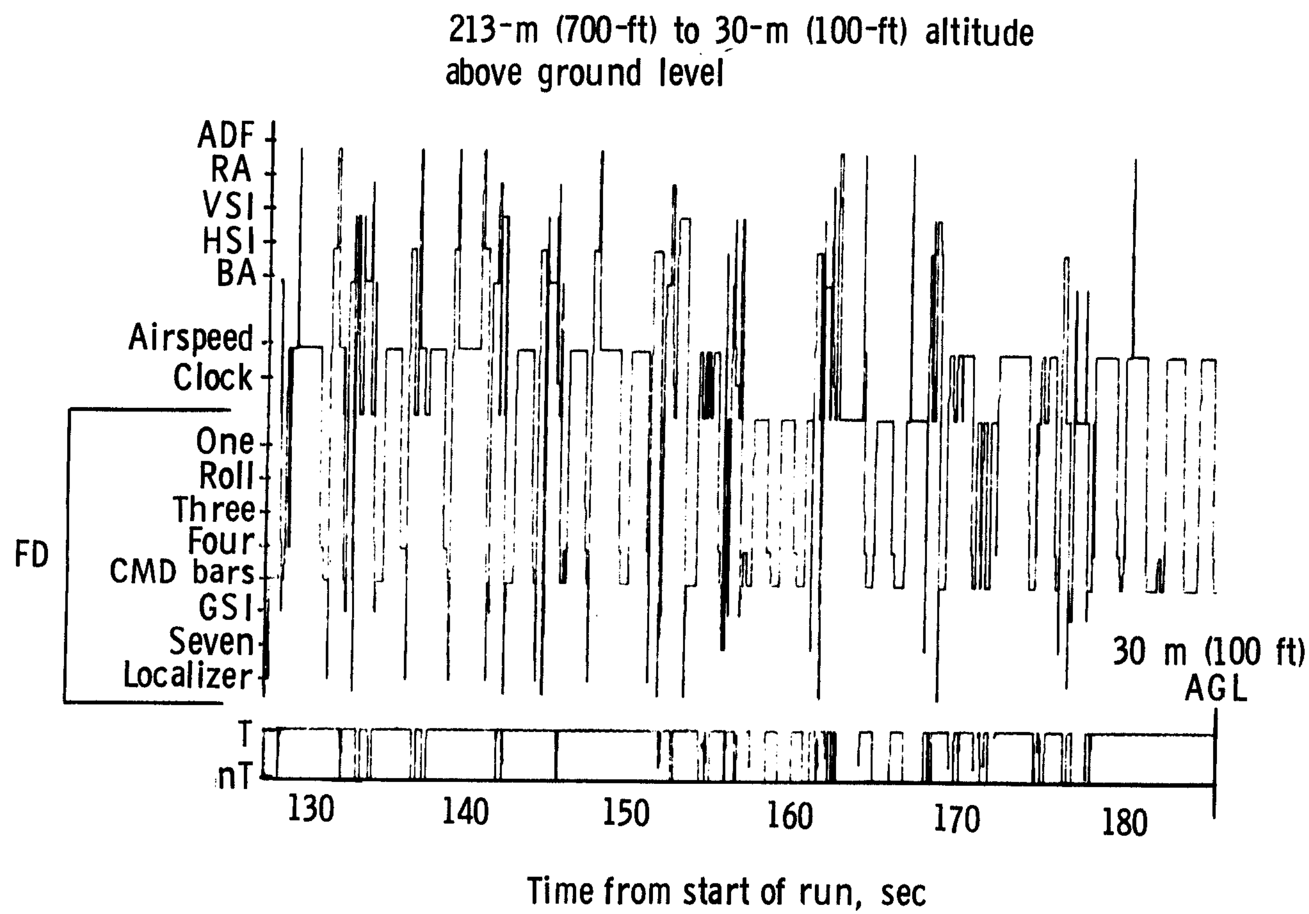


Figure 8.- Mean and standard deviation of airspeed during approach; five pilots, three runs each.



(a) Manual.

Figure 9.- Time histories of one pilot's scan during approach.



(b) Coupled.

Figure 9.- Concluded.

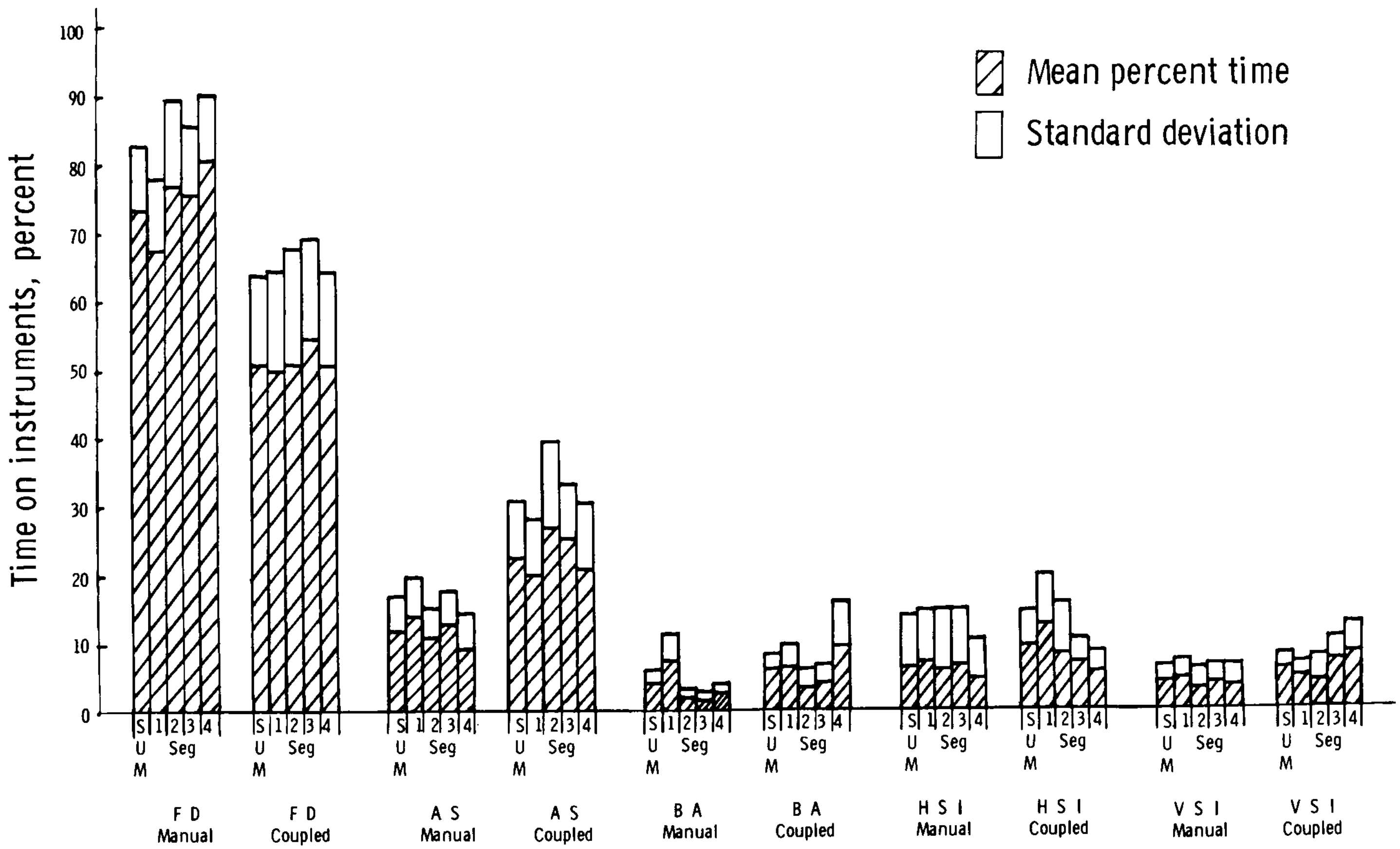


Figure 10.- Percent time on individual instruments for manual and coupled ILS approaches with no turbulence; seven pilots, three runs each.

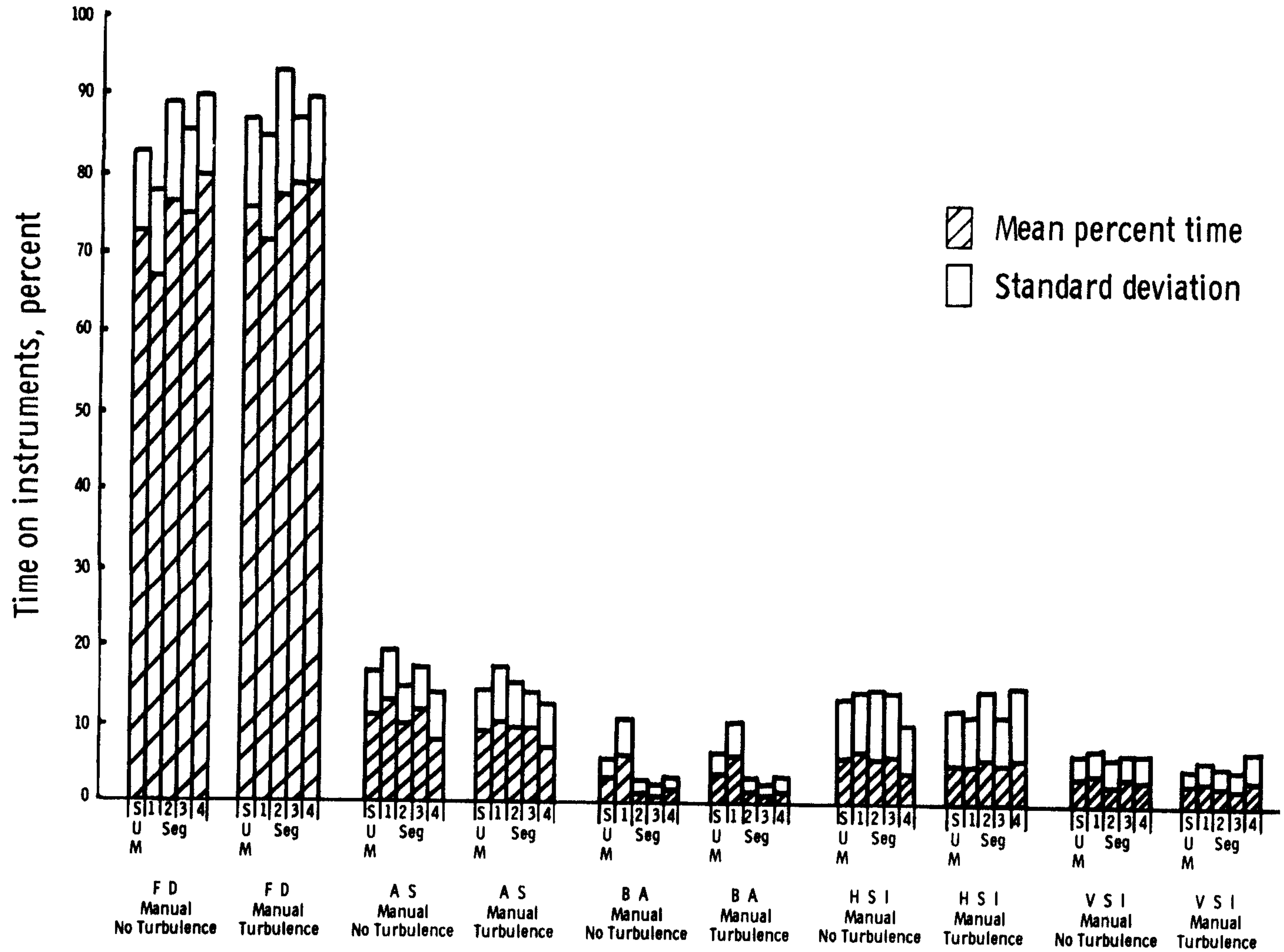


Figure 11.- Percent time on individual instruments for manual ILS approaches with and without turbulence; seven pilots, three runs each.

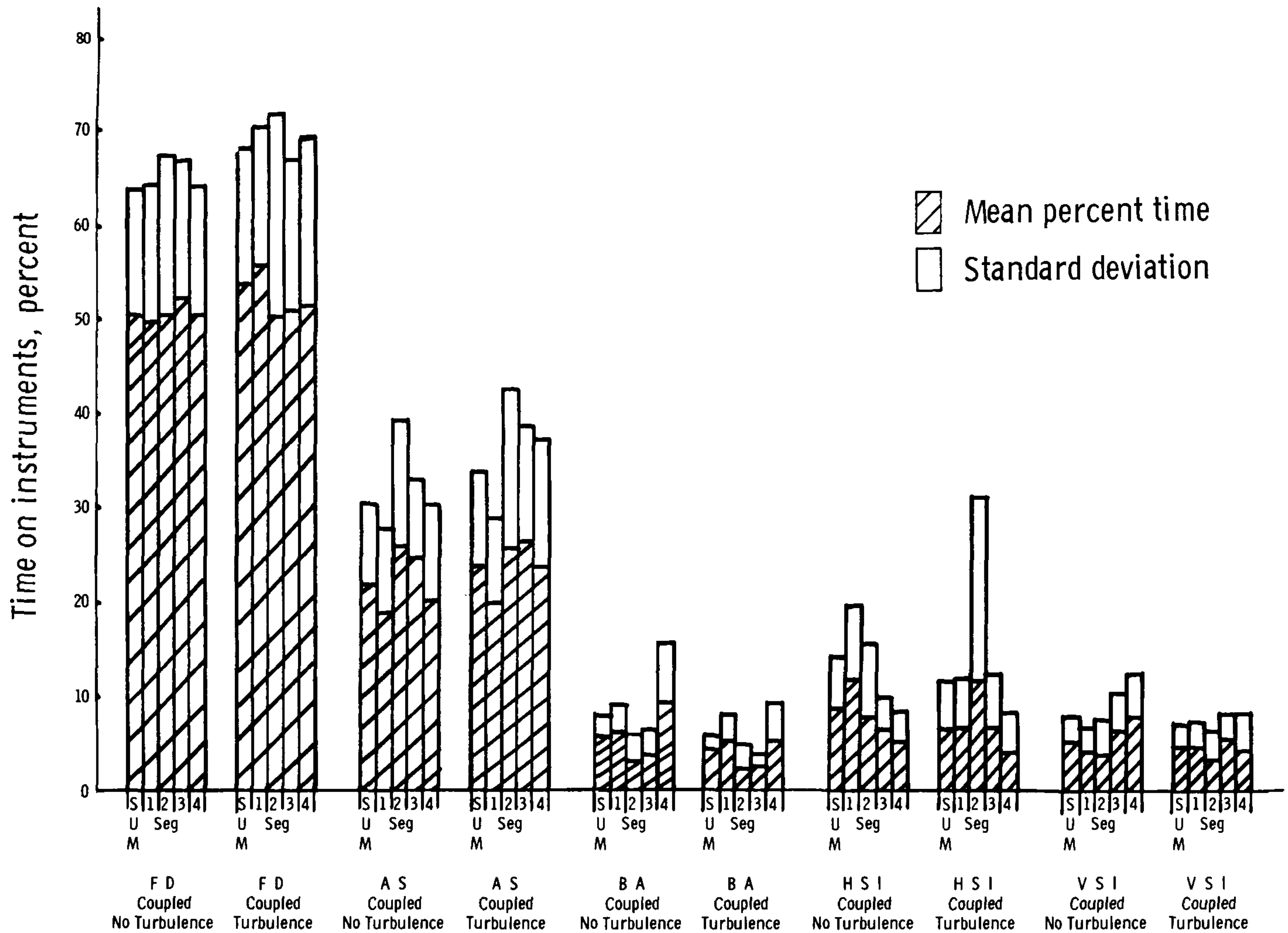


Figure 12.- Percent time on individual instruments for coupled ILS approaches with and without turbulence; seven pilots, three runs each.

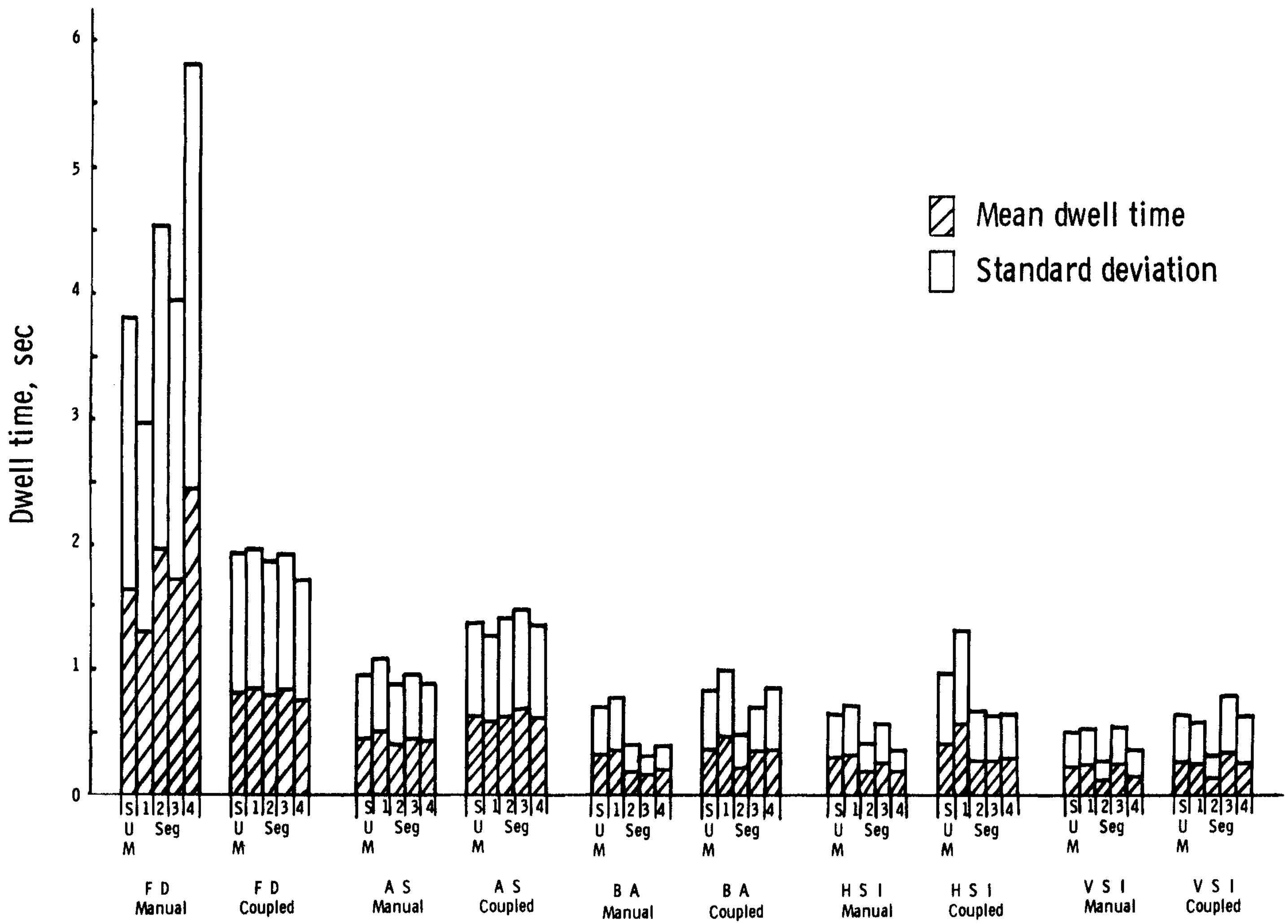


Figure 13.- Dwell time on individual instruments for manual and coupled ILS approaches with no turbulence; seven pilots, three runs each.

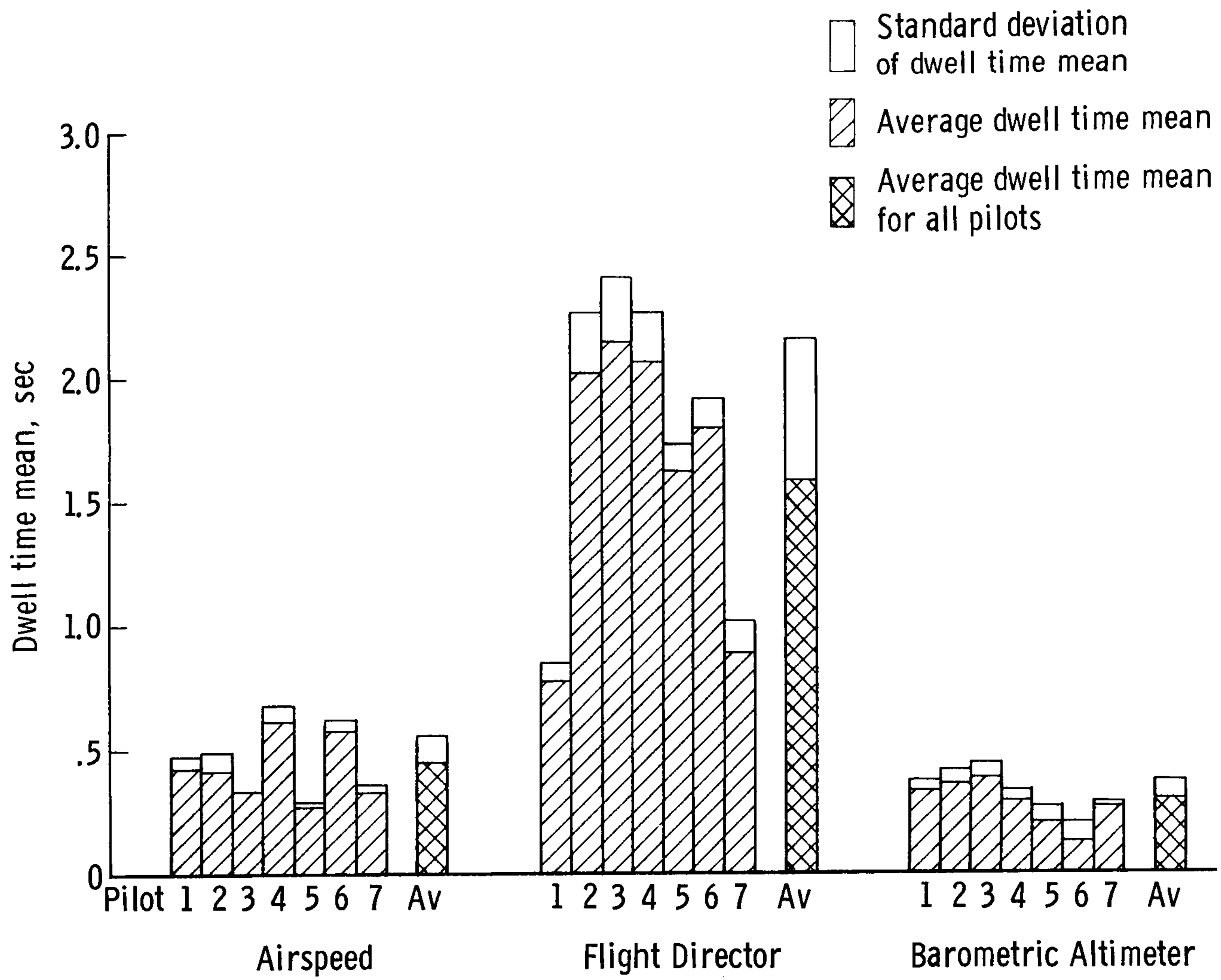


Figure 14.- Average and standard deviation of dwell time mean for each pilot (three runs each) and for all pilots; manual with no turbulence.

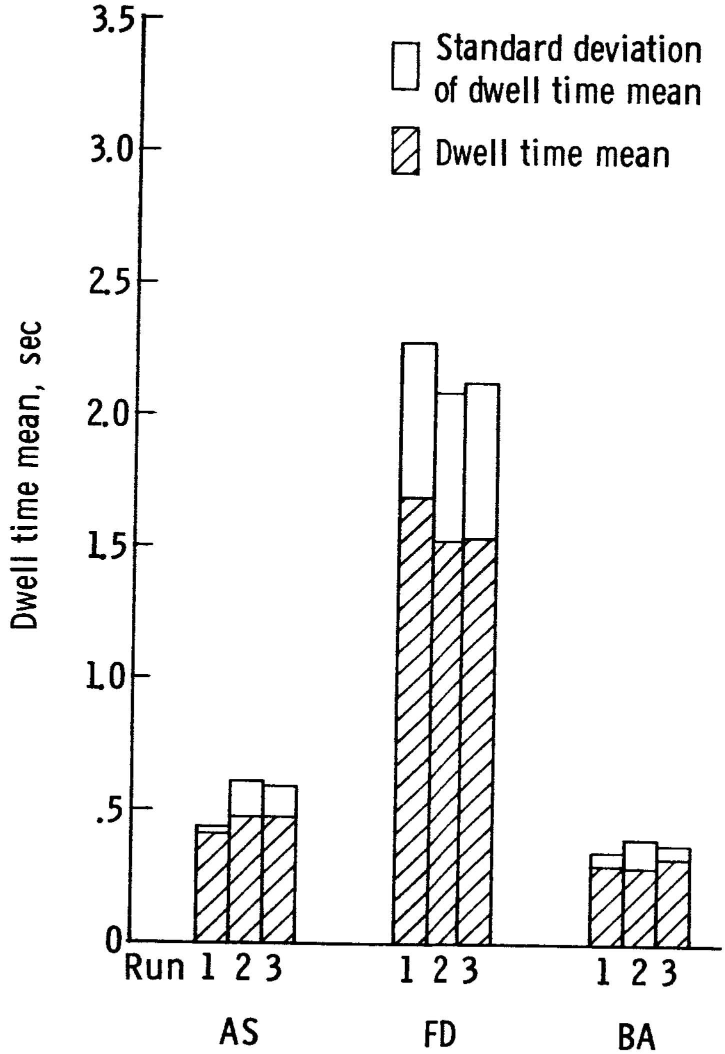


Figure 15.- Average and standard deviation of dwell time mean as function of run order; seven pilots, three runs each; manual with no turbulence.

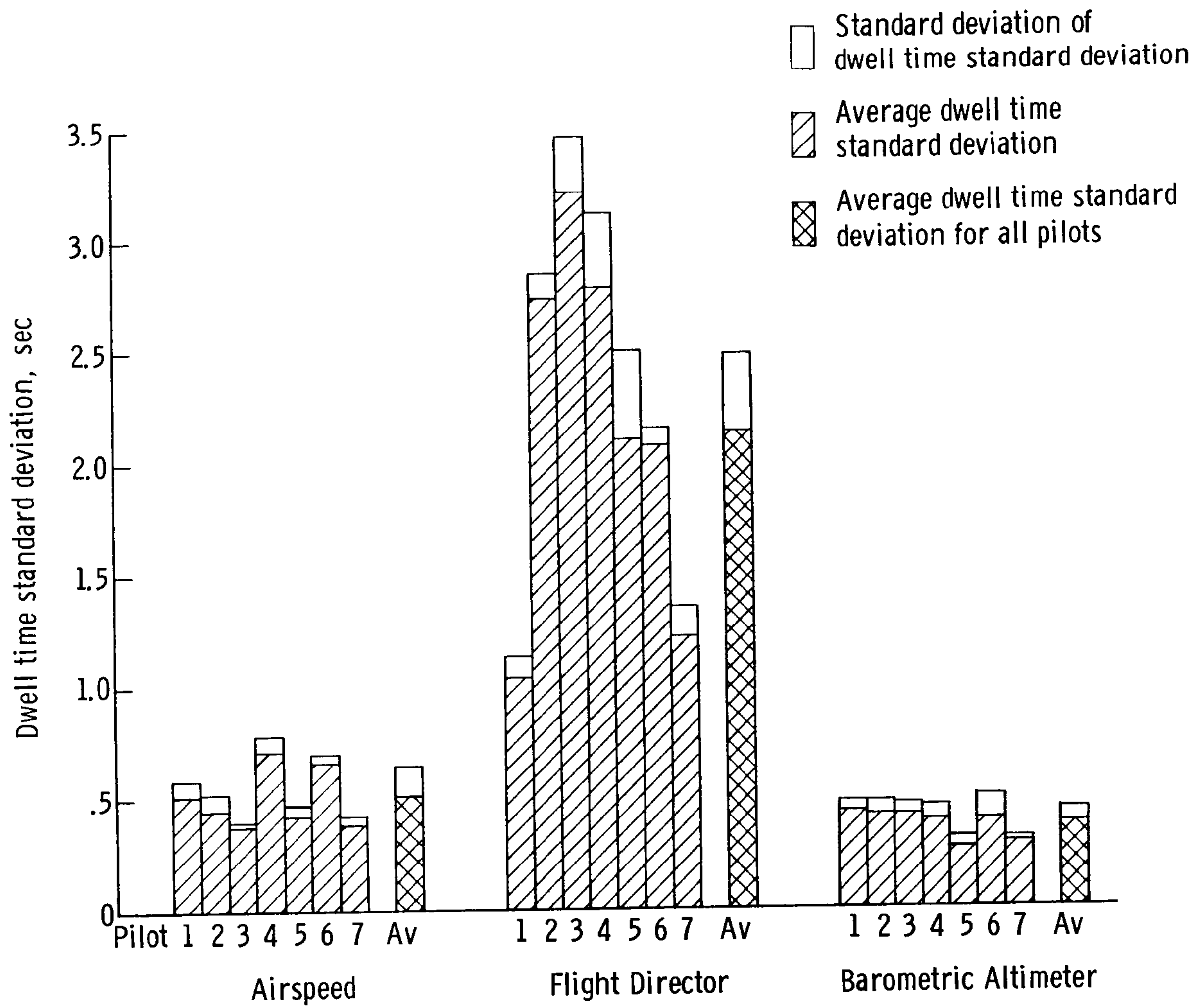


Figure 16.- Average and standard deviation of dwell time standard deviation for each pilot (three runs each); manual with no turbulence.

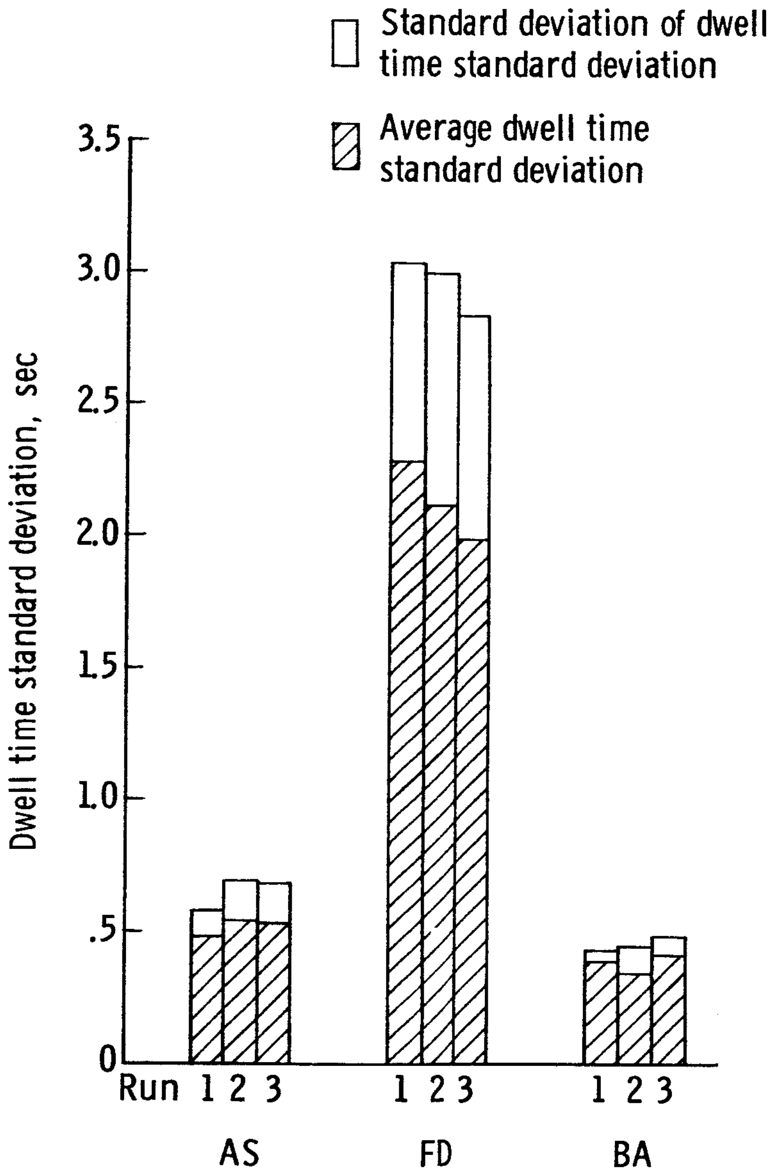


Figure 17.- Average and standard deviation of dwell time standard deviation as function of run order; seven pilots, three runs each; manual with no turbulence.

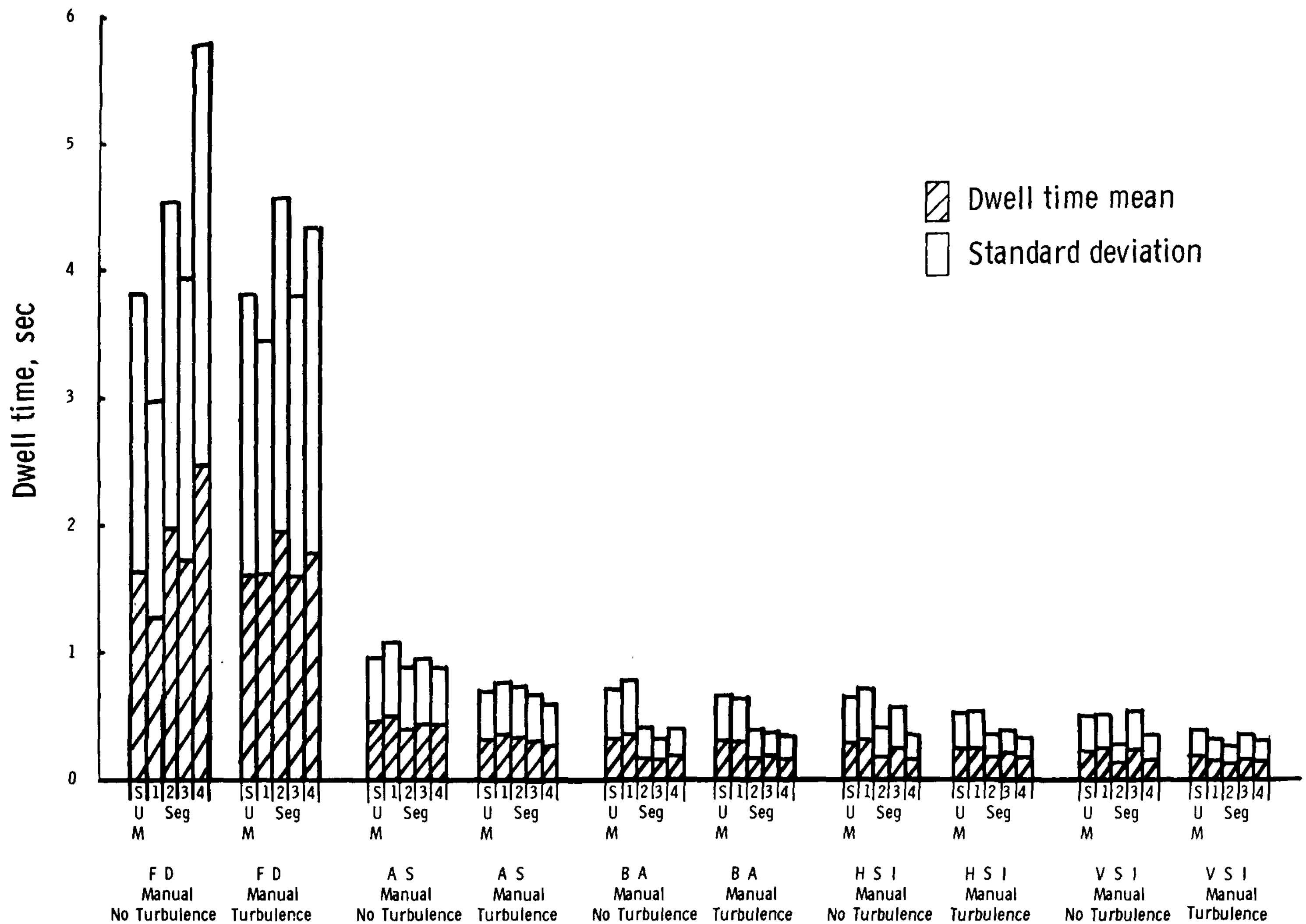


Figure 18.- Dwell time on individual instruments for manual ILS approaches with and without turbulence; seven pilots, three runs each.

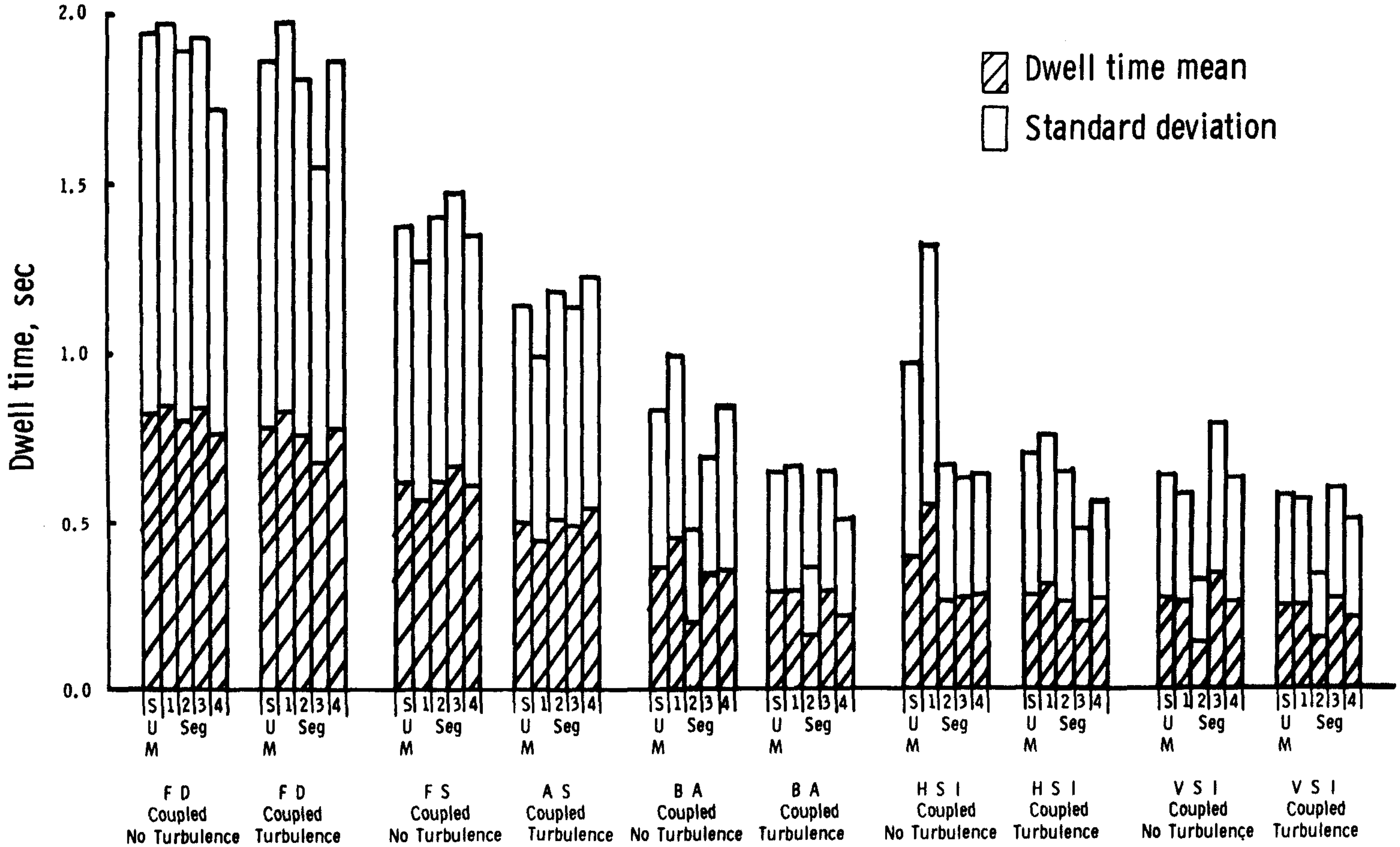
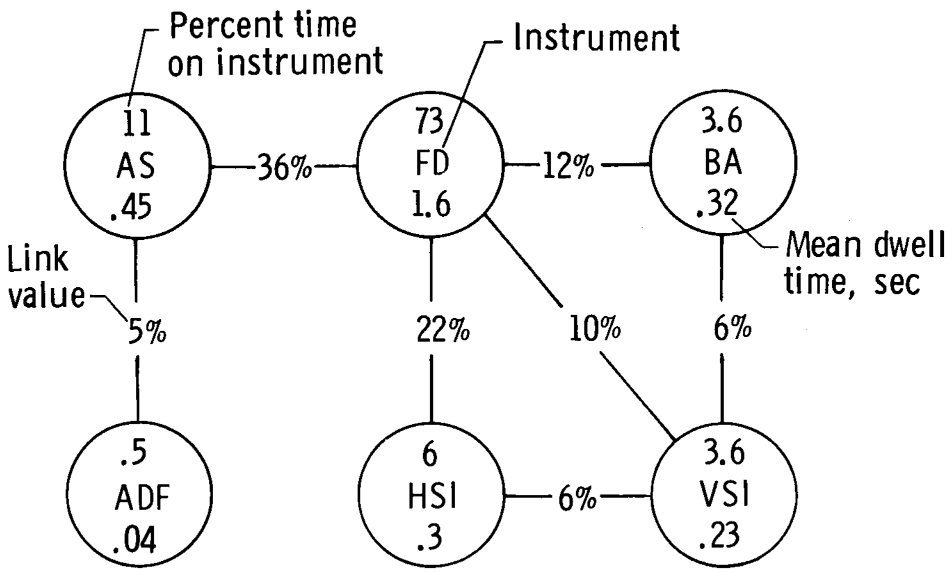
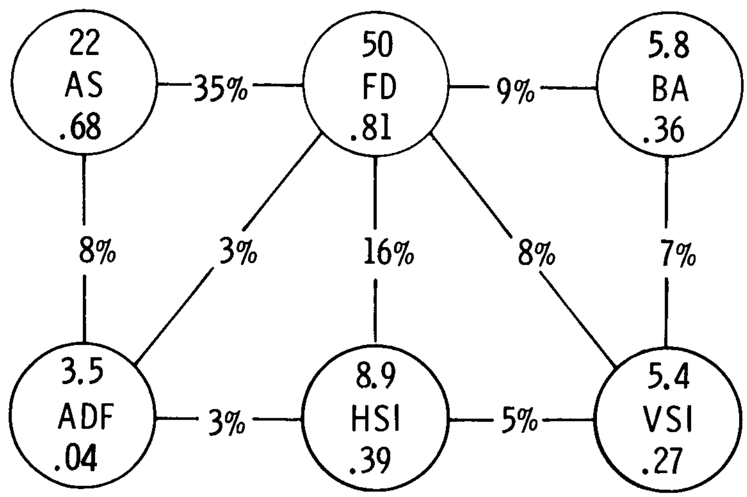


Figure 19.- Dwell time on individual instruments for coupled ILS approaches with and without turbulence; seven pilots, three runs each.

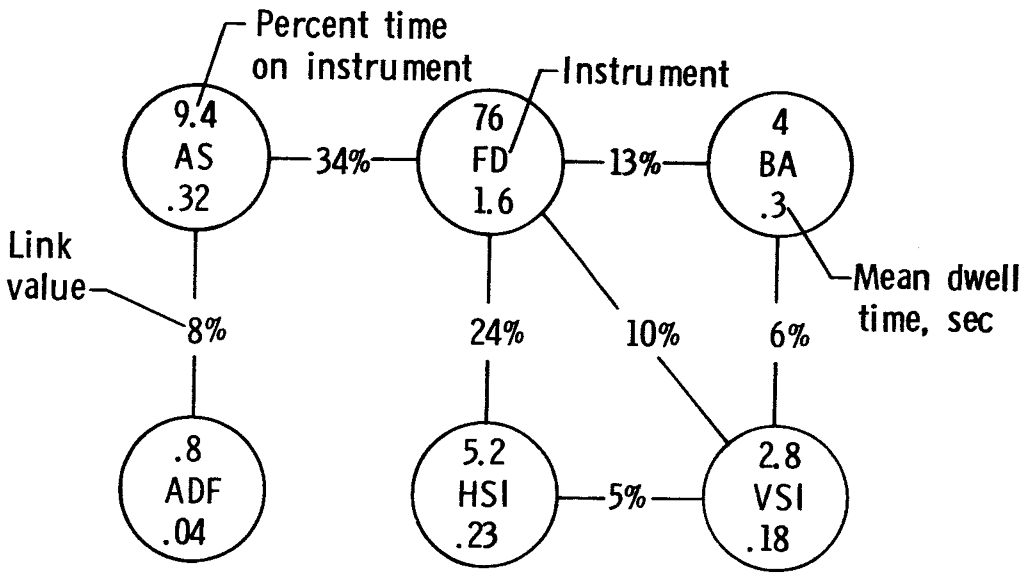


(a) ILS manual, no turbulence.

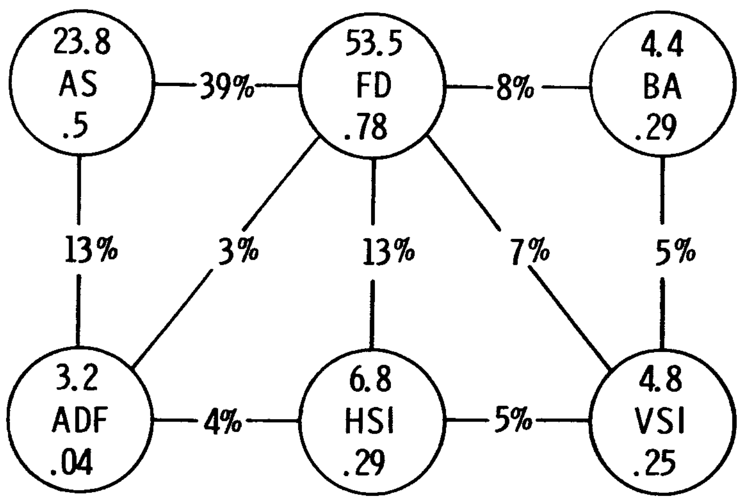


(b) ILS coupled, no turbulence.

Figure 20.- Manual and coupled ILS approaches with no atmospheric turbulence; link values less than 2 percent omitted.



(a) ILS manual with turbulence.



(b) ILS coupled with turbulence.

Figure 21.- Manual and coupled ILS approaches with atmospheric turbulence; link values less than 2 percent omitted.

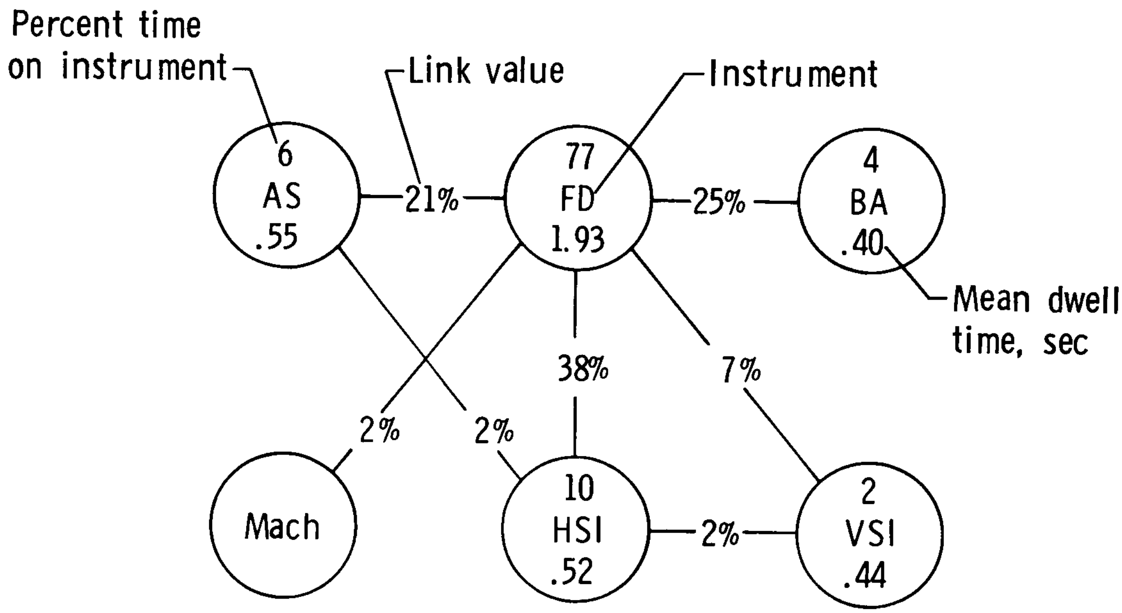


Figure 22.- Link value data for four pilots flying ILS approaches in DC-8 simulator (ref. 4).

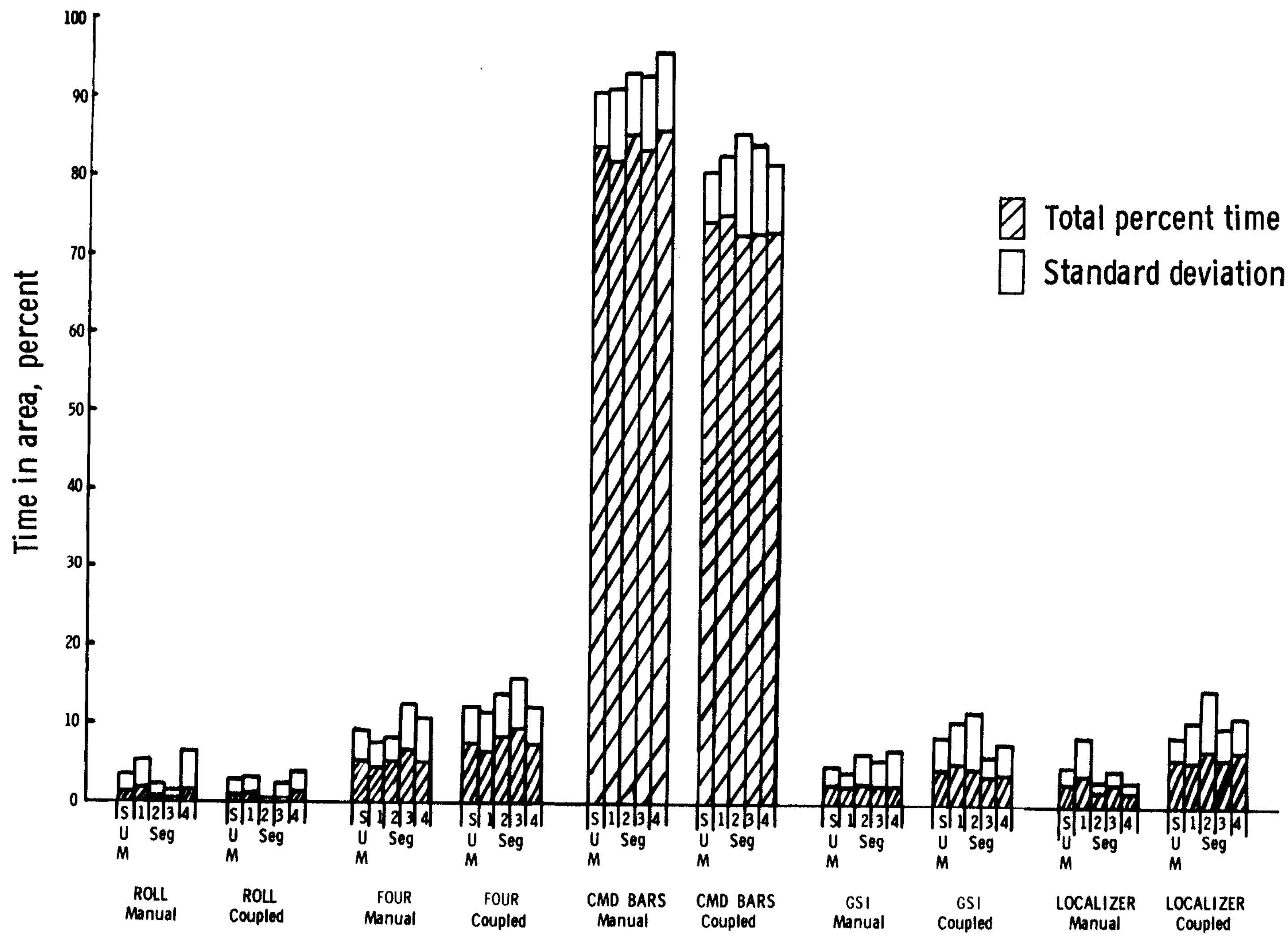


Figure 23.- Percent time in flight director areas for manual and coupled ILS approaches with no turbulence.

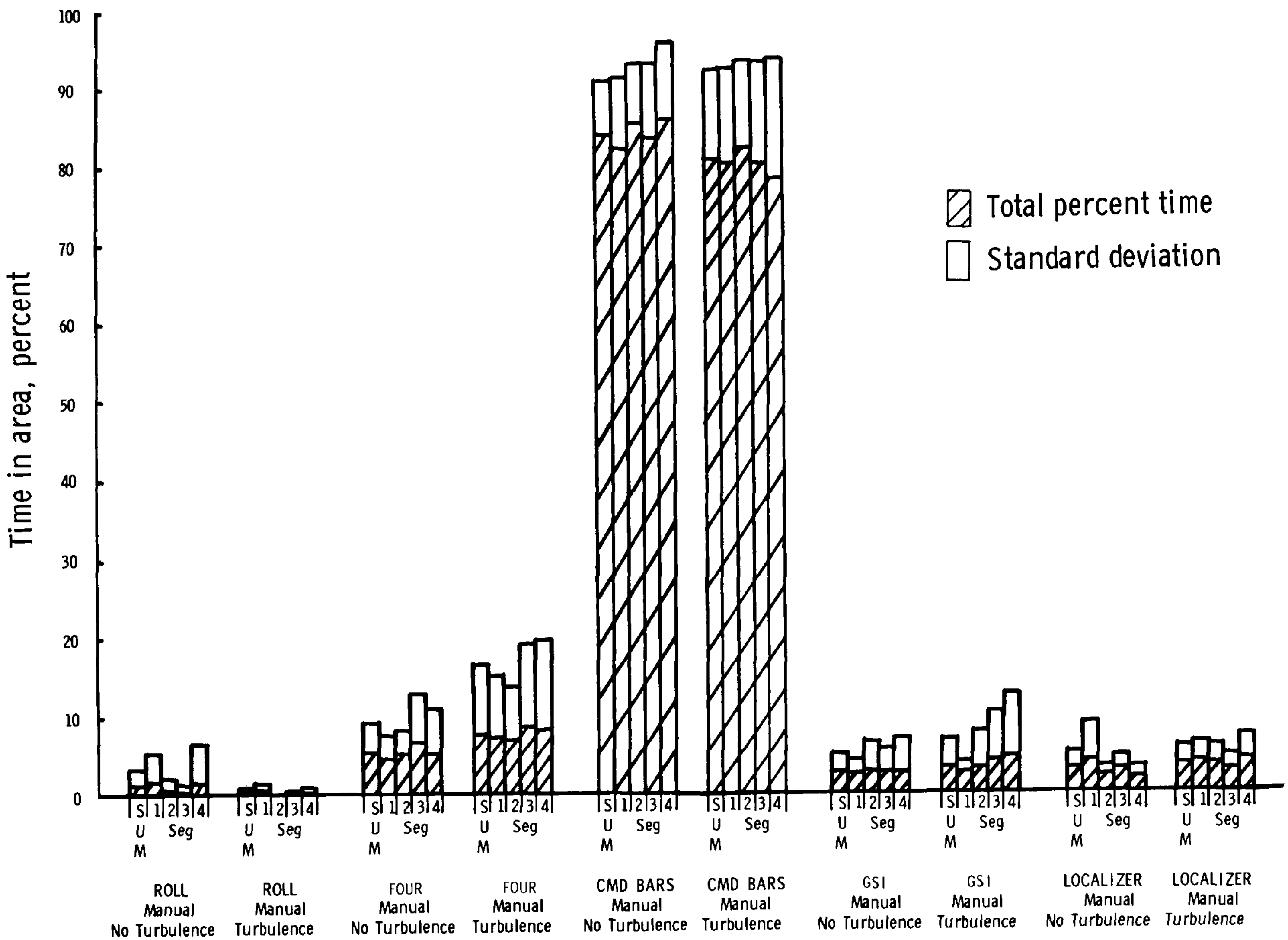


Figure 24.- Percent time in flight director areas for manual ILS approaches with and without turbulence.

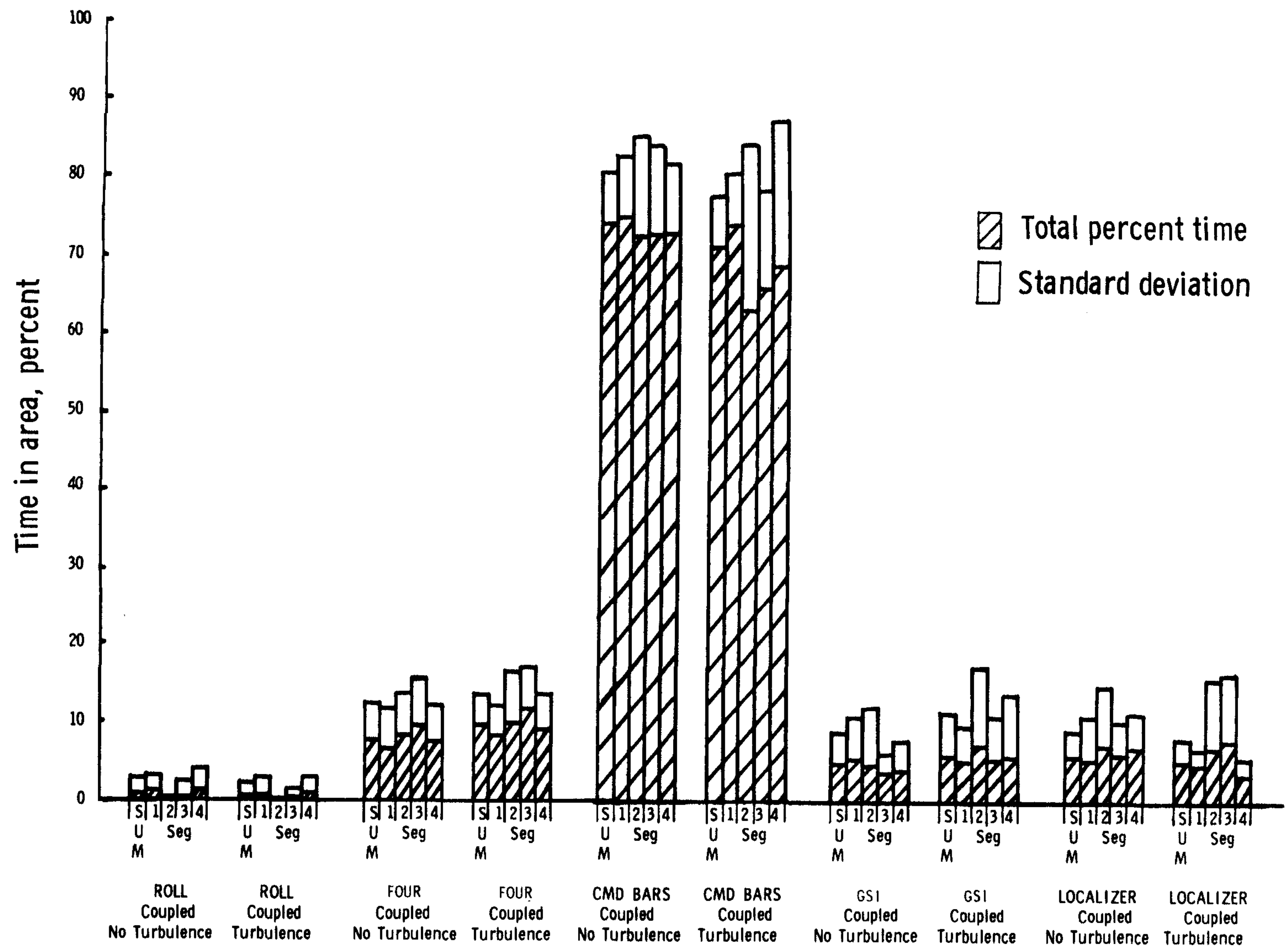


Figure 25.- Percent time in flight director areas for coupled ILS approaches with and without turbulence.

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15. Supplementary Notes

Appendix A by Marion A. Wise and James D. Holt.

16. Abstract

A series of instrument landing system (ILS) approaches have been conducted using seven airline-rated Boeing 737 pilots in a Federal Aviation Administration (FAA) qualified simulator. The test matrix included both manual and coupled approaches with and without atmospheric turbulence in Category II visibility conditions. A nonintrusive oculometer system was used to track the pilot eye-point-of-regard throughout the approach. The results indicate that, in general, the pilots use different scan techniques for the manual and coupled conditions and that the introduction of atmospheric turbulence does not greatly affect the scan behavior in either case.

A comparison between objective measures of the instrument scan (oculometer data) and subjective pilot opinion, ranking their use of each instrument, has been included. The pilots consistently ranked the instruments in terms of most used to least used. The ranking obtained from the oculometer data agrees with the pilot ranking for the flight director and airspeed, the most important instruments. However, the pilots apparently ranked the other instruments in terms of their concern for information rather than according to their actual scanning behavior.

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