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LANDING APPROACH EVALUATION OF AN INTEGRATED CRT DISPLAY FOR GENERAL AVIATION AIRCRAFT

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Approaches made with visual references only, with a conventional ILS displacement instrument, and with the CRT display were compared in terms of tracking performance and pilot workload.

Tracking performance of three research pilots using the CRT display was superior to that using the conventional ILS instrument and comparable to that under VFR conditions. Pilot workload (based on pilot comments) was not clearly decreased.

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SUMMARY

A flight director adaptable to general aviation aircraft was evaluated for the landing approach task in a twin turbojet business aircraft. The flight director combined aircraft heading, pitch and roll attitude, and ILS (Instrument Landing System) signals into a single picture on a small cathode ray tube (CRT) to give the pilot an integrated picture of the aircraft situation. The display is unique in that it presents the information on a CRT and gives quasi-command signals to the pilot. The particular display investigated was a preproduction version of the Kaiser Model FP-50 flight director.

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INTRODUCTION

General aviation aircraft equipped to make instrument approaches to ILS equipped airports commonly use an ILS displacement instrument as the primary approach reference. This instrument displays deviation from glideslope and lateral offset from runway center line which is called situation information. The pilot is then expected to use this information to stay on the glideslope during the landing approach and arrive with minimum lateral and vertical offset when the runway is sighted. Use of this instrument requires that the pilot scan and integrate information from several panel instruments.

Modern transport aircraft and military airplanes are frequently equipped with navigation and landing approach displays which either combine elements of the situation information, or modify it and present command information, in one single display instrument. The command type are referred to as flight directors. The intent of combining this information into one instrument is to decrease pilot workload during the landing approach and thereby to enable an approach to be made with an ease and precision comparable to that under VFR (Visual Flight Rules) conditions. The cost of these displays has precluded their use in general aviation aircraft.

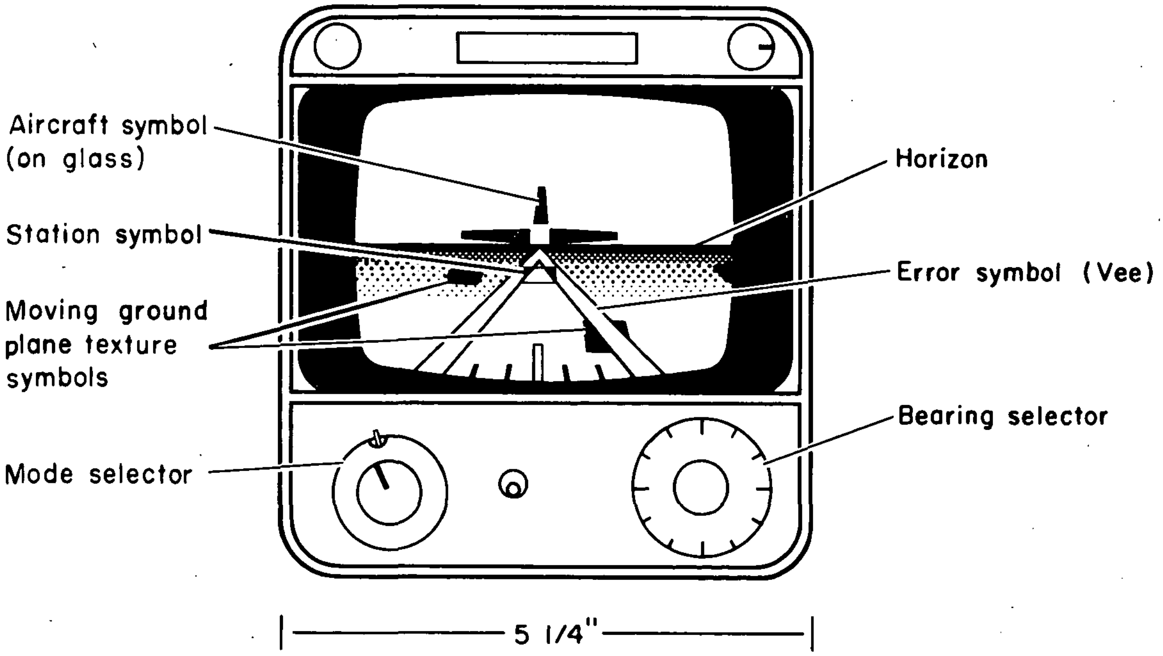
This report is an evaluation of a display developed specifically for general aviation aircraft. The model evaluated was a preproduction version of the Kaiser Model FP-50 flight director. The logic and sensitivities used were those proposed by the manufacturer. The instrument combines aircraft heading, pitch and roll attitude, and ILS signals (of airplanes already equipped with these instruments) into a single picture on a small CRT to give the pilot an integrated picture of the aircraft position and error situation. This class of displays (and flight directors) is aimed at small business aircraft rather than very light, single-engine personal-owner-type aircraft. The display is unique in that it presents the information on a CRT and presents quasi-command signals to the pilot.

This report compares the relative tracking precision of approaches. Included are the pilots' subjective assessments of their workload with the CRT display and with the conventional ILS instrument. The evaluation was conducted in a Lear 23 twin turbojet business aircraft.

DISPLAY AND TEST EQUIPMENT

Display

The display, shown in figures 1(a) and 1(b), was located at the bottom of the airplane instrument panel, to right of center. The aircraft symbol or reticle is located on the glass face and therefore remains fixed with respect to the case of the instrument.



(a) Display features and controls.

Figure 1.– Integrated CRT display device.

Aircraft bank attitude is represented by the horizon angle with respect to the aircraft symbol, representing the real horizon with respect to the aircraft. Pitch attitude is represented by vertical displacement of the horizon line. For a 20° nose-up pitch attitude, the horizon line is at the bottom of the display.

The station symbol moves right or left in proportion to the difference between aircraft heading and runway heading. Provided the heading at the time is the same as the selected runway heading, the station symbol remains centered, even if the aircraft is laterally displaced from the localizer centerline.

The ground texture symbols move continuously from the horizon to the bottom of the display; lateral drift is introduced when aircraft bank angle exceeds a fixed value. During these tests, the ground-texture feature operated erratically, and the symbols were sometimes smeared or absent. The pilots appreciated this feature when it functioned properly, but its absence was not believed to significantly affect the results presented in this report.

(b) Airplane instrument panel.

Figure 1.– Concluded.

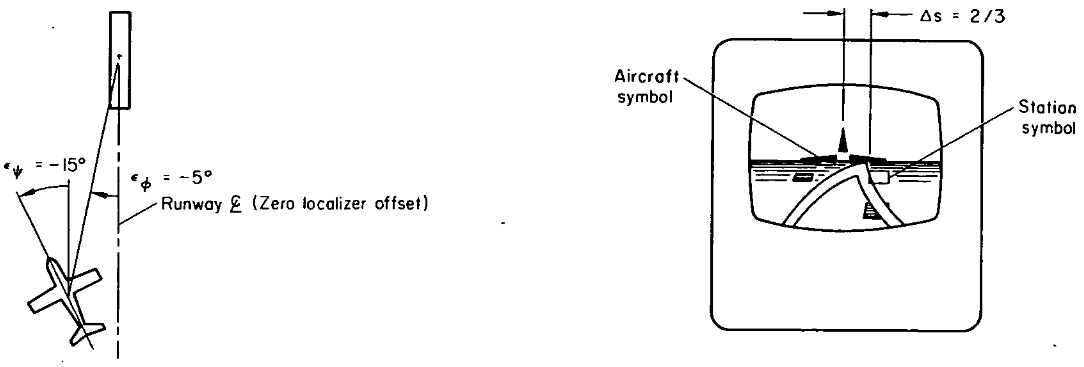
The inverted vee pathway responds to localizer and glideslope deviations. Glide-slope offset is displayed directly as a 0.64-cm (0.25-in.) vertical displacement of the apex of the vee from the horizon for each 0.1° error in glide slope. The apex is above the horizon for deviations below glide slope. The airplane is controlled such that the horizon is brought to the apex of the vee.

The lateral displacement of the vee apex is affected by both localizer offset (in degrees) and errors between airplane heading and runway heading. The lower legs of the vee remain fixed, and the apex moves right or left, giving the effect of a curving highway seen in perspective with the apex appearing as the highway vanishing point. A curvature to the left represents a steering command to the left, to be stopped when the vee symbol is centered and symmetrical. Thus the display and steering information is a quasi-pictorial type, implying, in a rather natural and compelling way, the appropriate attitude and flight path for intercepting and tracking the localizer and glide-slope beams.

The movement of the vee symbol laterally is controlled by heading errors and localizer errors as follows (see figs. 2(a) and 2(b) for example and definition of terms):

$$\Delta s = (\epsilon_\psi/45) + (\epsilon_\phi/15) \quad 0 \leqslant |\epsilon_\phi| \leqslant 15^\circ$$

$$\Delta s = (\epsilon_\psi/45) + 1 \qquad |\epsilon_\phi| > 15^\circ$$



(a) Aircraft situation.

(b) Display.

Figure 2.– Display and aircraft situation for localizer error and heading error.

The units of Δs are semispans of the aircraft symbol (reticle). For example, if the aircraft is off localizer to the left 5°, and has a heading error of −15°, the apex of the vee would be displaced right from the center of the reticle two thirds of the distance to the reticle "wing-tip."

Zero error is displayed if $\epsilon_\psi = -3\epsilon_\phi$. That is, if the instantaneous localizer error is compensated by an appropriate heading that would result in ultimate beam interception, the pilot sees a straight-ahead steering command.

The effect of localizer error is limited to offsets of ±15°. Beyond that point, only errors in heading further displace the vee.

The incorporation of this type of logic accounts for two special characteristics of this display: Limiting the ϵ_ϕ term to 15° results in a commanded 45° localizer intercept angle – that is, to null out the ϵ_ϕ term requires that ϵ_ψ be 45°. Additionally, if a crosswind is present during the approach and $\epsilon_\phi < 15°$, steering such that the vee symbol remains centered results in an approach on some radial other than the runway centerline radial. The approach angle ϵ_ϕ is a consequence of the crosswind component and the position law that governs the position of the symbol.

Referring to figure 2(c), the airplane is shown approaching the runway with a crosswind from the left. The ground track angle ρ is described by

$$\tan\rho = (V_c + V\sin\psi)/V\cos\psi$$

$$\rho \cong (V_c/V) + \psi$$

If the aircraft heading ϵ_ψ is adjusted so that the aircraft approaches along a localizer radial ϵ_ϕ, the aircraft will track toward the localizer transmitter. That is,

$$\frac{V_c}{V} + \epsilon_\psi = -\epsilon_\phi$$

If the vee symbol is kept centered, then

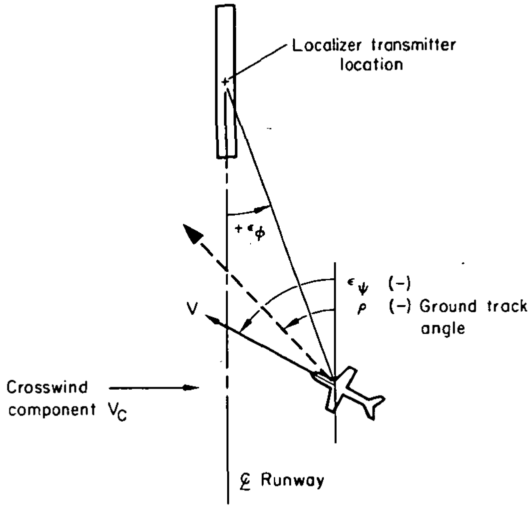
$$\epsilon_\psi = -3\epsilon_\phi$$

and hence

$$\epsilon_\phi = (1/2)(V_c/V)$$

and

$$\epsilon_\psi = -(3/2)(V_c/V)$$



(c) Crosswind landing situation.

Figure 2.– Concluded.

To the pilot, the instrument appears to have computed a wind-drift solution, since his basic task is unchanged from a zero crosswind approach. Actually, he is forced to correct for drift continuously by heading changes until the errors in ϕ and ψ are as described. This logic results in offsets from the runway centerline upon arrival at the threshold, if the localizer transmitter location is down the runway from the threshold. For a 15-knot crosswind and a 120-knot approach speed with a transmitter located 305 m (1000 ft) from the threshold, ϵ_ϕ is 3.6° and the lateral offset at the threshold is 19 m (62 ft). Breaking out at this point, the pilot would view the touchdown position (from his altitude about 15 m (50 ft)) to the right at an angle of 11° from the aircraft heading.

This feature has been found to be unsatisfactory by the manufacturer in independent tests and has been modified in development models to eliminate long-term ϵ_ψ contributions to the error signals near the threshold.

The standard ILS instrument used was scaled so that a one-dot deviation of the horizontal needle corresponded to a 0.1° glide-slope error and a 3-dot deviation of the vertical needle corresponded to a 2.5° localizer error.

Test Instrumentation

Fourteen parameters were continuously recorded during the approach on a 14-channel onboard analog tape recorder. Some of these and additional parameters were also simultaneously recorded on a strip-chart recorder for monitoring by the test engineer during the approach. The recorded parameters were: aircraft attitude, rates and accelerations at the center of gravity, aileron and rudder position, angle of attack, sideslip, airspeed and altitude, and glide slope and localizer deviations. Pilot comments were recorded on a separate voice recorder during each run.

Test Aircraft

The test aircraft was a Lear Model 23 twin-turbojet light business aircraft. No modifications were made to the aircraft other than the installation of a nose-boom system for measuring airspeed, angle of attack, and sideslip. This aircraft is equipped with a yaw damper device to minimize dutch-roll disturbances at landing approach speeds. This device was disengaged during the test runs. The landing approaches were made at normal gross weight.

TEST PROCEDURE

Before the actual data flights, each pilot had the opportunity to become generally familiar with the display by making several approaches while checking out the recording system and display. During each test series, a single pilot made between 9 and 13 approaches which included practice approaches and runs for data. First, a visual approach was made for practice, checking of recording equipment, and establishing a racetrack pattern for the remaining runs.

The downwind leg of the pattern was extended to well beyond the outer marker. Every attempt was then made to trim the aircraft for final approach with the assistance of the safety pilot and to have zero glide slope and localizer errors upon arrival of the outer marker – approximately 13 km (7 n.mi.) from the runway threshold. Initial entry into the approach seemed to have some bearing on subsequent performance during the approach. If approach speed, throttle, or position were not correct and coordinated at the entry, subsequent tracking was poor. Therefore, the safety pilot was allowed to assist the pilot in setting the airplane up so that a good approach entry could be assured on each run. Data recording was initiated before crossing the outer marker.

A conventional instrument flying hood was used by the pilot to prevent his using outside references during an instrument approach. The safety pilot removed the hood at approximately 70 m (220 ft) above runway altitude. The remaining maneuver consisted of a low approach followed by the next downwind leg.

During each test series, the pilot first made a minimum of two visual approaches and three conventional ILS approaches. The remaining approaches were then made with the CRT display. Three research pilots participated in the program. Of the three, pilot B was the least experienced in this type of aircraft, having only 60 hr as pilot, whereas pilot A had approximately 1,000 hr and pilot C had 500 hr.

TEST RESULTS

Analysis of Data

Tracking performance and pilot workload were of primary interest in this study. In order to compare runs, a standard time history segment of 130 sec, beginning at the outer marker, was analyzed. Typical localizer and glide-slope error time histories are shown in figure 3. The analog

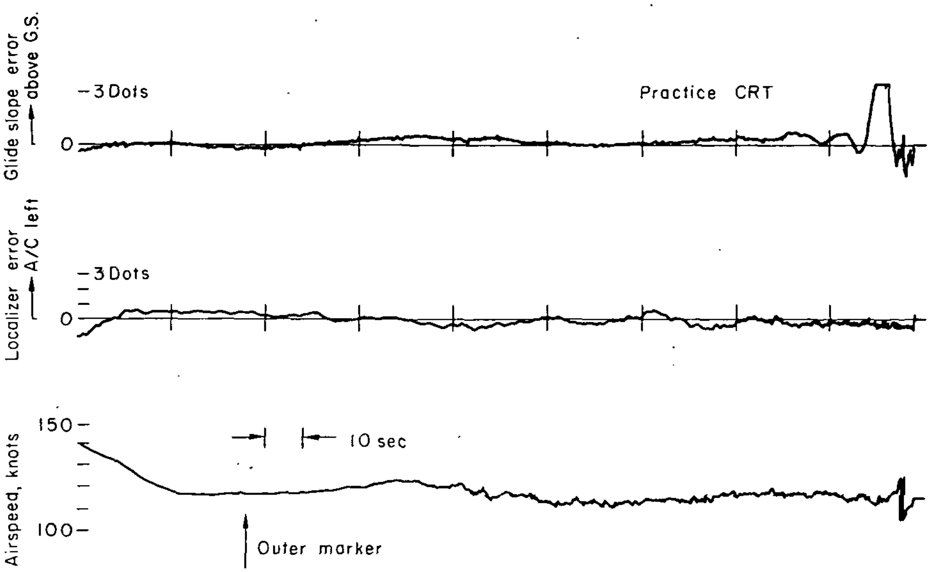


Figure 3.– Tracking time history.

time histories were digitized at a sampling rate of 10 samples per sec for analysis with digital computer programs.

Tracking Errors

Tracking errors were compared by computing their standard deviations. The standard deviation (σ) was used because the records showed means ($\bar{\epsilon}$) displaced from the localizer zero. There were a number of possible sources of a steady mean error: a crosswind, when using the CRT, because of the logic used; a large offset at the beginning of a run; the steady, small errors that may occur during an ILS approach, which could be acceptable to the pilot if the approach is otherwise satisfactory; electrical zero shifts; and, finally, lack of precise reference in visual approaches. Because the particular source of the mean error could not be identified for each run, the standard deviations, rather than root mean square (rms), were used as a measure of tracking performance to eliminate the contribution of a steady mean error.

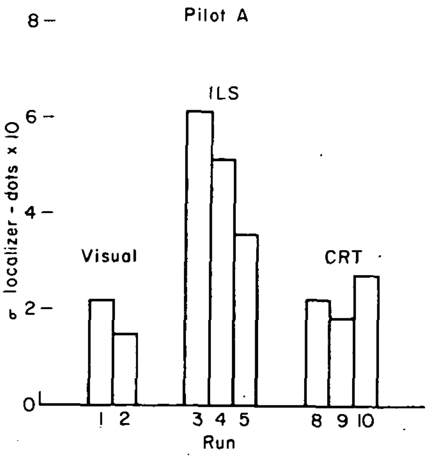


Figure 4.– Localizer error standard deviation.

Figure 4 summarizes the localizer tracking errors for pilot A. Results for the other two pilots are similar. The tracking performance using the CRT display is clearly superior to that using the conventional ILS instrument, and is comparable to that during a visual approach. An error histogram is shown in figure 5 for the best approaches of each type (runs 2, 5, and 9). The data were classified into 1/10-dot error bands. The ordinate of these histograms represents the number of data points, and hence time spent, between the upper and lower boundaries

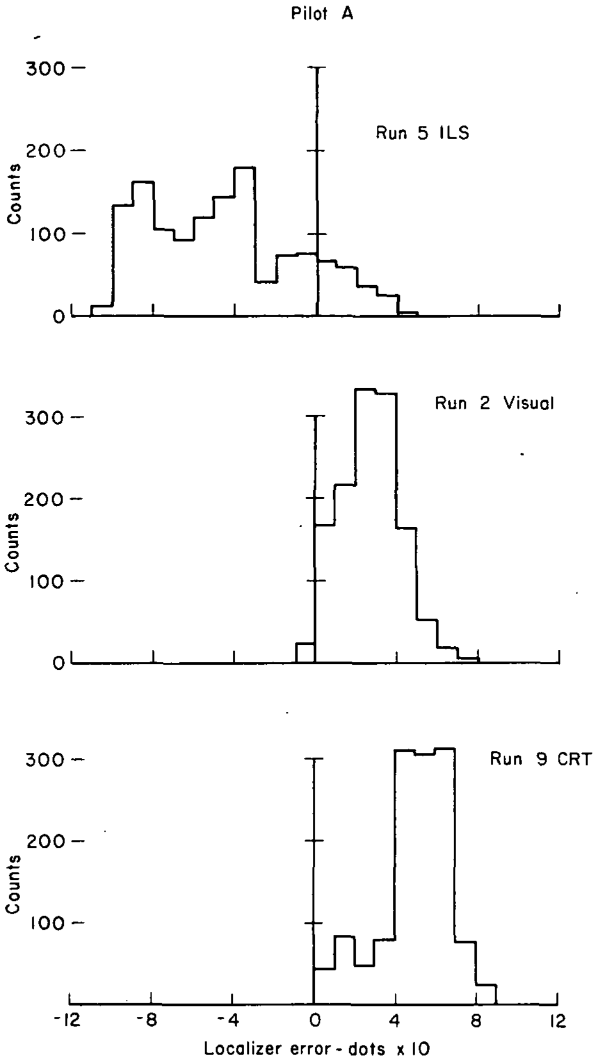


Figure 5.— Localizer error histograms.

of the 1/10-dot error band during the approach. Figure 6 presents the complementary cumulative error distribution, which is the percent of time the airplane exceeded a given displacement. Displacements relative to mean error are shown to facilitate direct comparison of the error distribution. The error range about the mean which is exceeded 2 percent of the total time is less for both the visual and CRT display approaches than for the ILS approach. This error range and the standard deviation are not proportional, since the data are not normally distributed.

Glide-slope tracking error standard deviations for pilot A are shown in figure 7. Again, similar results were obtained with pilots B and C. Glide-slope tracking errors while using the CRT display were less than those made during either the visual or raw ILS approaches. (This might be expected, since there is no clear reference during a visual approach.) It should be emphasized that visual approaches were made without reference to the ILS instrument.

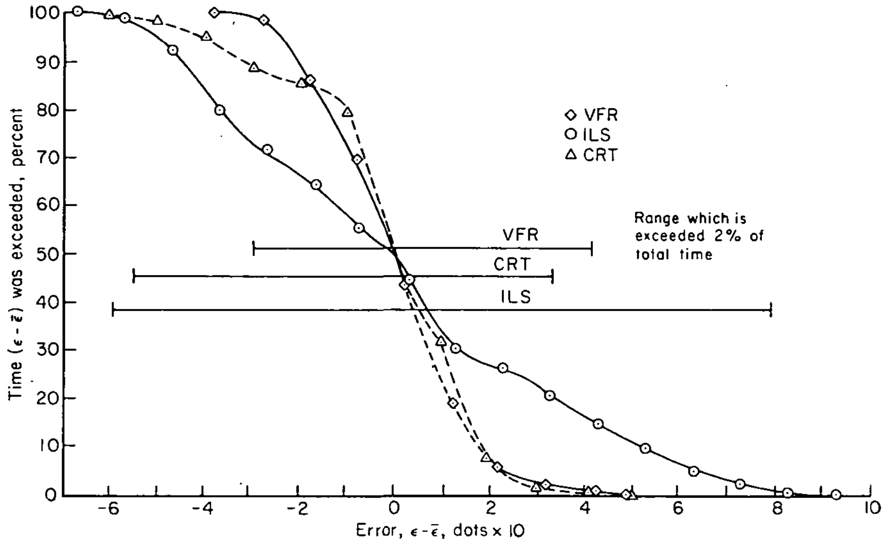


Figure 6.– Localizer cumulative error distribution.

The relationship between localizer errors and glide-slope errors is shown in the tracking performance summary of figure 8. The data are presented in this form, because it summarizes the main findings of this study. Also, because it had been conjectured that some negative correlation might exist between glide-slope and localizer errors on a given run, this method of presenting the data was chosen to emphasize any such relationship. A strong negative correlation between localizer and glide-slope errors would imply that the pilot concentrated on one axis at the expense of poor tracking of the other. No such correlation appears to exist.

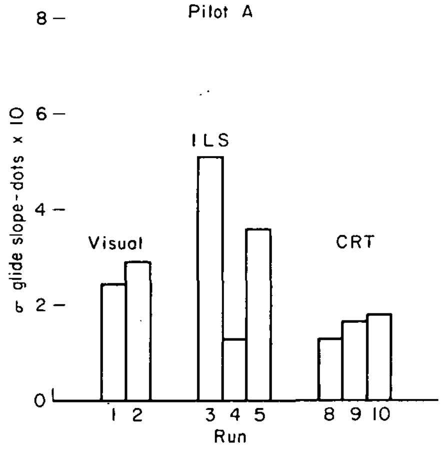


Figure 7.– Glide-slope error standard deviation.

Comparative performance of the three pilots is also shown by figure 8. The relative lack of experience in this aircraft of pilot B is a possible explanation for the larger tracking errors made by him in raw ILS approaches. Significantly, the performance of pilot B was greatly improved with the CRT. Also, the difference in performance is less among pilots using the CRT.

Averaging the data for the entire run obscures the variation of the errors as the airplane approaches the threshold. Because of the nature of the ILS display logic, a given linear displacement of the aircraft from the beam generates a larger ILS error signal near the threshold than at the outer marker. The rms deviation for 13-sec time intervals during the approach is shown in figure 9. The zero-error reference used to compute the rms value is the mean for the full 130-sec run in each case. Each symbol represents the average value for all runs of one type (visual, raw ILS, or CRT). The localizer errors are not significantly greater nearer the threshold, indicating that the pilot is maintaining a fairly constant performance with reference to this instrument, in spite of its increased sensitivity to actual aircraft displacements. Based on a limited inspection of glide-slope tracking performances, similar trends seem to be indicated.

Pilot Workload

The only measure of pilot workload available in these tests was the subjective opinion of the pilots regarding the relative difficulty of the landing approach task. Measurements of lateral and longitudinal stick activity (fig. 10) failed to show any correlation with tracking performance.

All pilots found the CRT display to be convenient to use. However, pilot C objected to the location of the instrument and found that he could not rely solely on the information presented by it. Speed, sink rate, and altitude, especially, required separate monitoring, and the scan pattern was awkward for these instruments and the CRT. Therefore, as installed, this display was not clearly less demanding of the pilot's time or attention even though tracking performance was improved. The pilots felt that the presentation on the CRT integrated display, being quasi-pictorial, was superior to the raw ILS display and equivalent in the tracking task to flying visually, with the added advantage of having a well-defined glide path. The signal gains or display sensitivities were judged appropriate for the tracking task.

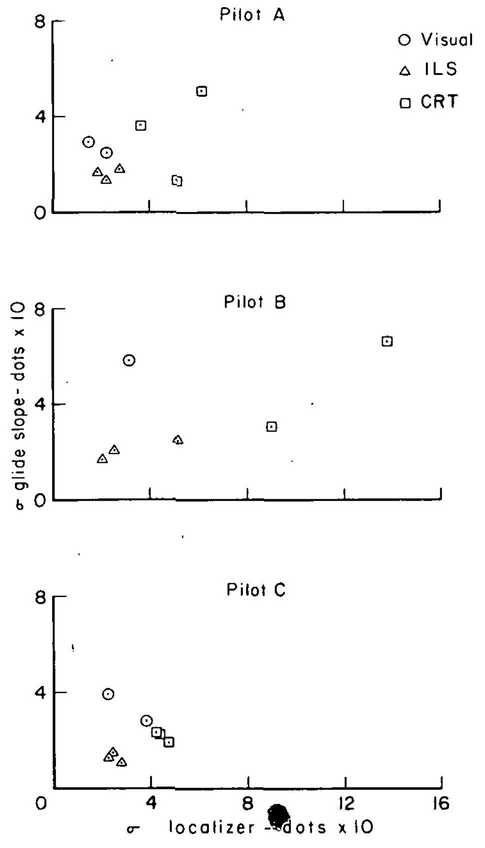


Figure 8.– Tracking performance summary.

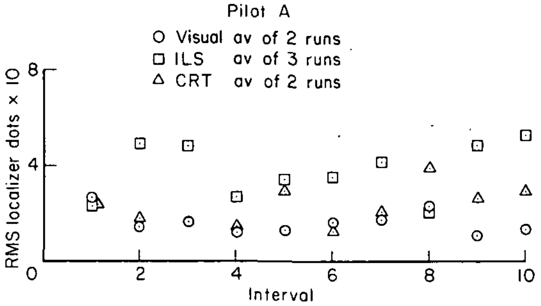


Figure 9.– rms of localizer deviations vs interval for 13-sec intervals.

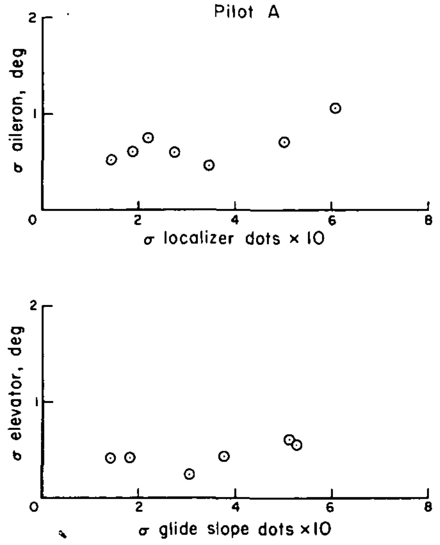


Figure 10.– Control position standard deviation vs. tracking error standard deviation.

CONCLUDING REMARKS

The results of the experiment indicate that the precision of the approach (expressed in terms of standard deviation of errors) on the localizer using the CRT display as the primary instrument was comparable to that for visual approaches and superior to approaches made with raw ILS information only, and that glide-slope errors using the CRT display were less than those made during either a visual approach or an ILS approach.

These tests do not identify the source of the improved tracking capability. Displacement gains on the symbols were maintained constant during the investigation and the display format was always presented as a whole.

Pilot workload was not clearly decreased by using the CRT display instead of the standard ILS instrument.

The CRT display is useful as the primary reference for a landing approach, but must be used in conjunction with separate rate of climb, altitude, and speed information.

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