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Simulator Study of a Flight Director Display

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SUMMARY

A study of the use of a flight director by general aviation pilots in a six-degree-of-freedom, fixed-base simulator has been conducted. The task performed was an instrument landing system (ILS) approach to landing. A special feature of the tests was that the sensitivities of the glide-slope and localizer signals were kept constant at values corresponding to either 5 n.mi. or 1.25 n.mi. from glide-slope ground intercept during any given test run. The flight director command needles were driven by an autopilot command law. Time histories of the pilot-aircraft-display system responses and standard deviations and means of the glide-slope and localizer errors were obtained.

The test results show that the pilot-aircraft-display system responses with the flight director were very similar to the autopilot-aircraft responses. Without the flight director command needles, using only the raw data indicators for guidance, the pilot-aircraft-display system exhibited less damping than with the flight director. The standard deviations of the glide-slope and localizer errors showed a corresponding degradation without the flight director. The sensitivity of the flight director command laws was judged to be about as high as it could be in these tests and precluded any further improvement in system tracking performance by increasing the gains in the command laws.

INTRODUCTION

Experiments with a flight director display have been conducted as part of a series of tests to determine the pilot-aircraft-display system response with general aviation flight instruments under instrument flight conditions. This effort is a part of the overall effort to determine the effect of instrument configuration on the control of the position of the aircraft and on the safety of flight. These studies, such as references 1, 2, and 3, have made it clear that the instrument configuration does have a major influence on the precision of control of the position of the aircraft. In reference 1, with conventional instruments such as the horizontal situation indicator (HSI) and the course deviation indicator (CDI), it is shown that the period of the dominant lateral mode of motion is 60 to 40 sec, and that this mode of motion can become unstable as the aircraft approaches the middle marker during instrument landing system (ILS) tasks. In contrast, the use of a pictorial display presented on a cathode-ray tube can result in stable, 10-sec system periods, as shown in references 2 and 3. The differences in pilot-aircraft-display system periods illustrated in these two cases indicate that differences in system tracking performance are to be expected, and references 2 and 3 also present data on this point. The studies in references 1 and 3 and the present study use the same simulator, aircraft model, and turbulence model.

The present study was aimed at establishing the system periods and performance that can be obtained with a flight director in an instrument approach task. The command laws used to drive the flight director command bars were the autopilot laws used in the study of reference 4 and described in references 5 and 6. A test format similar to that used in reference 1, where the glide-slope and localizer sensitivities were kept constant during any given run, was used. The pilot-aircraft-display system response to initial errors, and the standard deviations and means of the glide-slope and localizer errors in the presence of winds and gusts were obtained.

SYMBOLS

G_u, G_v, G_w gust spectrum transfer functions

h altitude, m

L_u, L_v, L_w gust characteristic wavelengths, m

P probability that the scores are equal

s Laplace operator, sec^{-1}

T_R aircraft lateral roll time constant, sec

T_S aircraft lateral spiral time constant, sec

u_g, v_g, w_g orthogonal random gust components, m/sec

V velocity, m/sec or knots

α angle of attack, rad

β angle of sideslip, rad

Δh glide-slope error, m

Δy localizer error, m

δ_a aileron deflection, rad

δ_e elevator deflection, rad

ζ_{DR} aircraft lateral Dutch roll damping ratio

$\zeta_{phugoid}$ aircraft longitudinal phugoid damping ratio

ζ_{sp} aircraft longitudinal short-period damping ratio

θ angle of pitch, deg or rad

$\sigma_u, \sigma_v, \sigma_w$ gust transfer function amplitudes, m/sec

ϕ angle of roll, rad or deg

ψ angle of yaw, rad or deg

ω_{DR} aircraft lateral Dutch roll frequency, rad/sec

$\omega_{phugoid}$ aircraft longitudinal phugoid frequency, rad/sec

ω_{sp} aircraft longitudinal short-period frequency, rad/sec

Nondimensional stability derivatives:

$C_{L_{\delta_e}}$ lift coefficient due to elevator deflection

C_{l_β} rolling-moment coefficient due to sideslip

C_{n_β} yawing-moment coefficient due to sideslip

$C_{n_{\delta_a}}$ yawing-moment coefficient due to aileron deflection

C_{Y_β} side-force coefficient due to sideslip

Subscripts:

c command

trim trimmed

Abbreviations:

CDI course deviation indicator

defl. deflection

HSI horizontal situation indicator

IFR instrument flight rules

ILS instrument landing system

Std. dev. standard deviation

A dot over a symbol denotes a derivative with respect to time.

DESCRIPTION OF EXPERIMENT

The purpose of these tests was to determine the pilot-aircraft-display system response with and without a flight director in an ILS landing approach task with the glide-slope and localizer sensitivities set at values corresponding to 5 n.mi. and 1.25 n.mi. from the glide-slope ground intersection. The following sections describe the aircraft model, the subjects, the wind inputs, the instrument signals, and the test procedure used in the simulation. The autopilot command laws used to drive the flight director needles are described in the appendix.

Aircraft Model

A six-degree-of-freedom, nonlinear model was used to simulate a typical high-wing, four-place, single-engine, general aviation airplane in this study. In addition to nonlinear kinematics, the following nonlinear aerodynamic factors and other special features were included in the model:

1. Nondimensional lift and drag coefficients were a function of α^2 as well as of α.

2. Nondimensional stability coefficients C_{Y_β}, $C_{L_{\delta_e}}$, C_{l_β}, $C_{n_{\delta_a}}$, and C_{n_β} were a function of α.

3. Asymmetric forces and moments as a function of thrust coefficient were included.

4. A hydraulic control loader provided control forces as a function of aerodynamic hinge moments.

5. A sound system provided realistic engine and airstream noise.

The nominal approach speed used in these tests was 85 knots. At this airspeed the small perturbation response of the aircraft was as follows:

Longitudinal response:	$\omega_{sp} = 2.01$ rad/sec	$\zeta_{sp} = 0.55$
	$\omega_{phugoid} = 0.21$ rad/sec	$\zeta_{phugoid} = 0.015$
Lateral response:	$\omega_{DR} = 1.95$ rad/sec	$\zeta_{DR} = 0.21$
	$T_R = 0.2$ sec	$T_S = 44$ sec

These aircraft response characteristics meet satisfactory handling quality requirements except for the phugoid damping, which is low.

A photograph of the simulator instrument panel, including the flight director instrument, is shown in figure 1. The flight director instrument provided pitch and bank information and raw data glide-slope and localizer indicators in addition to the flight director information. An HSI that provided heading information as well as duplicate glide-slope and localizer raw data was mounted directly below the flight director. Airspeed, altitude, vertical speed, and turn and bank instruments were also provided. The autopilot control panel can be seen to the right of the instruments. The angle-of-attack indicator seen at the left was not operative. The cathode-ray tube, which was an experimental display shown above the autopilot control panel, also was not in operation.

Subjects

Seven general aviation pilots took part in these tests. The subjects were all instrument rated, but they had varying amounts of experience. They were engineers working at the Langley Research Center who flew their aircraft on an occasional basis. All but subject 4 had considerable fixed-base simulator experience. These tests were the first experience in a fixed-base simulator for subject 4. The subjects' ages and accumulated flight hours are listed in the following table. The IFR time given for the subjects includes simulator time.

Subject	Age	Total flight hours	IFR flight hours	Previous flight director experience
1	55	325	50	Yes
2	24	400	60	No
3	46	400	70	No
4	33	485	100	No
5	33	1400	400	Yes
6	38	1600	400	Yes
7	37	2600	525	Yes

Wind Inputs

In some of the tests conducted as a part of these experiments, wind inputs were used as forcing functions. These wind inputs consisted of a steady crosswind of 1.22 m/sec and a random input used to represent gusts. These inertial axis gust inputs u_g, v_g, w_g were generated using random-number generators and filters based on the Dryden gust model (ref. 7). The filters were

$$G_u(s) = \sigma_u \frac{1}{s + \frac{V}{L_u}}$$

$$G_v(s) = \sigma_v \frac{s + \frac{1}{\sqrt{3}} \frac{V}{L_v}}{\left(s + \frac{V}{L_v}\right)^2}$$

$$G_w(s) = \sigma_w \frac{s + \frac{1}{\sqrt{3}} \frac{V}{L_w}}{\left(s + \frac{V}{L_w}\right)^2}$$

The scale lengths were

$$L_u = L_v = \begin{cases} h & \text{(For } h \geq 535 \text{ m)} \\ 44h^{1/3} & \text{(For } h < 535 \text{ m)} \end{cases}$$

$$L_w = h$$

The overall gust amplitude was adjusted so that the average gust root mean square was 1.22 m/sec at an altitude of 535 m. The mean value of the gusts was zero. These gust and wind conditions represent moderate disturbances.

Instrument Signals

The task performed in the simulator by the subjects was making an instrument landing system (ILS) approach. Although every effort was employed to make the appearance and response of the simulator realistic, the task was artificial in that the sensitivities of the glide-slope and localizer signals provided by the ILS system were kept constant during any one test run, rather than having them increase as range to the station decreased. This procedure eliminated the confounding effect of changing sensitivity on data analysis. The ILS signals were derived in the following manner.

The glide-slope signal was computed as

$$\text{Glide-slope signal} = \tan^{-1}\left(\frac{\Delta h}{9300}\right) \qquad \text{(For the 5 n.mi. case)}$$

or

$$\text{Glide-slope signal} = \tan^{-1}\left(\frac{\Delta h}{2320}\right) \qquad \text{(For the 1.25 n.mi. case)}$$

When this signal was applied to the raw data glide-slope needle in either the flight director instrument or the HSI, a gain was applied so that a 0.7° deviation would move the needle to full deflection. Full deflection therefore occurred at errors of 114 and 28.4 m.

The localizer signal was computed as

$$\text{Localizer signal} = \tan^{-1}\left(\frac{\Delta y}{9300 + 2140}\right)$$

or

$$\text{Localizer signal} = \tan^{-1}\left(\frac{\Delta y}{2320 + 2140}\right)$$

where the extra 2140 m is the additional distance from the glide-slope station. That is, when the distance from the ILS station is referred to as either 5 n.mi. or 1.25 n.mi., this value represents the distance from the aircraft to the glide-slope ground intercept point. The localizer station is an additional 2140 m past the glide-slope intercept point. When this localizer signal was applied to one of the raw-data indicators, a gain was applied so that a 2.5° deviation would move the needle to full deflection. Full deflection therefore occurred at errors of 500 and 195 m.

The flight director needles were driven by autopilot command laws (presented in the appendix) that combined pitch angle, pitch angle rate, rate of climb, and glide-slope error signals to drive the vertical command needle; and bank angle, bank angle rate, heading rate, heading error, and localizer error signals to drive the horizontal command needle. This autopilot was designed to provide a fairly high-performance system response. In particular, the displacement gains were set high to provide a high-frequency (approximately 0.2 rad/sec) displacement mode of motion, and forward loop integrators were used to reduce any steady-state errors to low values. These features tended to reduce system damping, and several inner loop signals, such as rate of climb and yaw rate, were added to improve system damping. A small amount of gain adjustment with velocity was also added to the system to improve damping.

The flight director information was presented to the pilot by means of a conventional flight director instrument. Cross-pointer needles mounted on an attitude indicator were used to present the information.

The sensitivity of the command signals can be described in the following manner. For the horizontal command needle, a static lateral error (with no heading or bank angle error) that would move the raw data localizer needle to full deflection would move the flight director needle to one-half of the full deflection. Because of the ratio of the bank angle and heading error signals to the localizer signal, this sensitivity was rated by the pilots to be too high when there was no filter on this signal. It is for this reason that the filter was added to the horizontal command signal. Even with the filter, the sensitivity of the indicator was rated high by the pilots.

The sensitivity of the vertical command signal cannot be described in the same manner because of a forward loop integrator that was used in the vertical command law. That is, the glide-slope error was used to command a pitch angle rate. Therefore, it was not possible to generate a steady vertical command needle deflection with a static glide-slope error. However, in the judgment of the pilots, the vertical command needle was equal in sensitivity to the horizontal command needle; that is, the sensitivity was high.

Test Procedure

The complete series of tests consisted of a run with initial errors in both the lateral and vertical directions at 5 n.mi. from the station; the same test at 1.25 n.mi. from the station; followed by two runs with no initial error but with crosswinds and gusts, one at 5 n.mi. and one at 1.25 n.mi. from the station. Each run lasted 3 min. Before the data-taking runs, every subject did each run at least once as practice. This allowed the subjects to become familiar with the simulator and the experiment. Time histories of the glide-slope and localizer errors and attitudes were taken for each run, and glide-slope and localizer standard deviations and means were also taken for the runs with winds and gusts. Following the tests with the flight director, each subject performed the same series of tasks with the flight director command needles inoperative. In these tests the subjects used the raw data glide-slope and localizer needles and the attitude indicators for guidance. A comparison of the results with and without the command needles illustrates the effect of the command needles.

One of the methods used to evaluate the system response is to note the pilot-aircraft linear response characteristics. This method of analysis, used in references 1 and 2, involves using a linear pilot model in combination with the nonlinear aircraft model to reproduce the time histories of the response of the subject pilot in combination with the aircraft model in tasks involving initial errors, and also analytically determines linear system characteristics of the pilot-aircraft system using the linear pilot model in combination with a linear version of the aircraft model. The linear analysis shows that the pilot-aircraft system is a sixth-order system for vertical control and an eighth-order system for lateral control. These systems involve the usual short-period aircraft modes (short-period longitudinal mode and Dutch roll lateral mode) plus new modes of motion that involve variables for which the aircraft has little or no stability (pitch and altitude for vertical control and bank, heading, and lateral displacement for lateral control). When the pilot is asked to control altitude and lateral displacement using glide-slope and localizer instruments, new modes of motion are created. These new modes of motion may be either oscillatory with damping that can range from unstable to well damped or overdamped modes represented by first-order type responses. In the present study, visual inspection of the time histories generated by the subjects is used to estimate the period and damping of the oscillatory characteristics or the time constants of the first-order responses of these pilot-generated modes of motion.

RESULTS

Autopilot-Aircraft System Response

With a flight director display system, the command laws used to drive the flight director command needles have a great influence on the system response. The system being examined in the present study used autopilot command laws discussed in a previous section of the paper. To illustrate the nature of these command laws, the response of the system with the autopilot controlling the aircraft is shown in figure 2. This figure shows that the dominant mode of the lateral response is moderately well damped and has a period of 43 sec at the 5-n.mi. range. At the 1.25-n.mi. range, the dominant mode has very low damping and a period of 30 sec. The dominant mode of the vertical response is a first-order type response with a time constant of approximately 35 sec.

Pilot-Aircraft-Display System Response

Typical system responses obtained from four subjects are shown in figure 3. A complete set of variables are presented for subject 2, and a selected set are shown for subjects 1, 4, and 7. These four subjects cover the entire range of flight experience of all seven subjects. The data for subjects 3, 5, and 6 did not differ in any significant way from those obtained from subjects 1, 2, 4, and 7. The time histories show that by using the flight director needles, subject 2 generated a response very similar to that obtained with the autopilot. By referring to the raw data localizer indicator, he was able to reduce the initial overshoot. But aside from this variation, the system period and damping were very similar to those obtained with the autopilot. This same duplication can be seen with all the subjects. The greatest departure from this type response came with subject 4. Probably because of his lack of experience with fixed-base simulation, he paid less attention to the flight director and greater attention to the attitude variations, restricted the excursions in attitudes, and thereby stretched out the system periods. The pilots injected a noisy signal into the system that consisted of time variations, dead-band type operations, dithers, and tremors. The injection of this noisy signal resulted in a steady-state oscillation that was larger in amplitude than that obtained with the noise-free computer implementation of the autopilot system.

The pilot-generated time histories of runs with winds and gusts added are as shown in figure 4. The movement of the command needles that occurred in these tests was objectionable to the pilots and required that they pay a large amount of attention to reading these indicators. It is because of this high-frequency movement of these needles that higher gains could not be used in the command laws in any attempt to improve the pilot-aircraft-display system tracking performance. The standard deviations and means of the glide-slope and localizer errors for all subjects are given in table I. In instances where repeated data runs were conducted, these values are included. The mean values of the errors are low because of the forward loop integration incorporated in the command laws. If the forward loop integrators were removed from the system, an increase in the mean values of the errors would be expected.

The pilot-aircraft-display system periods that can be observed in the time histories of figure 3 are as follows. At the 5-n.mi. range, the lateral periods vary from 40 sec (subject 2) to 60 sec (subject 4). The vertical mode of motion time constants vary from 30 sec (subject 1) to 50 sec (subjects 2 and 4). Subject 7 shows an oscillatory dominant mode with a period of 25 sec. At the 1.25-n.mi. range, the lateral periods vary from 30 sec (subjects 2 and 7) to 70 sec (subject 4). The dominant vertical mode of motion is either a first-order response with a time constant of from 35 sec (subject 4) to 45 sec (subjects 1 and 2), or an oscillatory mode with a period of 25 sec (subject 7). While these system response characteristics are not exactly the same as those obtained with the autopilot, they are close and reflect a strong influence of the control law. It is not expected that the pilot-controlled responses will be as consistent as those of the autopilot. The occasional increases in error that sometimes occur near the end of the run are examples of the lack of consistency exhibited by the pilots.

Tests With No Flight Director

For comparison purposes, tests were conducted with the flight director command needles inoperative, with the pilot using just the raw data to control the aircraft. Runs with initial errors and no winds are shown in figure 5, and runs with winds are shown in figure 6. The standard deviations and means of the glide-slope and localizer errors are shown in table II.

The time histories show that while in some cases the dominant mode of motion is quicker with no flight director, in other cases it is slower. On the whole, however, the system periods are similar with and without the flight director. With regard to system damping, in all cases, the system damping is judged to be less without the flight director than with the flight director. For subject 2, the lateral response at the 5-n.mi. range (fig. 5) has a period of 60 sec (longer than with the flight director) with a peak-to-peak amplitude that is greater than with the flight director (fig. 3). Also, at the 1.25-n.mi. range, the lateral response shows a larger peak-to-peak amplitude than with the flight director and therefore indicates a reduction in damping. The vertical responses show more overshoot without the flight director than with the flight director. This situation indicates in some sense (maybe more in a nonlinear sense than in a linear sense) a reduction in damping.

With subject 4 at the 1.25-n.mi. range, the lateral mode shows a 20-sec period (shorter than the 70-sec period obtained with the flight director), but with a nearly constant amplitude, whereas the response with the flight director is damping out. Again, the conclusion is that the system damping is less without the flight director. The vertical response for subject 4 without the flight director still has a slow first-order type response as the dominant characteristic, indicating good damping for this mode of motion. However, the oscillatory mode with the 25-sec period shows a much greater peak-to-peak amplitude (fig. 5 compared with fig. 3), and indicates low damping for this mode of motion. In this particular run, the final excursion in glide-slope error is ignored as being the result of a nonlinear loss of attention on the part of the pilot.

Subject 7 shows much less change in response between the flight director and the no flight director cases. However, an examination of the responses for subject 7 with wind inputs (figs. 4 and 6) shows larger peak-to-peak variations in both vertical and lateral responses with no flight director and indicates less system damping without the flight director.

The studies in references 1, 2, and 3 indicate that in a linearized pilot-aircraft system, the performance will depend on the system frequencies and damping ratios. If the damping ratios of two systems are above 0.1 and remotely equal, the system with the lower frequency will have the poorer performance. If the damping ratio is below 0.1, then it can have a great influence on system performance. Mainly because of the reduction in damping, the standard deviations measured in the present study in the cases with winds and gusts are larger without the flight director than with the flight director. The standard deviations with and without the flight director for both the lateral and vertical responses at each range were compared using a paired "t" test. The results are shown in table III and indicate that the differences are significant for each test condition at the 0.05 level or better. The means were also compared, and the results show that the differences were not significant at the 0.05 level except for glide-slope error at the 5-n.mi. range.

The results obtained in the present study with no flight director agree well with the results of reference 1 both in system characteristics evident in the time histories and in the standard deviations and means. Reference 1 documents a similar study on the use of conventional course deviation indicators and horizontal situation indicators, in which the same test format of constant localizer and glide-slope signal sensitivities was used.

CONCLUSIONS

A fixed-base simulation study of the use of a flight director in an instrument landing system (ILS) landing approach has been conducted. Seven subjects with varying amounts of flight experience controlled a typical single-engine general aviation aircraft in the study. An important feature of the study was that the ILS signal was kept at constant sensitivity corresponding to either 5 n.mi. or 1.25 n.mi. from the glide-slope ground intercept point during any one test run. An autopilot command law was used to drive the flight director needles.

The pilot-aircraft-display system response characteristics of period and damping were very similar to those of the autopilot-aircraft system. The sensitivity of the flight director command needles was rated high by all of the test subjects, and this factor would preclude any further improvement in the pilot-aircraft-display system performance by increasing the gains of the command law.

Without the flight director command needles, using only raw data for guidance, the pilot-aircraft-display system response characteristics showed periods similar to those obtained with the flight director command needles, but with a reduction in system damping. As a result, the system performance was degraded. The standard deviations of the glide-slope and localizer errors showed a corresponding degradation without the flight director. The contribution of the flight director command needles was to add damping to the system.

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APPENDIX

AUTOPILOT COMMAND LAWS

The autopilot lateral command laws used in the study are

$$\delta_a = -0.525\dot{\phi} + 1.5(\phi_c - \phi) - 0.175\dot{\psi} \qquad \text{(Limited to 0.2 rad)}$$

$$\phi_c = 0.5(\psi_c - \psi) \qquad \text{(Limited to 0.6 rad)}$$

when localizer error is greater than 2°

$$\psi_c = 4.5(\text{Localizer error}) \qquad \text{(Limited to 45°)}$$

when localizer error is less than or equal to 2°

$$\psi_c = \left(4.5 + \frac{0.3}{s}\right)(\text{Localizer error})$$

The autopilot vertical command laws used in the study are

$$\delta_e = -(1.53 - 0.007V)\dot{\theta} + (1.37 - 0.0048V)(\theta_c - \theta)$$

$$\theta_c = \frac{0.0066}{s}(\dot{h}_c - \dot{h})$$

$$\dot{h}_c = 4V \tan(\text{Glide-slope error}) - V \tan(\text{Glide-slope angle})$$

When the flight director was in operation, the control deflection signals from the autopilot command laws were used to drive the flight director needles in the following manner:

$$\text{Horizontal command} = (\delta_a)\frac{1}{0.3s + 1}$$

$$\text{Vertical command} = \delta_e - \delta_{e,trim}$$

The filter was added to the horizontal command to reduce the high-frequency movement of the needle, and the elevator trim term was added to the vertical command so as to properly zero the needle. The block diagram of the system is shown in figure A1.

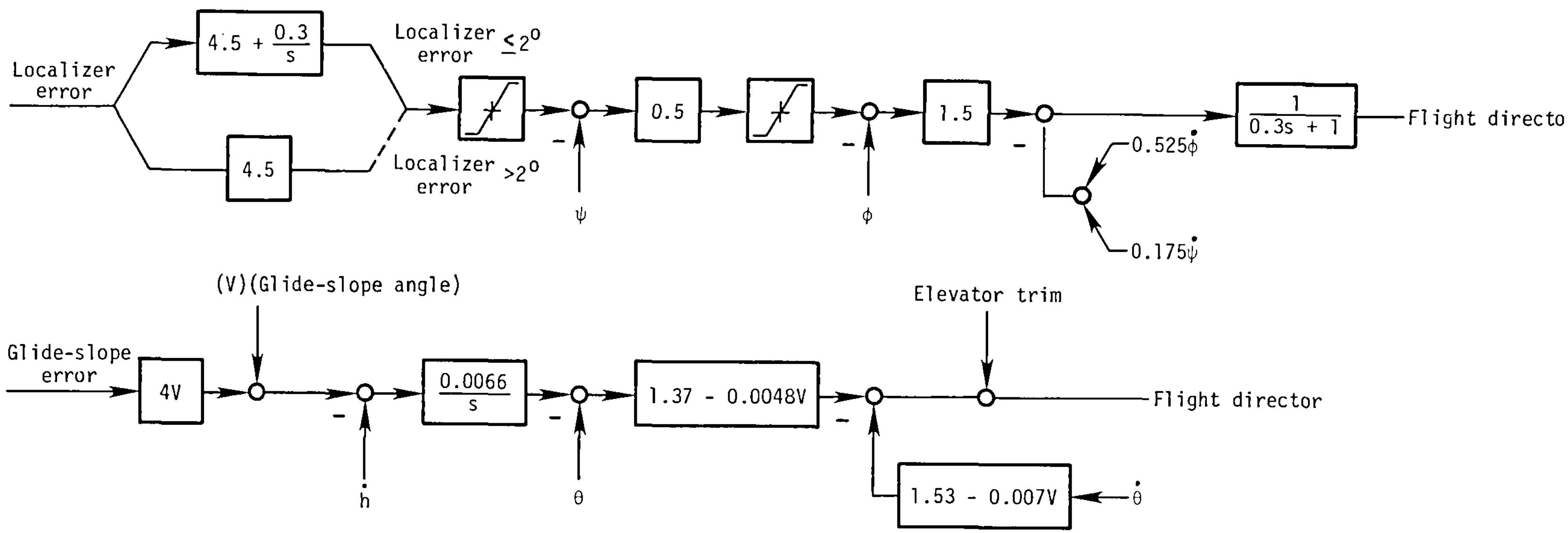

Figure A1.- Block diagram of the autopilot.

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TABLE I.- STANDARD DEVIATIONS AND MEANS OF GLIDE-SLOPE AND LOCALIZER ERRORS WITH FLIGHT DIRECTOR

Subject	Error at 5-n.mi. range, m				Error at 1.25-n.mi. range, m			
	Glide slope		Localizer		Glide slope		Localizer	
	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean
1	8.1	1.4	32.9	41.3	9.2	2.2	50.4	41.7
					7.7	.4	27.7	7.3
2	10.1	1.2	16.8	12.3	4.2	1.9	19.7	16.7
	5.1	2.6	13.2	-2.5	5.5	.1	7.1	1.0
					6.8	1.0	11.2	3.8
3	6.5	2.1	19.4	6.0	9.6	-2.1	14.0	-4.3
4	9.5	-14.2	51.6	125.2	6.2	-14.5	21.9	22.8
5	8.3	1.8	33.5	11.7	8.4	2.0	30.1	17.4
6	5.0	-13.7	31.5	12.9	5.6	-13.1	26.1	13.2
7	5.4	1.0	10.1	9.0	10.8	-12.2	34.3	25.4
					7.0	1.0	16.9	12.9
Mean	7.3	-2.2	26.7	27.1	7.4	-3.0	23.6	14.3
Std. dev.	2.0	7.3	15.2	41.6	2.0	6.7	12.2	12.8

TABLE II.- STANDARD DEVIATIONS AND MEANS OF GLIDE-SLOPE AND LOCALIZER ERRORS WITH NO FLIGHT DIRECTOR

Subject	Error at 5-n.mi. range, m				Error at 1.25-n.mi. range, m			
	Glide slope		Localizer		Glide slope		Localizer	
	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean
1	14.7	-8.0	41.6	8.0	14.5 13.1 8.6	-14.9 -27.3 -10.0	29.0 25.6 43.7	8.4 23.7 28.2
2	9.5	-3.5	17.5	25.1	23.9 17.7	23.4 15.3	59.9 39.3	18.9 25.9
3			43.2	10.6				
4	36.0	-31.1	88.6	63.8	22.2	-14.7	55.9	13.5
5							22.5	-2.2
6	13.4	-22.3	35.7	27.8	19.3	-17.2	32.0	18.6
7	10.7	-13.3	47.1	5.2	27.2	-18.0	21.7	26.9
Mean Std. dev.	16.8 10.9	-15.6 11.1	45.6 23.5	23.4 21.8	18.3 6.1	-7.9 17.7	36.7 14.1	18.0 10.0

TABLE III.- RESULTS OF t-TESTS COMPARING DATA OBTAINED WITH AND WITHOUT FLIGHT DIRECTOR

Test condition	P-value	
	Standard deviation	Mean
5 n.mi., glide slope	0.025	0.025
5 n.mi., localizer	.05	>.40
1.25 n.mi., glide slope	.0005	>.40
1.25 n.mi., localizer	.025	>.40

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Figure 1.- Instrument panel of simulator.

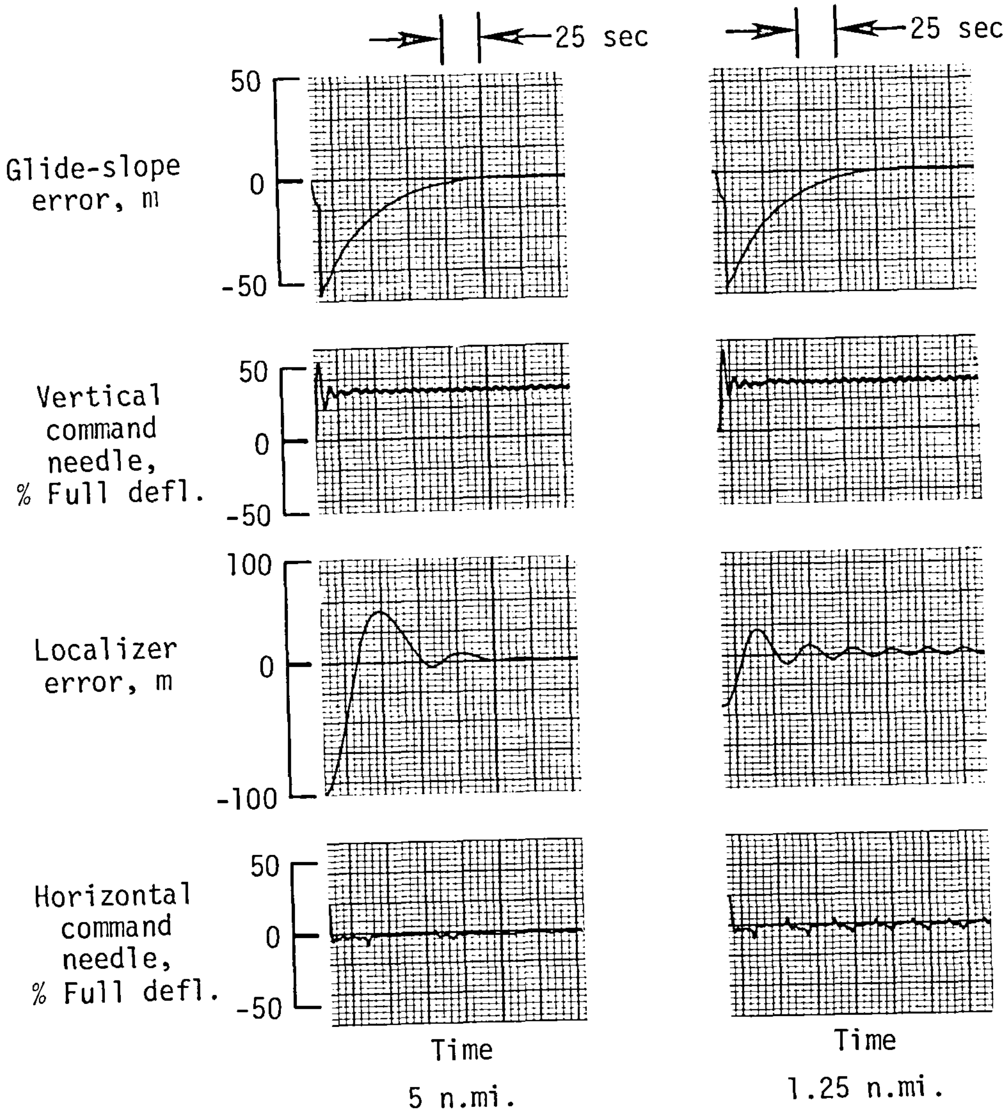
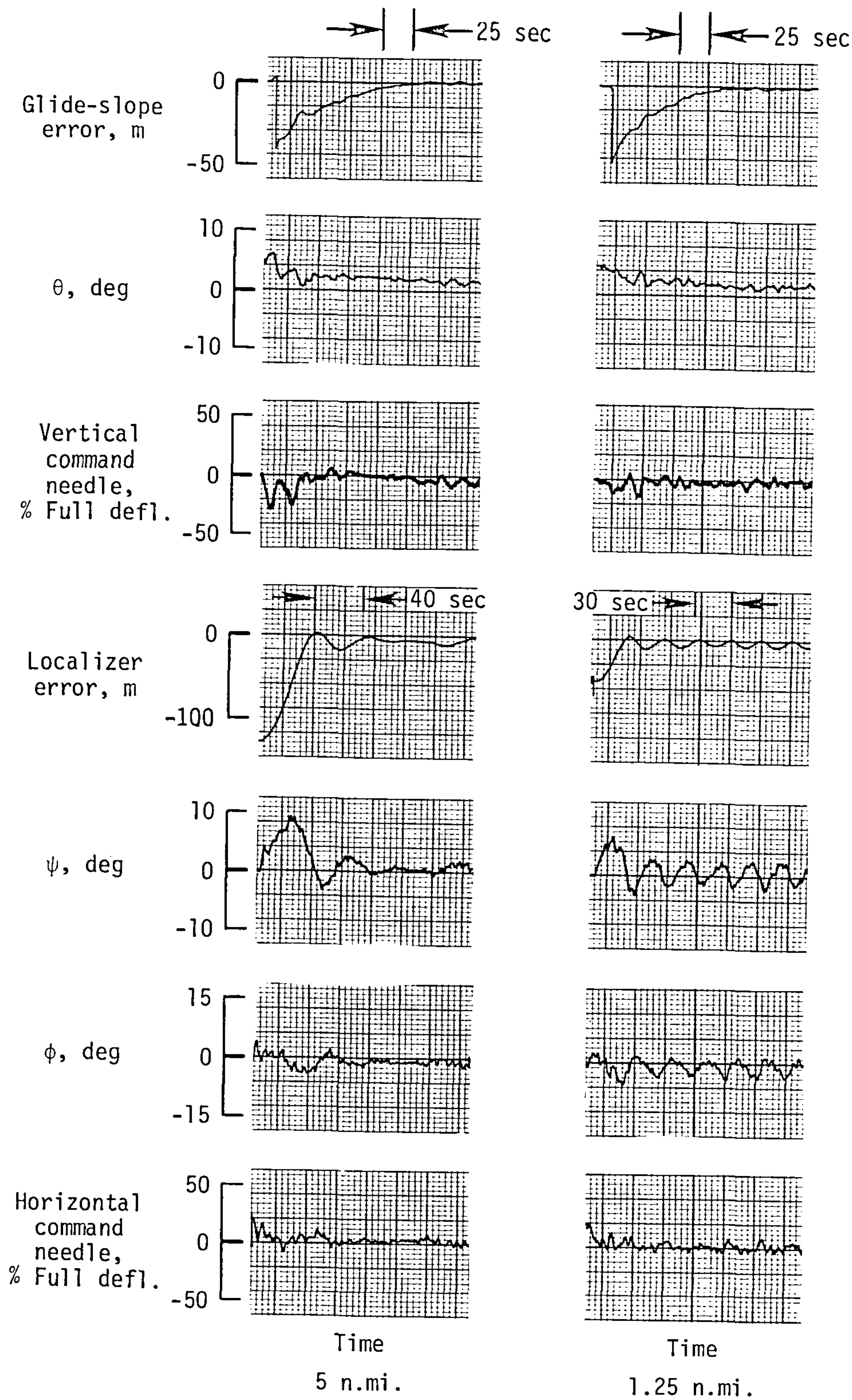
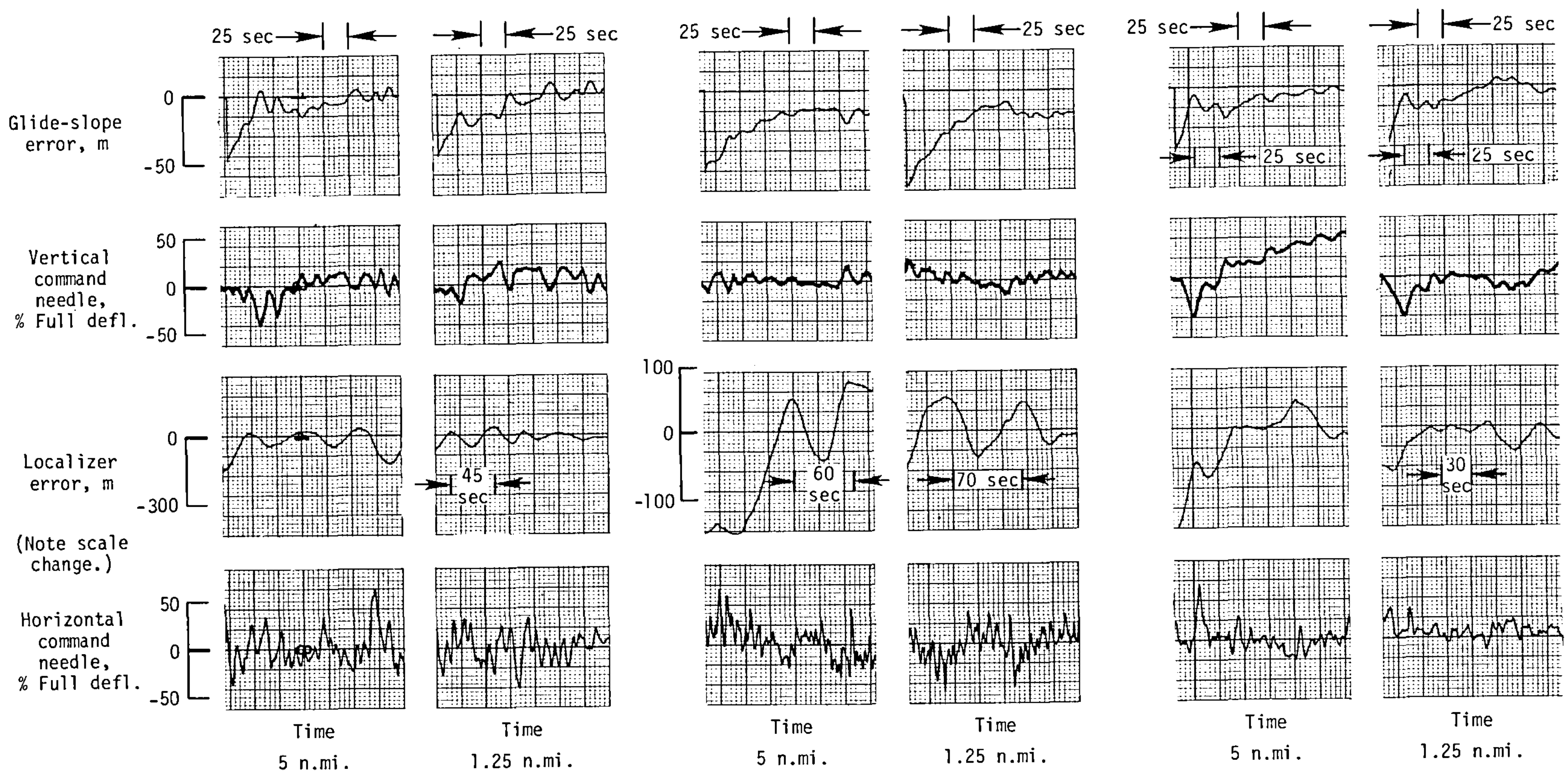


Figure 2.- Autopilot-aircraft system response.



(a) Subject 2.

Figure 3.- Pilot-aircraft-flight-director system response to initial errors.

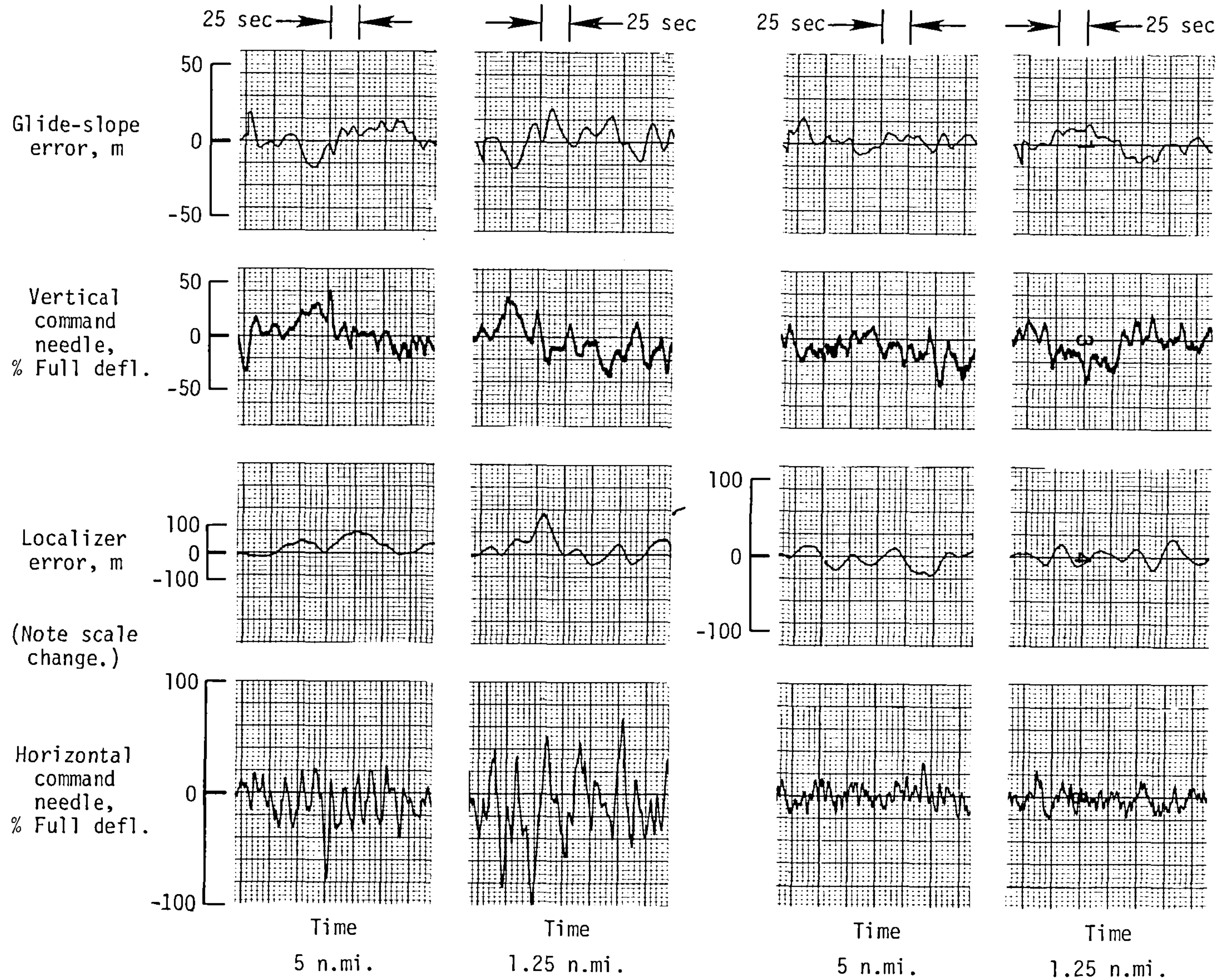


(b) Subject 1.

(c) Subject 4.

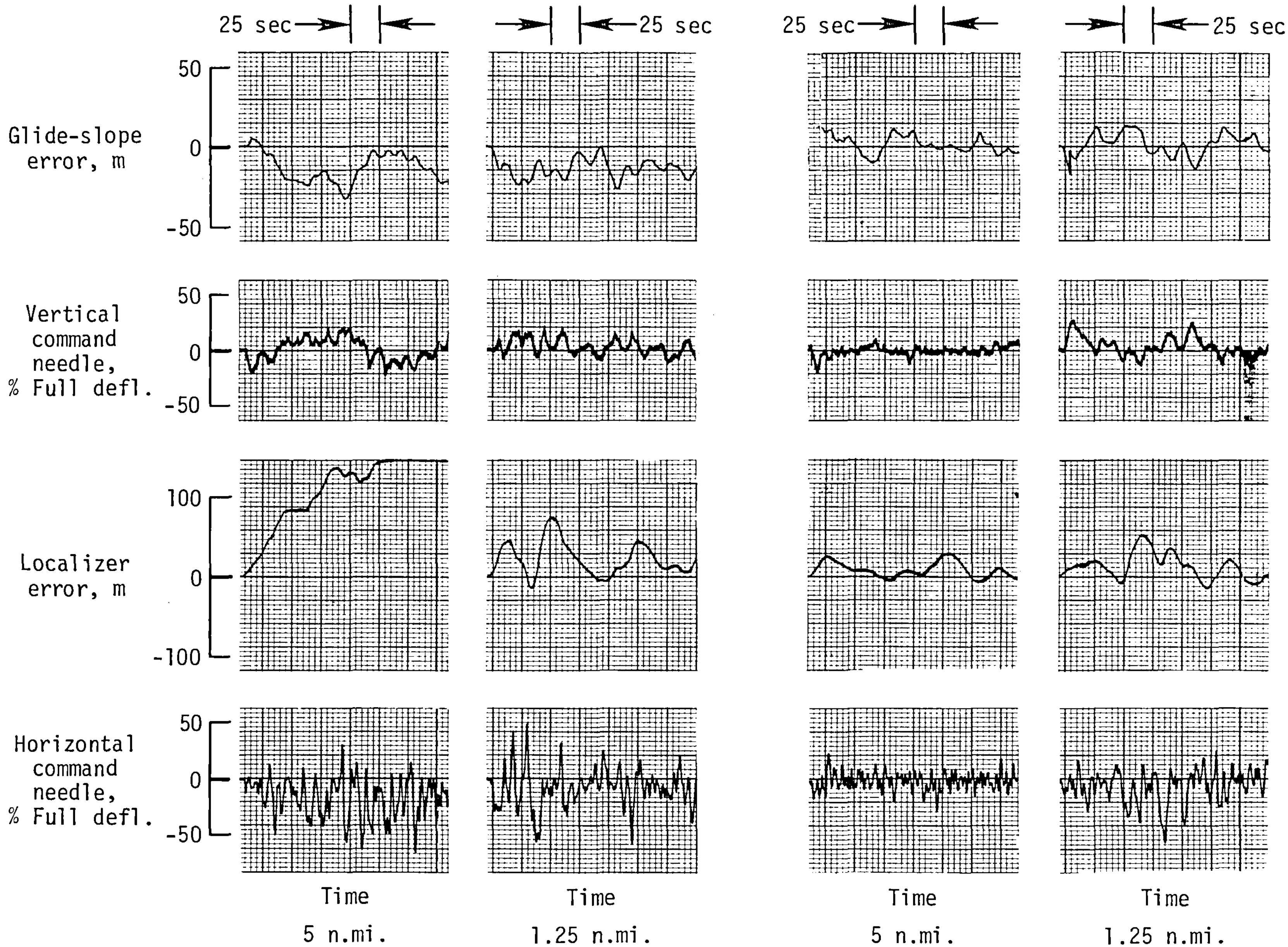
(d) Subject 7.

Figure 3.- Concluded.



(a) Subject 1. (b) Subject 2.

Figure 4.- Pilot-aircraft-flight-director system response in the presence of winds and gusts.



(c) Subject 4.

(d) Subject 7.

Figure 4.- Concluded.

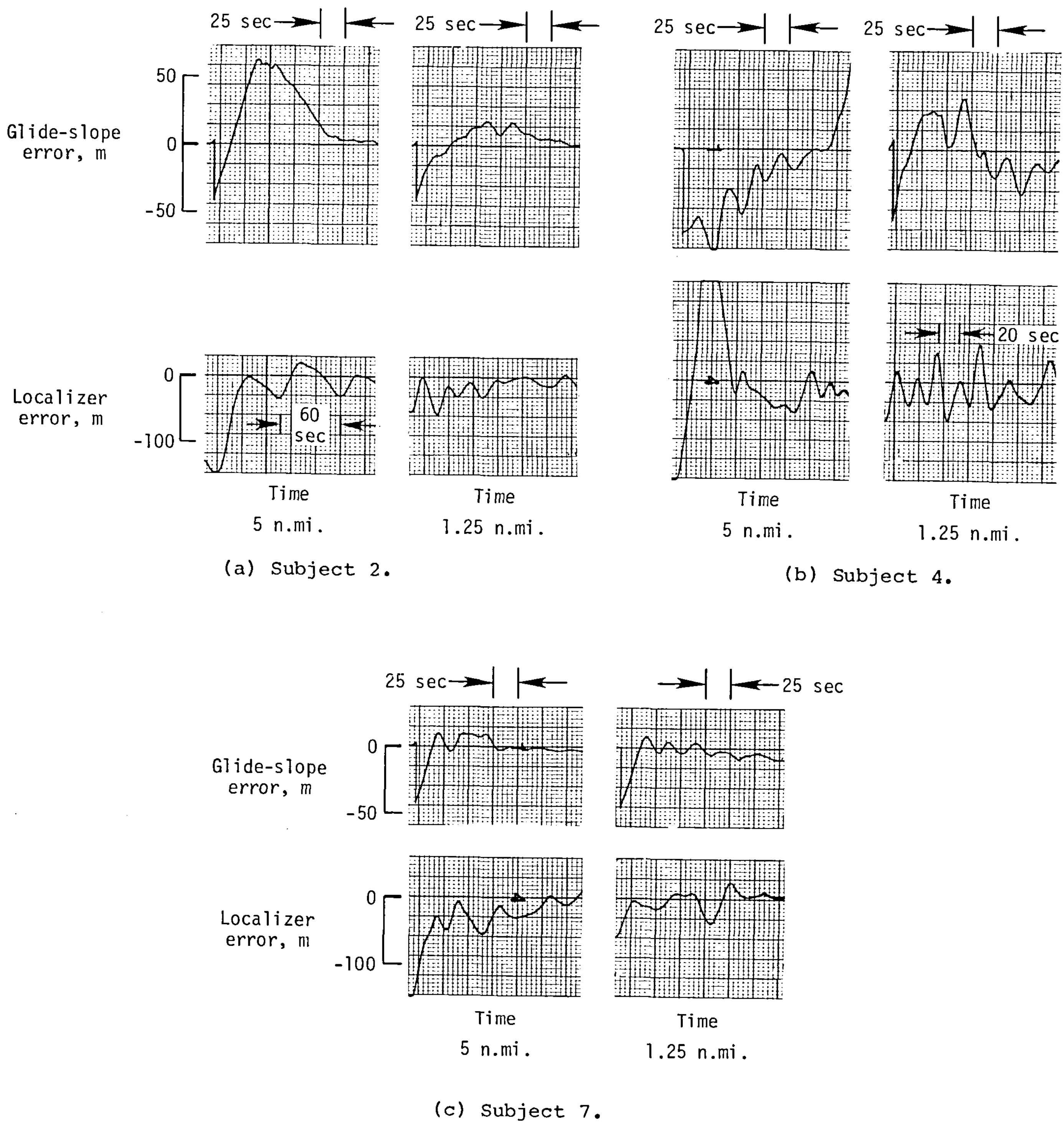


Figure 5.- Pilot-aircraft-display system response to initial errors with no flight director.

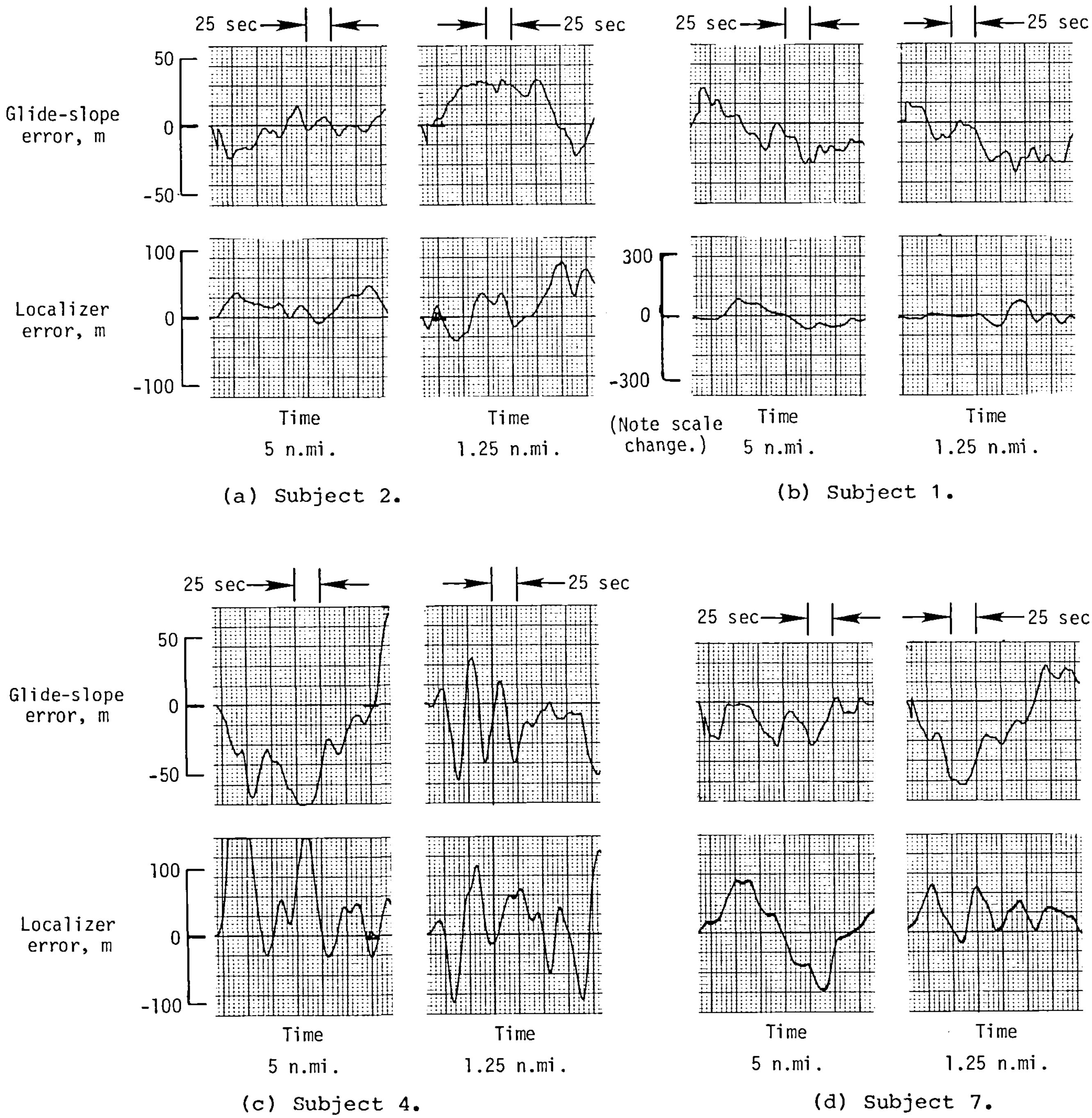


Figure 6.- Pilot-aircraft-display system response with no flight director in the presence of winds and gusts.

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16. Abstract

A six-degree-of-freedom, fixed-base simulation study of the use of a flight director by general aviation pilots in an instrument landing system approach was conducted. An autopilot command law was used to drive the flight director needles. Time histories of the pilot-aircraft-display system responses and standard deviations and means of the glide-slope and localizer errors were obtained. The pilot-aircraft-display system responses with the flight director were very similar to the autopilot-aircraft responses. Without the flight director, the pilot-aircraft-display system exhibited less damping than with the flight director. The sensitivity of the flight director command laws was judged to be about as high as it could be by the test subjects. Thus, further improvement in the pilot-aircraft-display system performance by increasing the gains in the command laws was precluded.

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