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RESULTS OF A SIMULATOR TEST COMPARING TWO DISPLAY CONCEPTS FOR PILOTED FLIGHT-PATH-ANGLE CONTROL

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SUMMARY

A transport airplane fixed-base simulator was used to investigate pilot flight-path-angle control performance using two different electronic display formats to present flight-path angle (γ). The baseline display format presented airplane γ , and a command format displayed pilot-commanded flight-path angle (γ_c) in addition to γ . Both displays were used with a velocity vector control mode which was designed to enhance piloted γ -control. A tracking task required pilots to make frequent flight-path-angle changes in the range of $\pm 4^\circ$ while in the landing configuration.

Results of tracking-task performance indicated that the command display format enhanced pilot capability to perform smooth and predictable changes in aircraft flight-path angle. Flight-path-angle oscillations, noted with the baseline display, were reduced when the command display was used. Pilot comments indicated that mental workload was reduced when using the command display.

INTRODUCTION

One of the objectives of the NASA Terminal Configured Vehicle (TCV) Program is research and development leading to electronic display concepts that will improve the pilots' performance during landing approach tasks. Utilizing the transport airplane shown in figure 1, research efforts have included the use of a velocity vector control mode which was designed to enhance the pilot's ability to manually control airplane flight-path angle (γ). The system utilizes conventional aircraft flight controls and a CRT electronic attitude director indicator (EADI) to display γ . Following simulator and flight tests of this control mode, pilot comments generally indicated that it was difficult to make precise flight-path-angle changes with the existing control system and γ -display arrangement. The dynamic response of the airplane following control inputs often caused γ to overshoot or undershoot the value desired by the pilot, and high levels of control activity were often the result.

In an effort to improve γ -control performance, a new display format was conceived which could be used with the existing control mode without necessitating changes to the control system design. The new format featured the presentation of pilot-commanded flight-path angle (γ_c) on the EADI in addition to the previously displayed γ . This display scheme permitted the pilot to monitor not only the current flight-path angle but also the value of γ which would ultimately result due to his control inputs.

This report presents results of a simulator experiment which was conducted in order to compare pilot γ -control performance using both the new display format and the format which had previously been used. Pilots flew a

variable flight-path-angle tracking task in the landing configuration. Pilot and airplane performance parameters were recorded and pilot comments noted for each case.

SYMBOLS AND ABBREVIATIONS

Values are presented in both SI and U.S. Customary Units. Calculations were made in U.S. Customary Units.

| | |
|------------|--|
| CRT | cathode ray tube |
| EADI | electronic attitude director indicator |
| INS | inertial navigation system |
| MSL | mean sea level |
| PMC | panel-mounted controller |
| PMC pitch | panel-mounted controller position forward/aft of neutral (aft, positive), cm |
| TCV | terminal configured vehicle |
| γ | airplane flight-path angle; angle between airplane inertial velocity vector (relative to earth's surface) and local horizontal reference plane (climbing, positive), deg |
| γ_c | pilot-commanded flight-path angle (climbing, positive), deg |
| γ_T | flight-path angle defined by the tracking task profile (climbing, positive), deg |

δ_{ec} elevator command (trailing edge down, positive), deg
 $\dot{\theta}$ pitch rate (nose up, positive), deg/sec

STATEMENT OF THE PROBLEM

The control law for the velocity vector control mode is shown in figure 2. During flight the input quantity γ is derived from onboard INS measurements. Pilot-commanded flight-path angle (γ_c) is obtained by integrating the PMC displacement signal. The difference between these two signals ($\gamma - \gamma_c$) is the error signal which is used to drive the elevator in order to maintain $\gamma = \gamma_c$.

The baseline EADI display is shown in figure 3. Flight-path angle was displayed on the pitch scale by a set of wedge-shaped symbols and horizontal bars.

The flight-test data in figure 4 illustrate the pilot control problem which existed when the baseline display format was used. The pilot's application of PMC pitch control resulted in the commanded flight-path angle shown as γ_c , although the pilot was only presented a display of the resulting aircraft motion (γ). When the pilot returned the PMC controller to neutral, γ was approximately 6° although the control law was commanding only 5.5° . Therefore, without further control inputs the airplane converged toward the commanded value (5.5°). Control difficulties in this flight mode were thus related in part to the fact that the pilot could not actually see the value of γ that he was commanding by his control inputs.

The command display format shown in figure 5, which presents γ_c along with γ , was conceived as a potential aid for improving pilot control by providing a means for the pilot to relate flight-path-angle command and performance information. This display scheme utilized the output of the control law γ_c integrator to drive the γ_c symbol on the EADI, and thus provided the pilot a direct indication of the flight-path-angle command resulting from his control inputs. Other features of the display remained identical to the baseline format.

EXPERIMENT DESIGN

Characteristics of the airplane shown in figure 1 were used in the simulation model. (See Table 1). The six degree-of-freedom model includes nonlinear aerodynamic data derived from flight and wind-tunnel tests. Handling qualities and performance measures of the simulation were previously matched to standards supplied by the aircraft manufacturer.

Simulator Cockpit

Figure 6 shows details of the simulator cockpit arrangement. Rudder pedals, throttles, flap lever and speed brake handle are all conventionally designed controls. However, the conventional control columns were replaced by a set of pitch and roll controllers, mounted on the instrument panel and referred to as PMC (panel-mounted controllers). The PMC consists of cylinders which slide fore and aft for longitudinal control and rotate about the cylindrical axis for lateral control. Handgrips with standard control column switches are attached to the cylinders.

The 20-cm (8-in) EADI was the primary display instrument used in this experiment. Pitch attitude information is provided by a horizon line, pitch scale and airplane symbol. A roll pointer and bank angle indices at the top of the display provide roll attitude. With the baseline display format, airplane flight-path angle was displayed by a set of wedge-shaped symbols and rectangular bars (fig. 3). With the command format, pilot-commanded flight-path angle was displayed on the wedges while γ was displayed on the rectangular bars.

Experimental Task

The pilot tracking task consisted of a variable flight-path-angle (γ_T) profile flown in the landing configuration. The task profile (fig. 7) was displayed on the EADI pitch reference line (fig. 3). Rate of movement of the reference line was approximately 0.25 deg/sec. Pilots were instructed to fly the task-commanded flight-path angles as closely as possible. Speed was maintained by the autothrottle. Flight conditions are shown in table 1.

Two pilots were used to gather performance data. Pilot A was a NASA research pilot with TCV flight and simulator experience. Pilot B was a military jet pilot with little exposure to the TCV simulator. Each pilot was given 3 practice runs with each display format prior to recording data. A subsequent run was used to gather the data which are presented in this report.

RESULTS AND DISCUSSION

Figures 8-11 show results of the tracking task for both pilots and both display formats. Although control techniques were somewhat different for the

two pilots, flight-path-angle tracking performance was very similar. First, note the γ_c traces for each pilot using the baseline display (figs. 8 and 9). It can be seen that the control inputs of both pilots resulted in discrete increments in γ_c (not displayed to the pilot) with numerous overshoots and undershoots of the γ_T profile. As a consequence, aircraft flight-path-angle response was marked by continuous oscillations around the desired (task) profile. Fairly high control activity marked by numerous instances of overcontrol and undercontrol are evident throughout the baseline runs.

Flight-path angle oscillations were noticeably reduced when γ_c symbology was added to the EADI. This is shown by the command display data in figures 10 and 11. Note that both pilots applied control inputs which made the γ_c wedges (fig. 5) follow the task profile very closely. Consequently, aircraft γ also followed the task profile more closely and in a comparatively stable manner.

Pilot Comments

The opinion of both pilots was that the airplane flight-path-angle response following control inputs caused a tendency to overcontrol or undercontrol while using the baseline display, resulting in an excessive number of pilot inputs. Considerable difficulty was experienced in getting γ to stabilize at a desired value or a desired rate of change. The relatively long period of the flight-path-angle oscillations were sometimes interpreted as a low-frequency γ drift.

The command display produced favorable pilot reactions. Both pilots commented that the mental workload was significantly reduced which provided

them much more time to scan other instruments. They indicated that the control workload also seemed to be reduced. The presentation of γ_c provided the pilots a direct readout of predicted γ , while the γ symbol allowed them to remain aware of actual airplane performance.

CONCLUDING REMARKS

A transport airplane flight simulator was used to compare pilot performance in controlling flight-path angle (γ) while using two different electronic display formats. A baseline format displayed aircraft γ and a command format displayed pilot-commanded flight-path angle (γ_c) in addition to γ .

Performance results following a flight-path-angle tracking task indicated that the command display format enhanced pilot capability to perform smooth and predictable changes in γ . Oscillatory flight-path-angle behavior, noted while using the baseline format, was reduced with the command format. The command format was more acceptable to the pilots because it provided a means for them to view the flight-path angle which would result from their control input, rather than having to wait for the aircraft to respond. Pilot comments also indicated that mental workload was reduced while using the command format.

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1. Kelley, Wendell W.: Simulator Evaluation of a Flight-Path-Angle Control System for a Transport Airplane With Direct Lift Control. NASA TP-1116, 1977.
2. Steinmetz, George G; Morello, Samuel A.; Knox, Charles E.; and Person, Lee H., Jr.: A Piloted-Simulation Evaluation of Two Electronic Display Formats for Approach and Landing. NASA TN D-8183, 1976.
3. Salmirs, Seymour; and Tobie, Harold N.: Electronic Displays and Digital Automatic Control in Advanced Terminal Area Operations. AIAA Paper No. 74-27, Jan.-Feb. 1974.

TABLE I.- TCV AIRCRAFT CHARACTERISTICS AND SIMULATED
FLIGHT CONDITIONS

Weight, N (lb). 371 000 (83 500)

Moments of inertia:

I_{xx} , kg-m^2 (slug-ft²) 549 000 (405 000)
 I_{yy} , kg-m^2 (slug-ft²) 1 080 000 (797 000)
 I_{zz} , kg-m^2 (slug-ft²) 1 710 000 (1 260 000)
 I_{xz} , kg-m^2 (slug-ft²) 70 800 (52 200)

Center of gravity:

Percent of mean aerodynamic chord 19

Wing:

Area, m² (ft²). 91.04 (980)
Span, m (ft) 28.35 (93.0)
Mean aerodynamic chord, m (ft). 3.41 (11.2)
Aspect ratio 8.83
Sweep (1/4 chord), deg 25

Propulsion System:

Pratt and Whitney JT8D-7 engines (2)

Maximum uninstalled thrust per engine

(Sea Level Static), N (lb) 62 300 (14 000)

Initial Altitude (MSL), m (ft) 762 (2500)

Indicated airspeed, knots 130

Trailing edge flap position, deg 40

Landing gear position DOWN

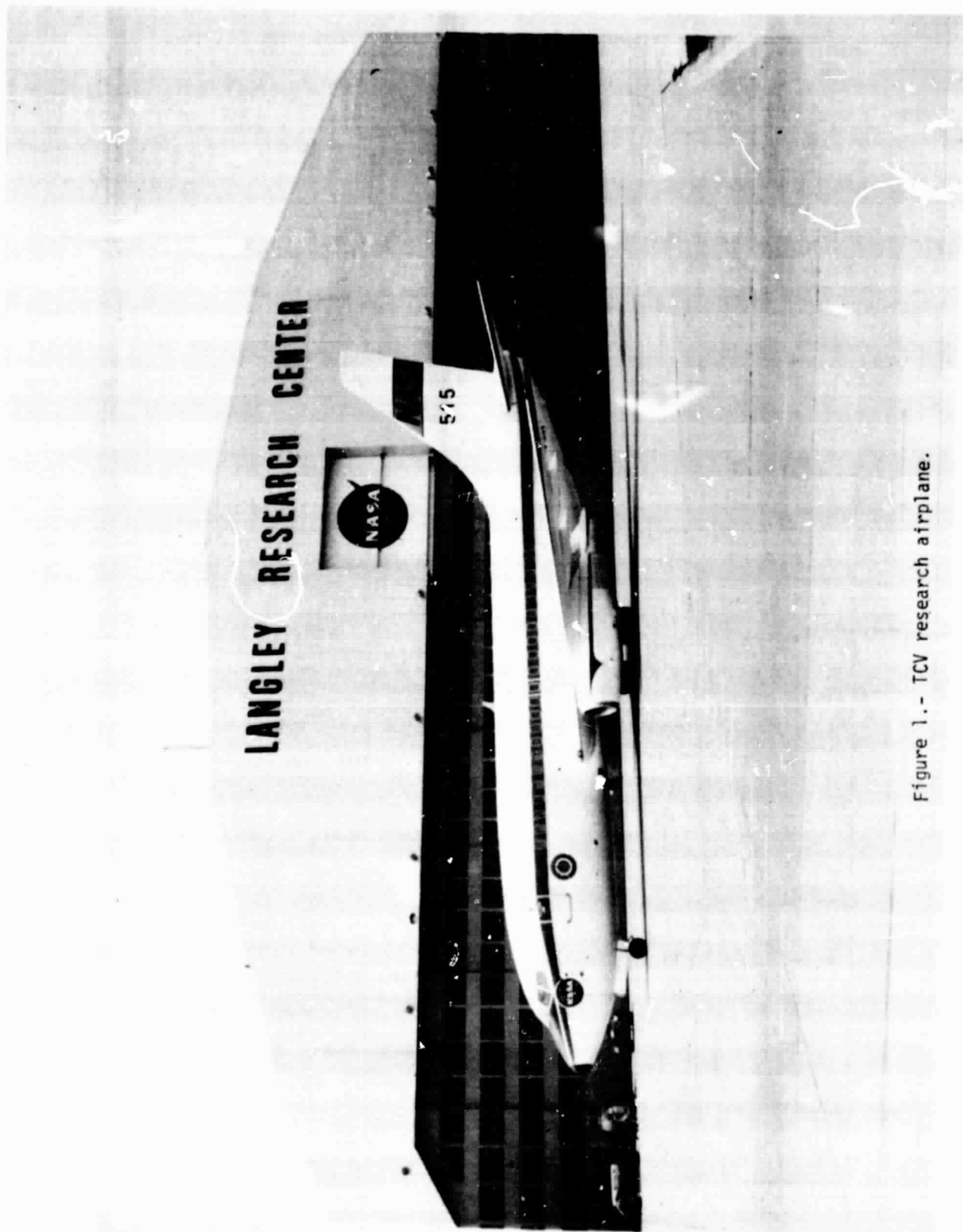


Figure 1.- TCV research airplane.

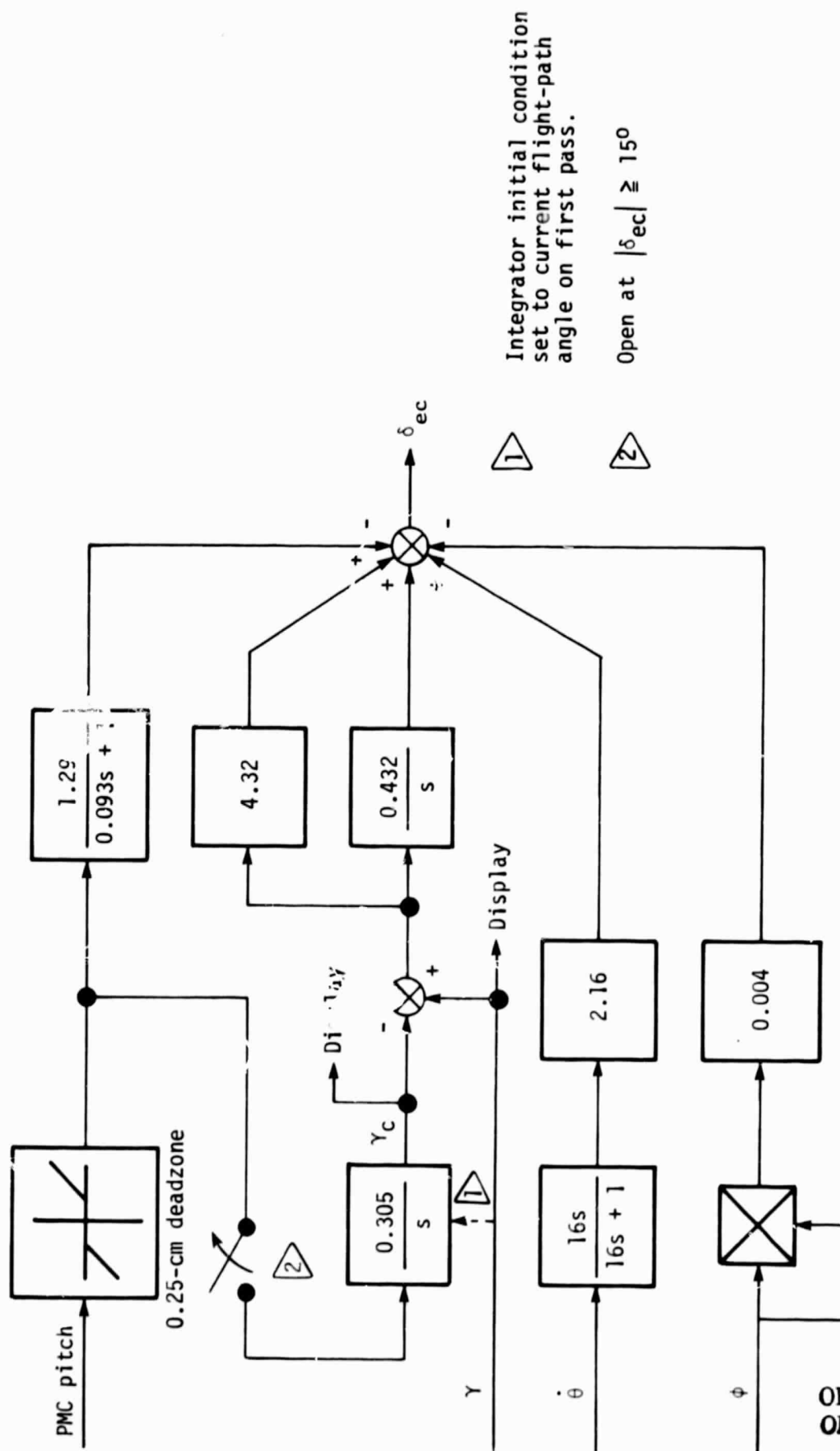


Figure 2.- Velocity vector control law.

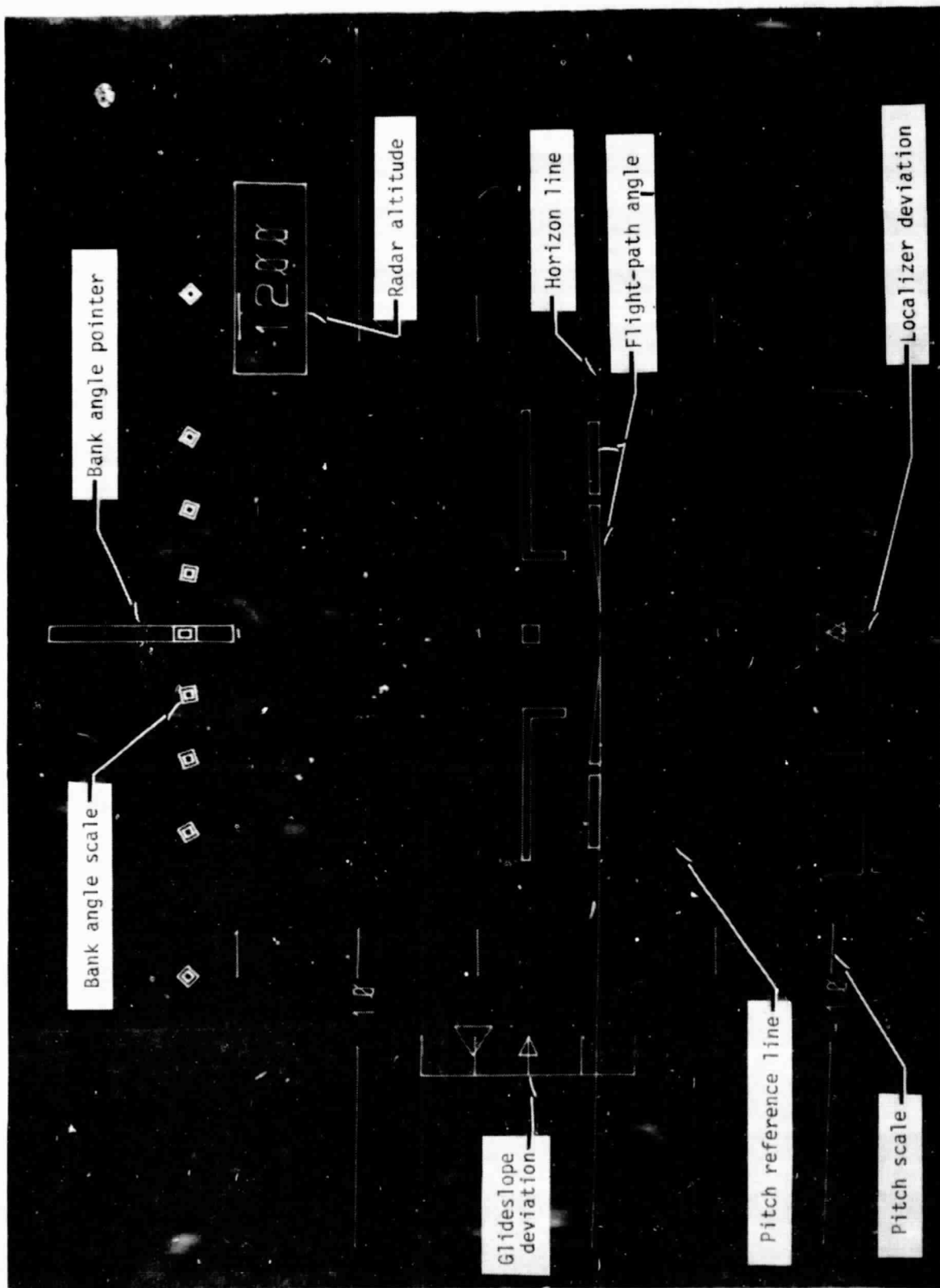


Figure 3.- EADI baseline display format.

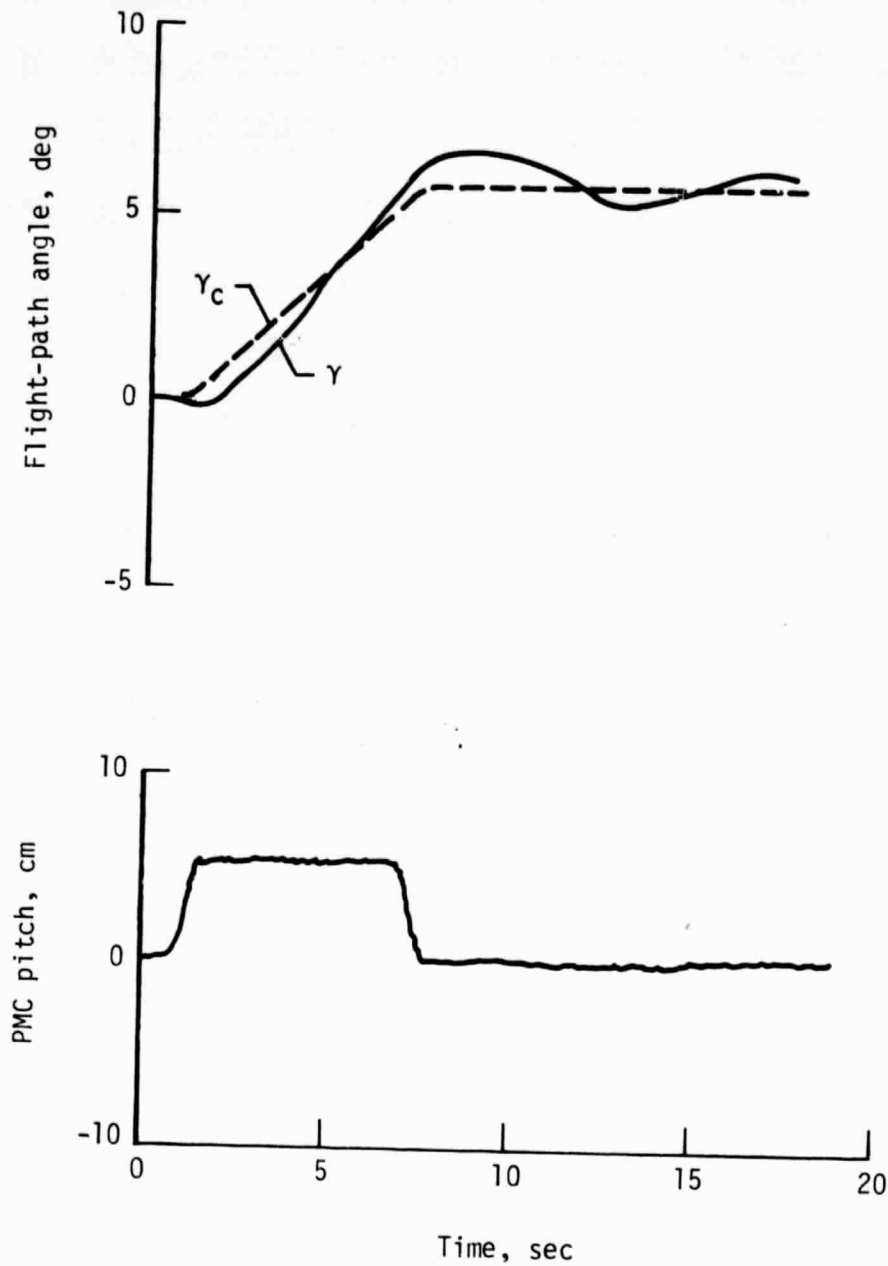


Figure 4.- Airplane response to a pitch control input (flight data).

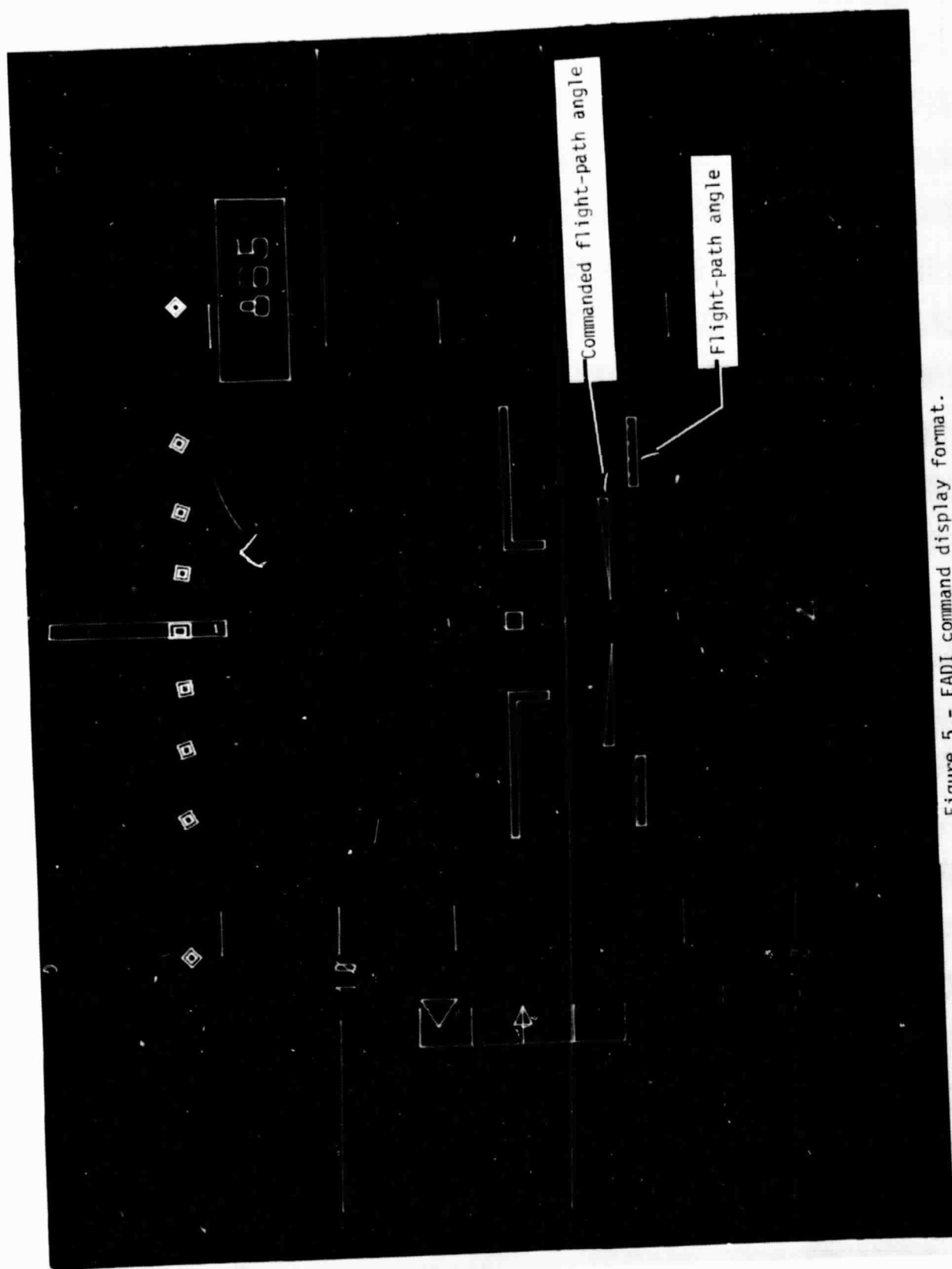


Figure 5.- EADI command display format.

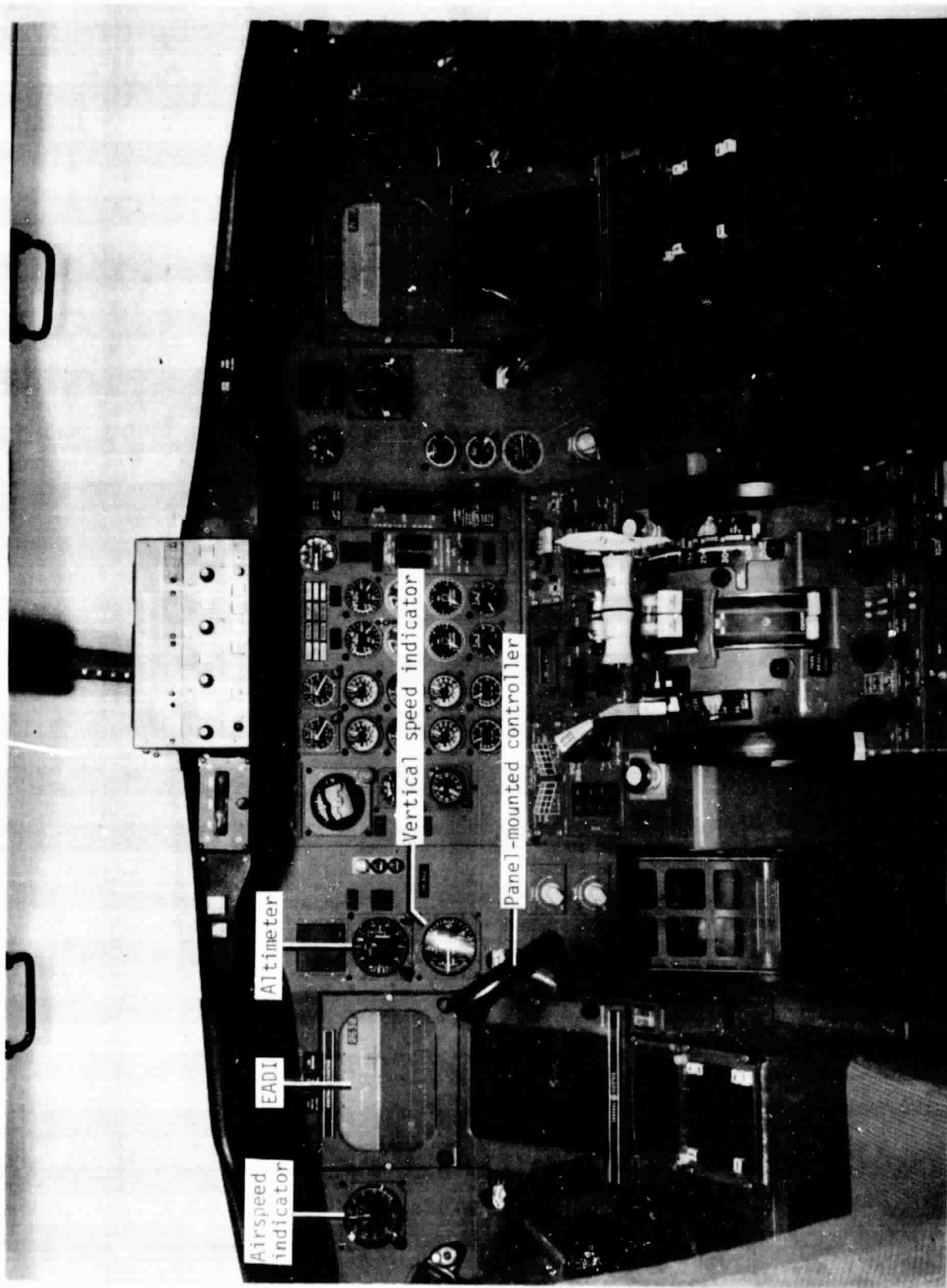


Figure 6.- TCV simulator cockpit arrangement.

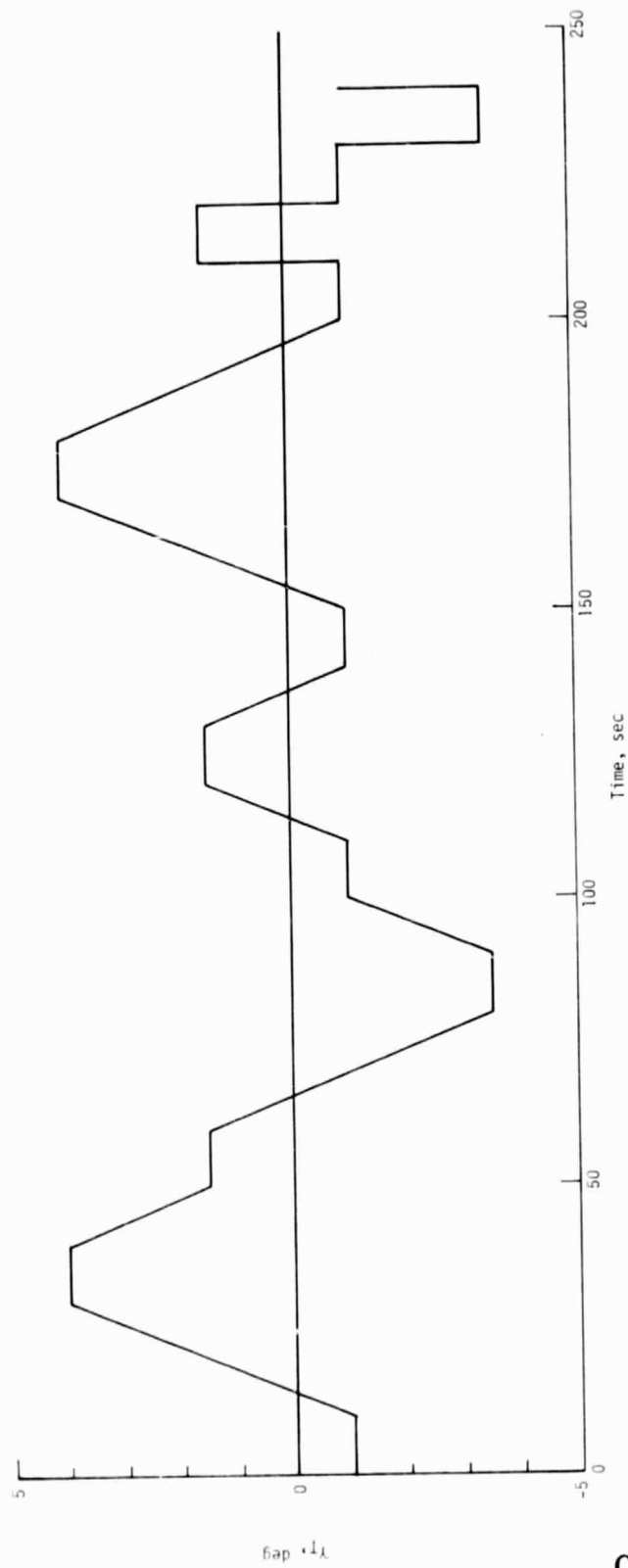


Figure 7.- Flight-path-angle tracking task.

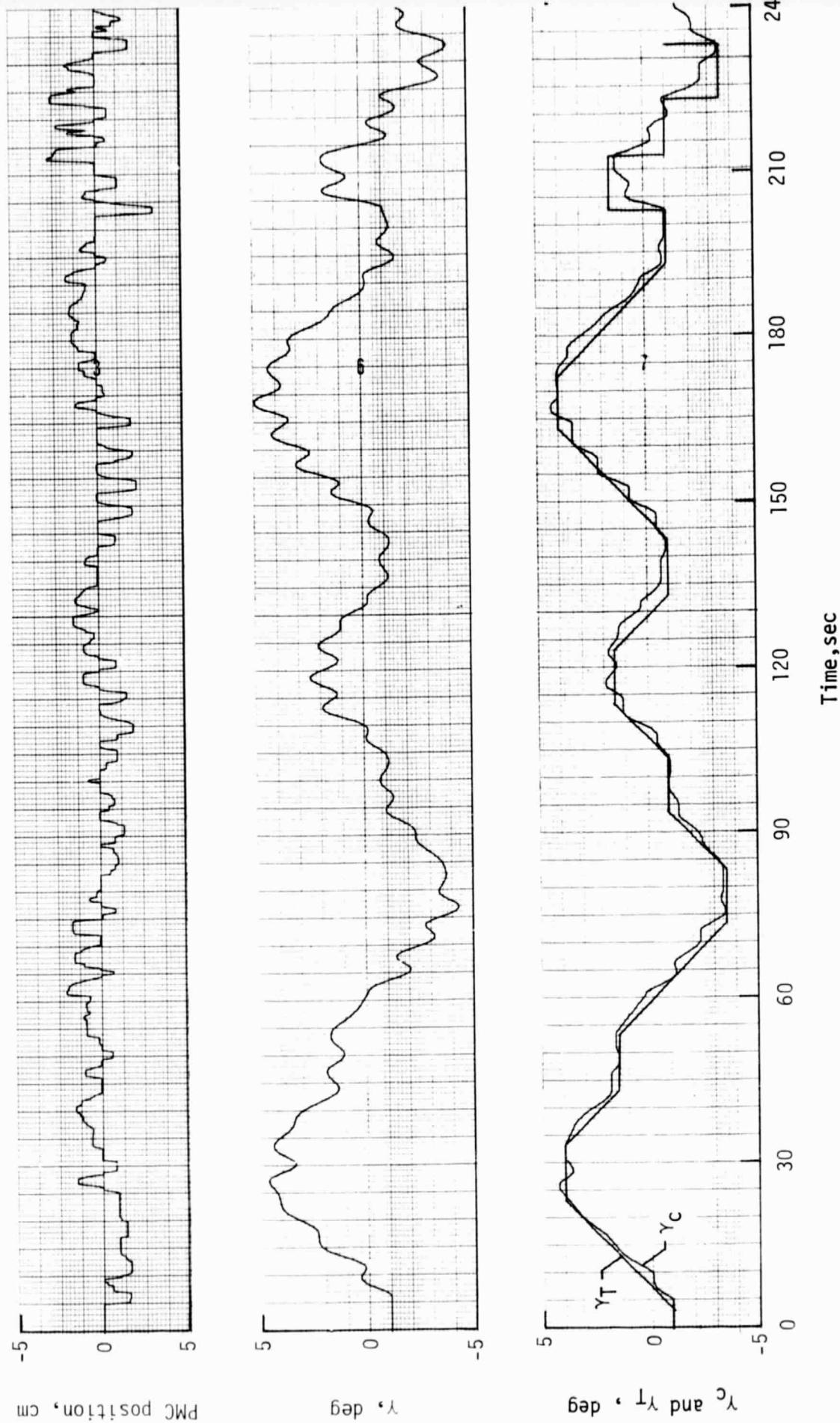


Figure 8.- Results of flight-path-angle tracking task with baseline display format; Pilot A.

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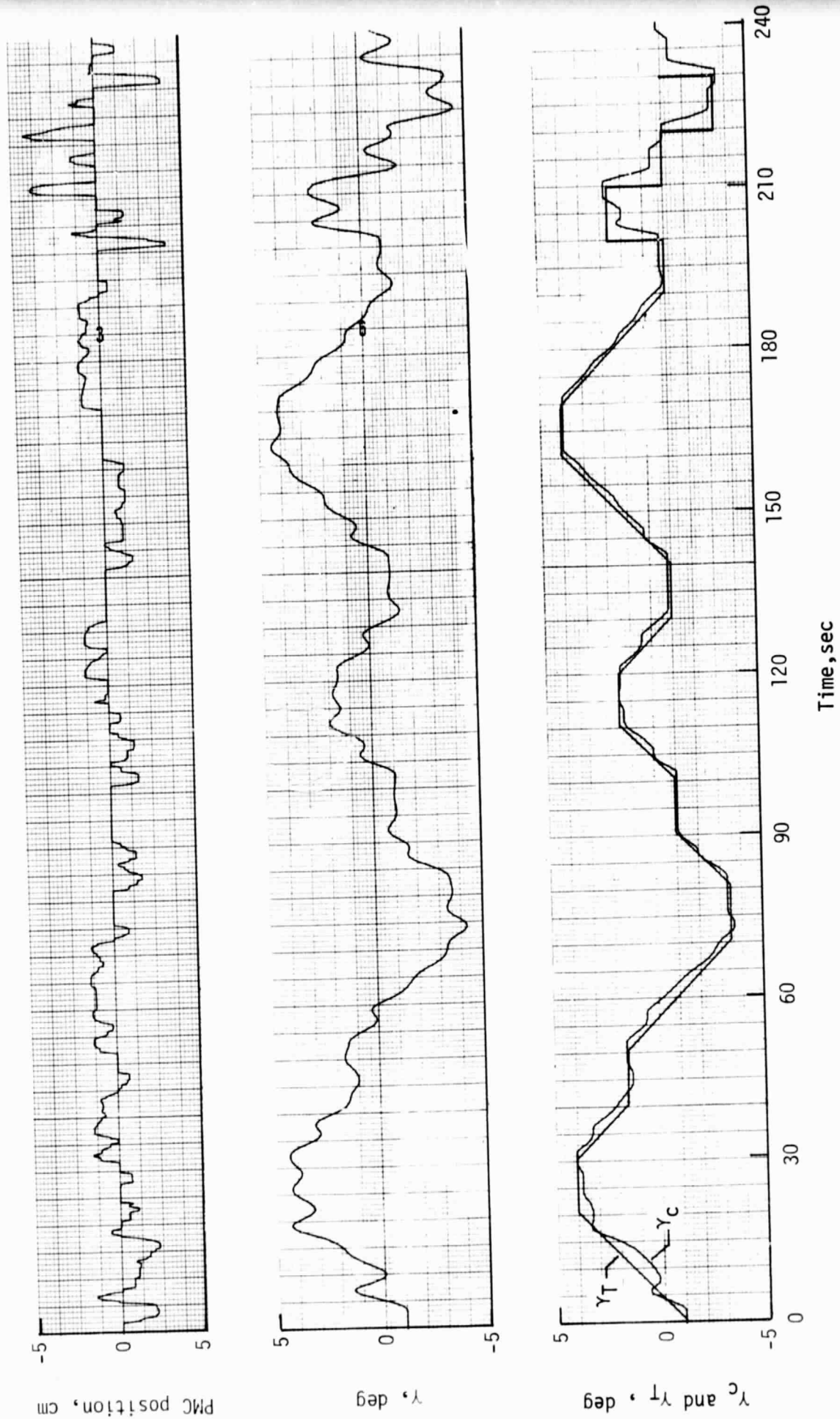


Figure 9.- Results of flight-path-angle tracking task with baseline display format; Pilot B.

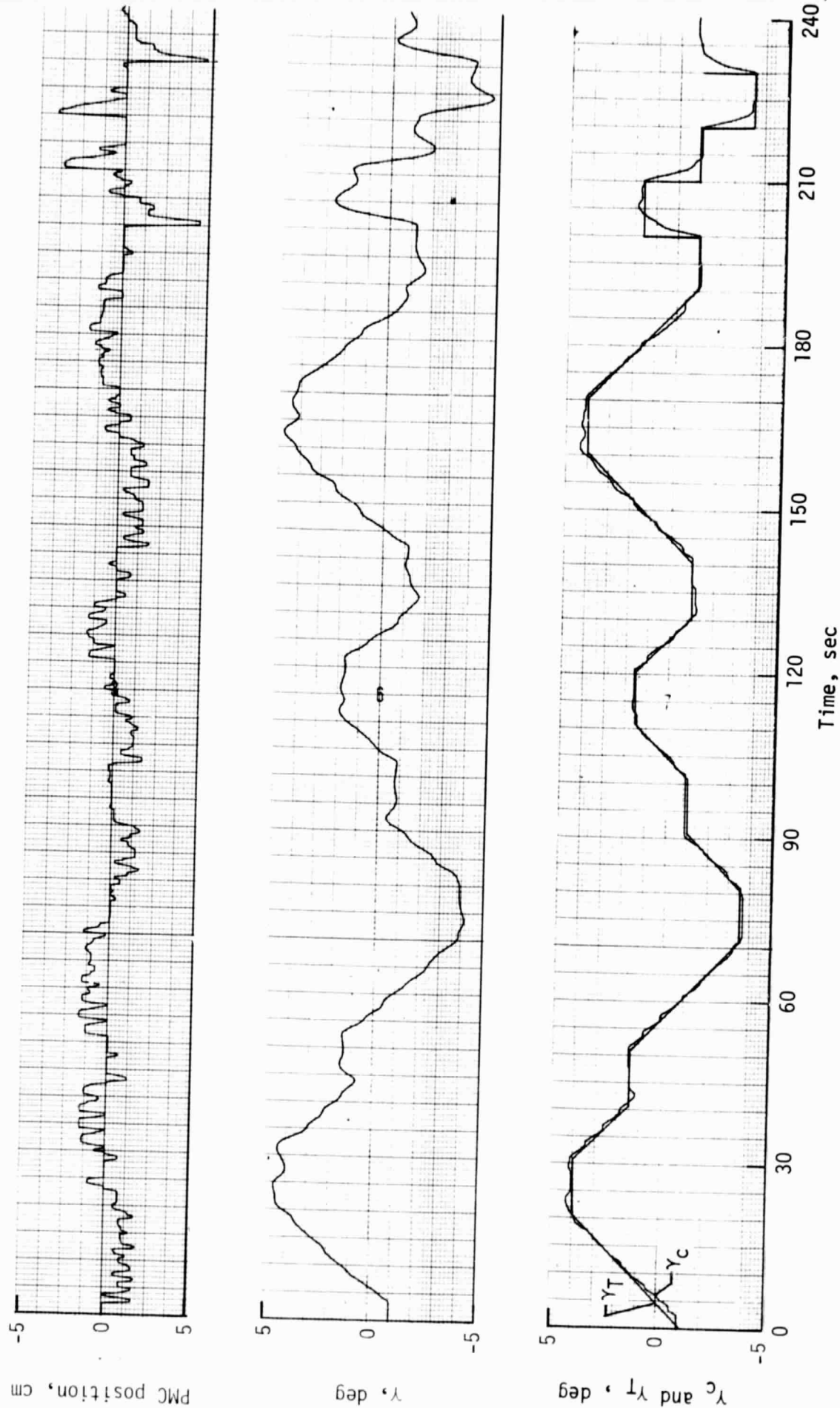


Figure 10.- Results of flight-path-angle tracking task with command display format; Pilot A.

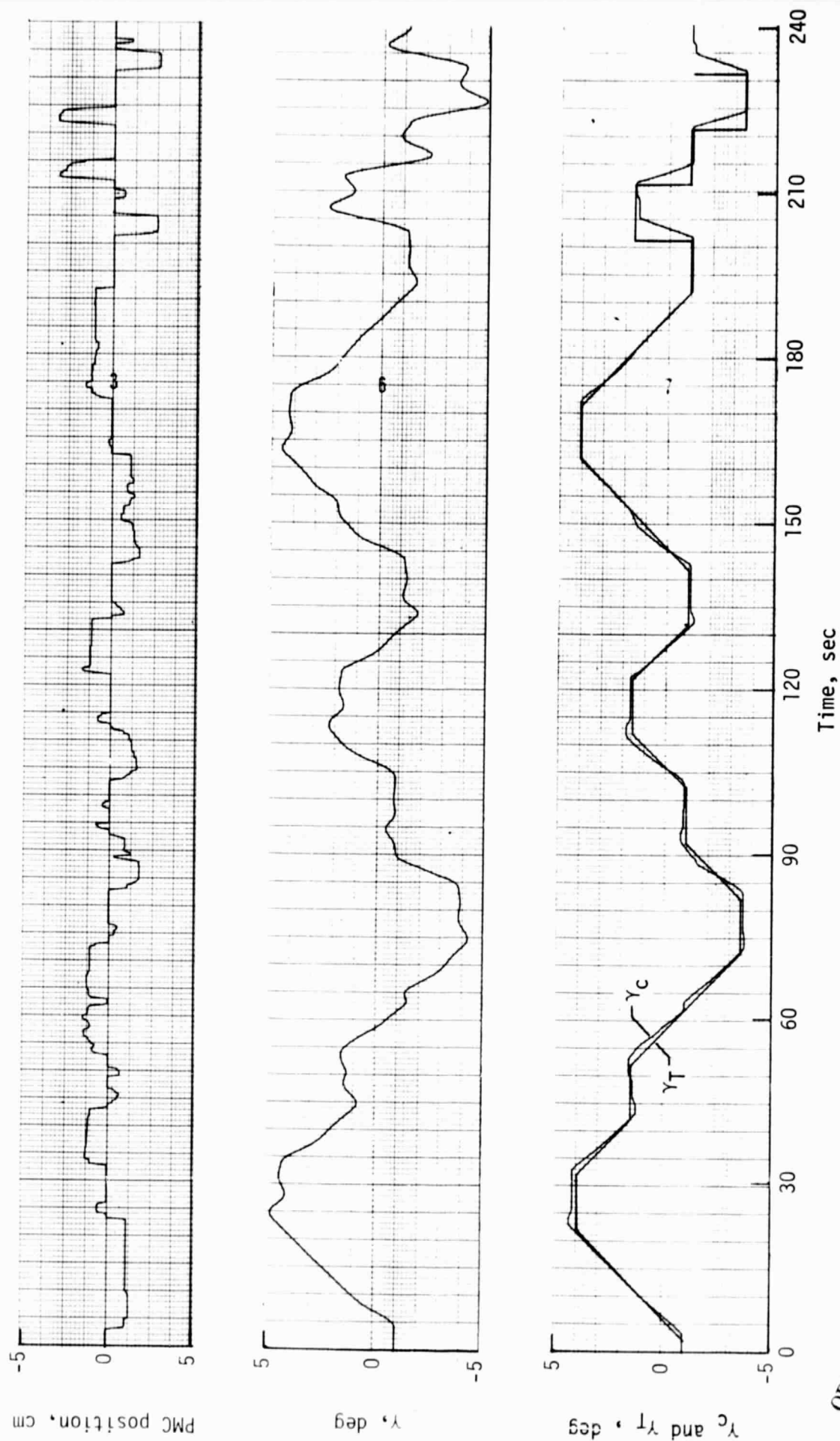


Figure 11.- Results of flight-path-angle tracking task with command display format; Pilot B.

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