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20. A Dynamic Response and Eye Scanning Data Base Useful in the Development of Theories and Methods for the Description of Control/Display Relationships*

RICHARD KLEIN

Systems Technology, Inc.

This paper documents a set of specially prepared digital tapes (STI master tape I) which contain synchronized measurements of pilot scanning behavior, control response, and vehicle response obtained during instrument landing system (ILS) approaches made in a fixed-base DC–8 transport simulator at the NASA-Ames Research Center. The objective of the master tape is to provide a common data base which can be used by the research community to test theories, models, and methods for describing and analyzing control/display relations and interactions.

The experimental conditions and tasks used to obtain the data and the detailed format of the tapes are described. Conventional instrument panel and controls were used, with simulated vertical gust and glide slope beam bend forcing functions. Continuous pilot eye fixations and scan traffic on the panel were measured. Both flight director (zero reader) and standard localizer/glide slope (manual) types of approaches were made, with both fixed and variable instrument range sensitivities.

INTRODUCTION

The experimental data described in this paper represent the results of one phase of a multiple-year research program to develop and validate a theory of manual control displays. The early phases included

- Evolution of a model for the display/pilot/vehicle system from extant data (refs. 1 and 2)
- Specific experiments aimed at developing and refining multiple instrument scanning models (ref. 3).

Development and validation of this work required simultaneous eye movement and pilot response data in flight control tasks under realistic approach conditions. This experimental phase has been accomplished, and selected data are now in hand for 31 simulated instrument approaches in a subsonic jet transport performed by three airline pilots. Detailed scanning statistics have been computed for these runs (ref. 4), and a concurrent phase is now under way to reduce the pilot response data for 12 of the 31 data runs.

As a by-product of this program it was decided to make the response and scanning data available to other researchers in this area. This would provide a common data base that could be used to test theories, models, and methods for describing and analyzing manual control/display relations and interactions. To this end, this paper will

(1) Summarize the experimental situations, pilot tasks, panel arrangement, forcing functions, etc., relevant to the data.

(2) Review the eye point-of-regard (EPR) manual data interpretation and reduction process.

(3) Describe the recorded variables and physical arrangement of the three specially prepared digital tapes (master tape I).

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SUMMARY OF THE EXPERIMENT

The experiment involved pilot control in a conventional category 11-like instrument approach in a six-degree-of-freedom fixed-base simulation of a DC–8 aircraft. The panel layout shown in figure 1 was typical of a subsonic jet transport, with some configurations employing a flight director (FD). The subjects were airline pilots and copilots. The task was to fly an ILS approach from the outer marker (30 000 ft from threshold) to the middle marker in the presence of pitch attitude disturbances, θ_c, and glide slope beam bends, ϵ_{GS_c}. Aircraft motions, displayed signals, pilot response, and pilot eye point-of-regard were FM-analog tape recorded during the experimental runs.

Experimental Configurations

The experimental configurations are described in table 1. Configuration *A* was a pitch attitude tracking task designed to provide single-loop response data on the present subjects for correlation with past data and models. Configurations *B*, *C*, and *D* involve a "raw presentation" of localizer and glide slope deviation, pitch and roll attitude, and peripheral instruments, but no flight director display. These tasks varied in their detail in order to explore effects of scanning and statistical stationarity. Configurations *E* and *F* employed all the displays of *C* and *D*, respectively, plus a lateral and longitudinal flight director display superimposed on the artificial horizon.

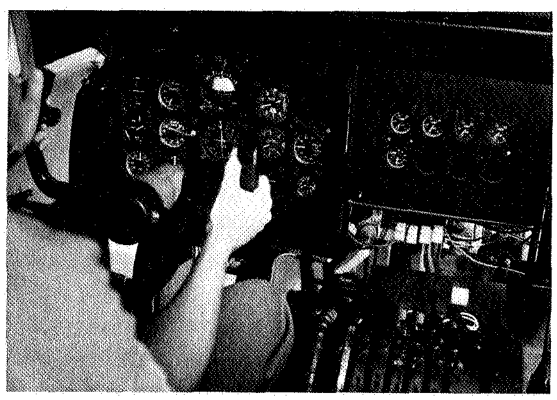

FIGURE 1.—Cockpit instrument layout.

TABLE 1.—*Experimental Configurations*

Configuration	Description
A (Pitch attitude regulation only)	Single-axis tracking task with pitch attitude display and θ_c forcing function. Other instruments masked. Other axes controlled by autopilot.
B (Split-axis manual ILS, fixed-range)	Three-degree-of-freedom longitudinal task. θ_c and ϵ_{GS_c} forcing functions on. Lateral axes under autopilot control, but meters visible.
C (Manual ILS, fixed-range)	All-axis approach task with both forcing functions on. The glide slope deviation computer range was fixed at 30000 ft from threshold.
D (Manual ILS, varying range)	All-axis approach task with forcing functions on. The range varied throughout the run. Glide slope deviation per unit altitude error increases with decreasing range.
E (Flight director, fixed-range)	All-axis approach task with forcing functions on. Flight director on and driven by forcing function. Same as configuration *C* plus flight director.
F (Flight director, varying-range)	All-axis approach task with forcing functions on. Flight director on. Glide slope component of *FD* forcing function attenuated with range by flight director computer. Same as configuration *E*, except range-varying.

The flight director provided pitch and roll commands. The longitudinal director mixed pitch attitude and "altitude" errors. The latter was computed from the angular glide slope deviation by multiplying by the range to the glide slope transmitter. This caused the forcing function amplitude (component due to the glide slope command) to decrease during configuration *F* runs. The lateral director mixed roll angle, heading angle, and (angular) localizer deviation errors. The flight director guidance equations are given in reference 4.

Properties of the other controlled elements are detailed in reference 4. The dynamics of the simulated vehicle were defined by a linearized set of perturbation equations in six degrees of freedom. The simulator was stabilized with full flaps and gear down at 135 kt on the approach path at the outer marker at the start of the run. No changes in flaps, trim, or power setting were required during the run. The dynamic properties of the flight instruments and elevator, aileron, and rudder controls were also measured and are given in reference 4. The rudder pedals moved in a normal manner, but were disconnected from the lateral equations of motion to insure single-axis control.

Run Sequence

Each pilot was given several initial familiarization runs of both manual ILS and flight director tasks without input forcing functions. This enabled the pilots to evaluate the aircraft's flying characteristics, become familiar with new instrumentation, and experience the cockpit procedures.

Practice runs followed the familiarization and enabled the pilots to experience the input forcing functions as applied to the three basic configurations (B, C, and E). Fixed-range tasks were used in practice because they could be of any run length, allowed stationary pilot behavior, and were to comprise the bulk of the final data runs. During the practice runs the EPR system was explained and the equipment fitted to the subject.

All formal record runs (after the familiarization and practice sessions) included two or three "warm-up" runs. The final data runs were made with the EPR system. A data session usually involved five or six 100 sec runs in succession, divided at random between manual ILS and flight director configurations. Fixed-range and varying-range configurations were not mixed in the same session, but were run on separate days.

Rest periods of 15 to 20 min for every five runs (about 30 min of data taking) were required. Normal data taking sessions were 2 to 2-1/2 hr duration, including EPR setup, with only one session per day per pilot.

Signals Recorded

The displayed signals, pilot response, vehicle motions, and eye movements recorded on 14-channel FM tape included

- Vertical coordinate of eye point-of-regard, EPR_V
- Horizontal coordinate of eye point-of-regard, EPR_H
- Pitch attitude command, θ_c
- Glide slope command, ϵ_{GS_c}
- Pitch attitude error, θ_e
- Glide slope deviation error, ϵ_{GS_e}
- Elevator deflection, δ_e
- Displayed roll angle, φ_d
- Displayed localizer deviation, ϵ_{LOC_d}
- Aileron deflection, δ_a
- Displayed rate of climb, $\dot{h}_d$
- Heading angle, ψ
- Voice commentary and identification
- 40 Hz digitizing tone.

During flight director runs (configurations E and F the pitch and roll director commands were recorded in lieu of rate of climb and heading angle.

The 40 Hz digitizing tone, signifying the start of the 100 sec run was turned on about 10 sec after the start of the run. After approximately 2 min of running, the experimenter would call "run completed," at which time the digitizing tone was turned off and the simulator reset. The digitizing signal enabled a common time base to be maintained regardless of recorder speed variations.

EPR DATA INTERPRETATION

This section describes the data interpretation procedure that was used to obtain a unique set of eye point-of-regard data from the raw vertical and horizontal coordinates of the EPR records. This involved the allocation of *all* elapsed time into discrete intervals, each corresponding to a dwell on a given region of the panel. The six instruments and other regions of the panel were numbered as shown in figure 2. There were no looks to regions 9 and 10, and looks at region 8 were usually blinks.

Using a high-speed strip chart playback of the horizontal and vertical EPR signals, it was possible to very accurately distinguish between dwells. A typical bona fide dwell was usually greater than 0.3 sec. The transition time was defined as the time between looks at two different instruments, and was assumed to be no greater than 0.13 sec. Normally there is a clear-cut switch (of about 0.02 sec duration) in the trace, as shown in figure 3. For this case the transition is divided evenly between adjacent dwells. If the duration was greater than 0.13 sec

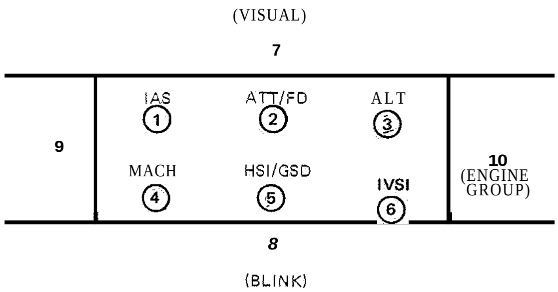

FIGURE 2.—EPR regions on instrument panel.

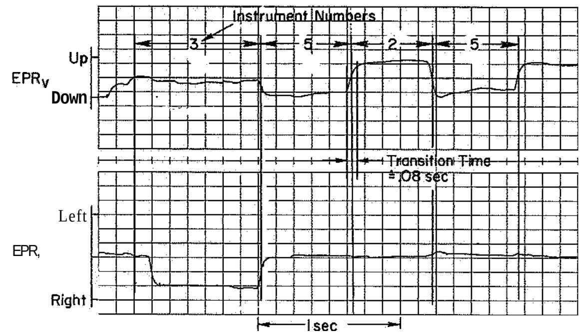

FIGURE 3.—Raw EPR data showing normal transitions.

it was included in the tabulation as a separate entry, rather than allocated to adjacent dwells.

Once the dwells were discretized and assigned to regions, the region number and dwell duration were transferred to punch cards. The region numbers were then digitized and merged with the other recorded variables using a BOMM* program.

To maintain time correlation with the other variables, EPR data reading began at the first complete dwell following the digitizing tone, and proceeded through exactly 100 sec. This resulted in truncation of the last dwell. In reference 4, however, the nearest complete dwell to 100 sec was used. Hence EPR statistics obtained from master tape I will differ slightly from those presented in reference 4.

DESCRIPTION OF MASTER TAPE I

The master tape contains a total of 34 data runs, each exactly 100 sec long. These runs were selected from over 100 total runs because of the quality of the EPR data, motivation of the pilot subjects, and compatibility of the response data with that of actual approaches (based on pilot comments and tracking errors). Thirty-one of the data runs contain EPR data. Three additional runs (with no EPR data) include two single-axis (configuration *A)* for tie-in to other single-axis compensatory tracking data, and one analog pilot run for checkout of data reduction techniques.

The 34 data runs are recorded on three 7-track digital tapes which together comprise master tape I. The allocation of runs, in order of their appearance on the tapes, is presented in table 2. The column labeled "recorder key" specifies the set of variables recorded for that run. Table 3 defines this recorder key and gives the units and sign convention of each variable.

Each tape has the following digital characteristics:

Tape tracks = 7
Tape density = 556 bits/in.
BCD format = (1X, 11E, 10.3)
Sampling rate = 20 samples/sec
2000 records per file
11 variables (words) per record
10 characters per word.

One file of data may be read using the following FORTRAN IV statements:

```
DIMENSION (22000)X
READ (TAPE UNIT, 1)X
1 FORMAT (1X, 11E 10.3)
```

Copies of STI master tape I may be obtained from NASA-Ames * or through STI.

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* BOMM—A system of programs for the analysis of time series. Written by E. C. Bullard, F. E. Oglebay, W. H. Munk, and G. R. Miller of the Institute of Geophysics and Planetary Physics at the University of California at La Jolla, Apr. 1964.

* Man-Machine Integration Branch.

TABLE 2.—*Master Tape Index*

Tape	File no.	Config-pilot	Run no.	Recorder key
I	1	A1	17–14	1
	2	D1	17–16	1
	3	B1	17–18	1
	4	B1	19–5	1
	5	B2	19–17	1
	6	A2	19–20	1
	7	D1	26–05	1
	8	D1	26–09	1
	9	D1	27–03	3
	10	D1	27–06	3
	11	D3	28–05	3
	12	D3	28–08	3
2	1	Analog pilot	17–08	1
	2	C1	17–15	1
	3	C1	19–04	1
	4	C1	19–10	1
	5	C1	19–11	1
	6	C1	19–13	1
	7	C2	19–16	1
	8	C2	19–19	1
	9	C2	19–21	1
	10	C2	19–23	1
	11	C2	19–25	1
3	1	E1	17–19	2
	2	E1	19–08	2
	3	E1	19–12	2
	4	E2	19–18	2
	5	E2	19–22	2
	6	E2	19–24	2
	7	E1	13–20	2
	8	F1	26–07	2
	9	F1	26–08	2
	10	F1	27–05	3
	11	F3	28–07	3

TABLE 3.—*Recorded Variables*

Position within record	Recorder key* 1	Recorder key* 2	Recorder key* 3	Name	Sign convention and symbol	Positive value	Units
1	TE	TE	TE	Pitch attitude error	$+\theta_e$	Meter indicates nose down	rad
2	GE	GE	GE	Glide slope error	$+\epsilon_{GS_e}$	Meter indicates below beam	rad
3	TI	TI	TI	Pitch attitude command	$+\theta_c$	Meter indicates nose down	rad
4	GI	GI	GI	Glide slope command	$+\epsilon_{GS_c}$	Meter indicates below beam	rad
5	DE	DE	DE	Elevator angle	$+\delta_e$	Trailing edge down	rad
6	DA	DA	DA	Aileron angle	$+\delta_a$	Right aileron up	rad
7	PH	PH	PH	Display bank angle	$+\phi_d$	Right wing down	rad
8	LO	LO	LO	Display localizer angle	$-\epsilon_{loc_d}$	Left of localizer	rad
	HD			Display altitude rate	$+\dot{h}_d$	Climbing	ft/sec
9		FP		Pitch flight director error	$+FD_{pe}$	Bar up	units
			R	Range	$+X$	Before glide slope trans.	ft
	PS		PS	Heading angle	$+\psi$	Right turn	rad
10		FR		Roll flight director	$+FD_r$	Bar counterclockwise	units
11	EPR	EPR	EPR	Eye-point-of-regard		All positive	integers 1 to 8

* Abbreviated symbol names for use in digital analysis.

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