PAPER PILOT PONDERS SUPERSONIC TRANSPORTS

John R. Stone
Flight Dynamics Laboratory
Wright-Patterson AFB, Ohio

ABSTRACT

This paper describes the application of the digital program Pitch Paper Pilot to a presimulation analysis of a large delta wing aircraft similar to the Concorde supersonic transport. Pilot acceptance (in terms of Cooper-Harper ratings), pilot model parameters, and pilot-vehicle performance were predicted by Paper Pilot and compared to actual inflight measures. Results are good and illustrate the value of using the Paper Pilot concept during the planning stages of simulation.

I. INTRODUCTION

The technical community relies heavily on simulation to test complex systems. New ideas can be examined and questions can be answered during simulation that would prove very costly to study on actual systems. However, for the simulation to be most efficient careful planning is necessary. This paper presents an example of an automated analysis that can predict important pilot-aircraft information for planning purposes. The information includes predictions of pilot-vehicle performance, pilot rating, and pilot model parameters; in addition, critical experimental parameters can be derived. The analysis is accurate, fast, economical, and can accommodate complex systems.

To test the presimulation planning capabilities of the technique, which is based on the digital computer program Pitch Paper Pilot (Ref. 1), data for an inflight simulation of a supersonic transport (Ref. 2) was analyzed before the results of the simulation were available. The predictions were generated and then compared to the actual inflight measurements.

II. PRESIMULATION ANALYSIS

PITCH TASK

The inflight simualtion modeled the landing approach task of a supersonic transport. For this task it has been well established that the primary pilot function for transport-type aircraft is the maintenance of pitch attitude (Refs. 2 and 3). Thus, the use of the Pitch Paper Pilot program, which only models the longitudinal pitch tracking task, was reasonable in this investigation, especially since the lateral configuaration remained constant

A brief review of the Pitch Paper Pilot program shows that the pitch tracking task is modeled by a single closed-loop system with pilot control of elevator (Fig. 1). Included are a commanded pitch input, pilot model Y_p, airframe dynamics, and stability augmentation system (SAS). The commanded pitch input is generated by passing white noise through a first order filter with a break frequency equal to one radian per second. The pilot model is of the form:

$$Y_p = k_p(T_L s + 1)e^{-\tau s} \approx \frac{-k_p(T_L s + 1)(s - 2/\tau)}{(s + 2/\tau)}$$

where

s = Laplace transform notation

k_p = pilot gain

T_L = pilot lead, seconds

τ = effective pilot central processing delay, seconds

The aircraft dynamics are the standard three degree-of-freedom longitudinal equations of motion with dimensional stability axis derivatives.

PROGRAM DESCRIPTION

To use the Pitch Paper Pilot program the aircraft stability derivatives, longitudinal airspeed, commanded input model parameters, pilot time delay, initial guess of pilot gain and lead, SAS gains, control system lags, and data used in the minimization routines are input. The first computational step in the Paper Pilot rating scheme finds a stable set of pilot parameters. The cost functional J is minimized with respect to the pilot parameters; subject to the constraint T_L = 5 seconds. J is given as

$$J = Perf + R_1 + R_2 + 1.0$$

where

$$PERF = \begin{cases} .1/(.974 - \sigma), & \sigma < .974 \\ 10^{11}(.974 - \sigma)^2 - 3 \times 10^7(.974 - \sigma) + 3 \times 10^3, & \sigma \geq .974 \end{cases}$$

$\sigma = \sigma_e/\sigma_i$ = root mean square (rms) tracking error normalized by the rms commanded input

$$R_2 = \begin{cases} -2.5T_L, & T_L < 0 \\ 2.5T_L, & 0 \leq T_L \leq 1.3 \\ 3.25, & T_L > 1.3 \end{cases}$$

$$R_3 = \begin{cases} 0, & T_L \leq 5.0 \\ 100(T_L - 5)^3, & T_L > 5.0 \end{cases}$$

The minimizing pilot parameters are then used to compute a closed-loop Pitch Paper Pilot rating in Cooper units as given by

$$PR = \begin{cases} R_1 + R_2 + 1.0, & PERF + R_2 + 1 \leq 10 \\ 10, & PERF + R_2 + 1 > 10 \end{cases}$$

where

$$R_1 = .1/(.974 - \sigma).$$

The Cooper ratings are converted to Cooper-Harper ratings which will be used in this paper. A rating of one is excellent; ten may be catastrophic.

APPLICATION OF PITCH PAPER PILOT

Pitch Paper Pilot was used to analyze the longitudinal flying qualities of fourteen supersonic transport configurations in landing approach. The stability derivatives were those used for the simulation, the break frequency was selected to equal one radian per second, and the pilot time delay was chosen to be 0.3 seconds. This value includes a mental processing delay of about 0.2 seconds and a neuromuscular delay of 0.1 seconds.

III. SIMULATION

FLYING QUALITIES EXPERIMENT

In the summer of 1972 an inflight simulation program was conducted by the Air Force Flight Dynamics Laboratory (AFFDL) and CALSPAN Corporation to establish flight characteristics criteria for airworthiness certification of supersonic transports during landing approach (Ref. 2). This program dealt specifically with the static longitudinal stability of the bare unaugmented airframe and required pilot ratings of the aircraft's handling qualities, and, thus provided an excellent example to test the Paper Pilot concept as a presimulation analysis tool. The method for obtaining the needed inflight handling qualities data to fly actual landing approaches in the Total In-Flight Simulator (TIFS) (Fig. 2) on which were programmed the equations that described various longitudinal configurations of a large delta-wing jet transport of the Concorde class. The simulation included statically unstable configurations ($Cm_\alpha > 0$), and those on the backside or bottom of the thrust-required curve ($1/T_{h1} < 0$). In most cases the short period mode had degenerated to two real roots, one of which was unstable. Three stable configurations with conventional dynamics were also tested. The Paper Pilot program was able to accurately rate the flying qualities of twelve of the fourteen unconventional configurations inspite of the fact that no written specifications exist for such configurations. After all, to define the specifications was the purpose of the TIFS experiment.

PILOT DESCRIBING FUNCTION EXPERIMENT

To help validate the predicted pilot model parameters and performance, a limited pilot describing function experiment was performed. Two pilots were instructed to fly a stable configuration of an inflight compensatory pitch tracking task with simulated turbulence. After a brief training period (both pilots were already familiar with the configurations because of the earlier TIFS evaluations), five experimental runs of one hundred-second duration were analyzed using a Describing Function Analyzer (Ref. 4) The pilot describing function and pilot performance data were than compared to the predicted values. The pilots also gave comments which were helpful in comparing the describing function experiment to the flying qualities experiment.

It is important to note the differences between the vertical gust input used in the describing function experiment and the commanded input used in the Paper Pilot predictions. First of all, the gust input entered the system directly through the aircraft equations. Consequently, the aircraft equations appeared as a higher order filter operating on the gust. Futhermore, the gust input was shaped to resemble the Dryden gust spectrum, with a break frequency of about one-half radian per second. On the other hand, the Paper Pilot commanded input was generated by passing white noise through a first order filter with a break frequency of one radian per second. Thus, the Paper Pilot predictions, compared to the describing function experiment, were based on an input which had a higher break frequency and energy content for the same tracking task. Inspite of these differences, both inputs approximated heavy turbulence.

As a footnote to the pilot describing function experiment, the digitally recorded inflight data is currently being analyzed at AFFDL with a parameter identification routine based on L. W. Taylor's work (Ref. 5). Pilot parameters identified with Taylor's method should provide interesting comparisons to those measured with the describing function analyzer.

IV. RESULTS

The findings of the TIFS study indicated that the pilots rated the configurations differently depending on the amount of training and the gust level. Consequently, the TIFS researchers attempted to eliminate training and gust effects and thereby derived "compensated" pilot ratings. Table 1 shows the very good comparison of the Paper Pilot predictions to the compensated ratings, as well as to the "raw" pilot ratings. In only two cases, where the actual ratings were 10, were the predictions notably different.

The pilot describing function experiment yielded measurements to validate the predicted performance and pilot model parameters. Table 2 shows good comparison between predictions and measurements, except for pitch rate. And the Bode plot of Figure 3 indicates that the predicted pilot model is very similar to the models of the actual pilots, especially in the vicinity of the crossover frequency which is about five radians per second.

The above results in terms of pilot rating, performance, and model parameters can indicate good and bad aircraft configurations which should be known in planning a simulation. However, additional information in terms of critical experimental parameters should also be known. The use of the Paper Pilot program indicated that the important parameter was the static stability Cm_{α}, the induced drag $C_{D_{\alpha}}$ and the pitch damping (Cm_q + $Cm_{\dot{\alpha}}$) were not as important. The inflight evaluations confirmed these predictions.

In summary the Pitch Paper Pilot program, which was developed from a base of fighter data, can analyze the handling qualities of large transport-type aircraft. Perhaps the form of the commanded pitch input, as opposed to a gust input through the aircraft equations, has a normalizing effect with respect to aircraft size. On the negative side of the picture, the Paper Pilot had difficulty in stabilizing and then finding the minimum pilot rating for some of the unstable configurations. Besides the problem of identifying the proper stabilizing gain (Fig. 4), there are preliminary indications that more than one set of pilot gain and lead would satisfy the minimization requirements. This leads to the interesting possibility of two ratings for the same configuration, and may explain why different pilots sometimes rate the same configuration quite differently, for example, Configurations 1 and 3 of Table 1. Such observations will be clarified as more complete simulations and data reductions are accomplished, in particular, if the measurement of pilot model parameters is emphasized.

REFERENCES

1. Anderson, R. C., A. J. Connors, and J. D. Dillow, "Paper Pilot Ponders Pitch, AFFDL-TM-70-1, January 1971.

2. Wasserman, R. and J. F. Mitchell, "In-Flight Simulation of Minimum Longitudinal Stability for Large Delta-Wing Transports in Landing Approach and Touchdown," AFFDL-TR-72-143, February 1973.

3. Gerken, G. J., F. Unfried, et al, "A Piloted Power Approach Sumulation," AFFDL-TR-73-27, March 1973.

4. Peters, R. A. and R. W. Allen, "Operational Manual for Describing Function Analyzer," W-P-406-2, Systems Technology, Inc., October 1970.

5. Taylor, L. W. and K. W. Iliff, "Systems Identification Using a Modified Newton-Raphson Method--A Fortran Program," NASA TN D-6734, May 1972.

TABLE 1

COMPARISON OF PILOT RATINGS

Conf	P Pilot	TIFS Pilots A	B	C	D	Compensated Ratings	T_2 sec
BL	6.1	-	-	-	-	-	5
1	5.6	-	2C	2B	5D	-	stable
2	6.0	4D	7(5)	-	6-7	6	60
3	6.1	6-7D	6	9	5	6	8
4	6.5	5C	5	-	7-8E	6.5	4
5	6.5	10E	-	10	7D	10	2
10	6.0	5D	5	-	7D	6	9
11	6.2	5D(6B)	-	-	6D	6	5
12	8.0	10F	6-7	-	-	8.5	2
13	5.3	3C	1-2	-	-	-	stable
14	5.3	4C	-	-	6D	5	8
15	5.3	6B	-	5C	7.5D	7.5	4
16	5.8	10E	-	-	10F	10	2
20	5.3	3C	-	-	4C	-	stable

TABLE 2

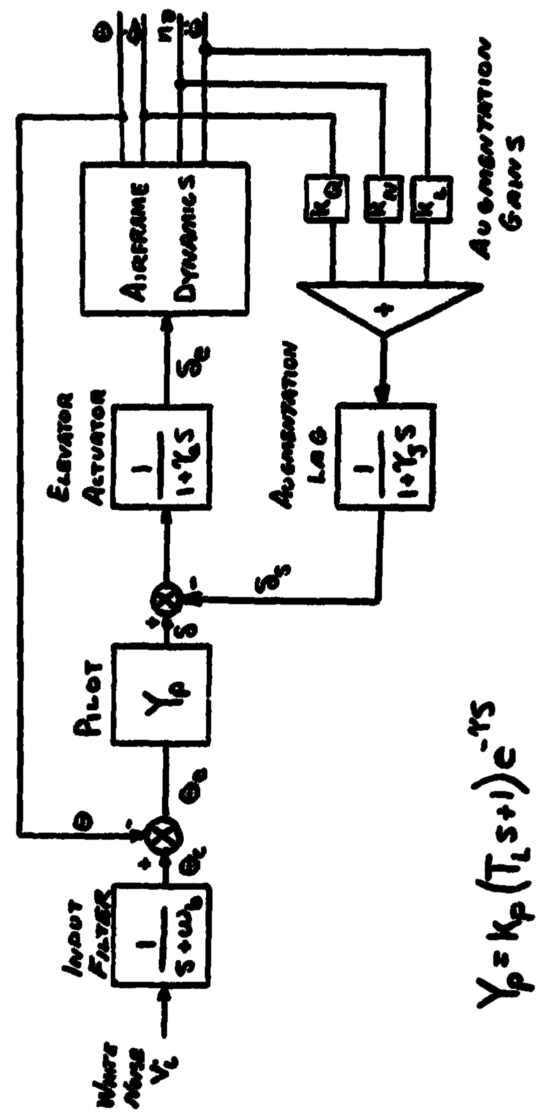
RMS VALUES, CONFIGURATION 20

	σ_{δ_e} (deg)	σ_θ (deg)	σ_q (deg/sec)	σ_α (deg)	σ_u (ft/sec)
PPP	.78	.71	1.52	.7	2.1
SC	.5	.5	.4	.8	2.2
DFA	.62	-	-	-	-

PPP - Pitch Paper Pilot predictions

SC - Approximate rms values from strip chart, averages of five runs, (rms = 1/3 x max value)

DFA - Describing Function Analyzer measurement

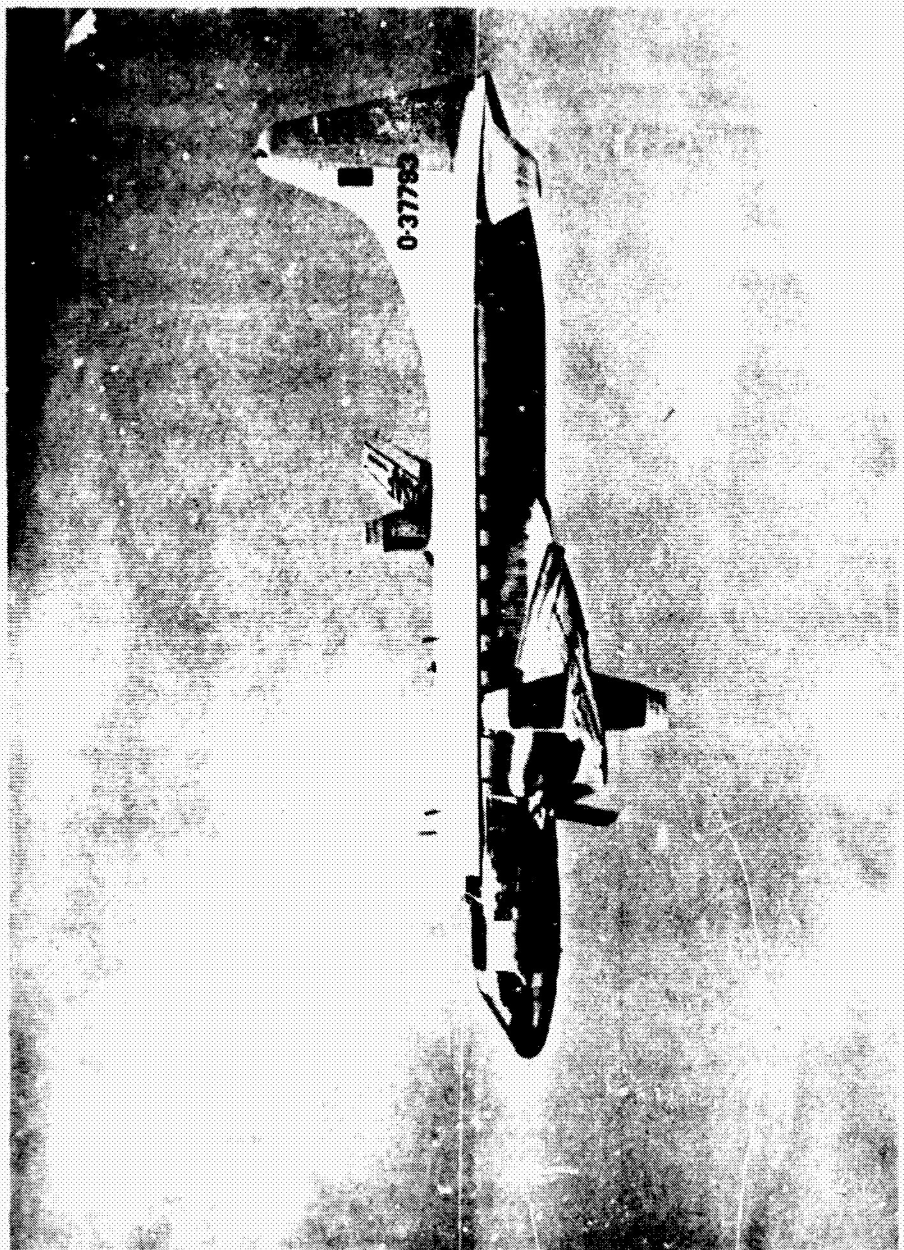


$$Y_p = K_p(T_L s+1)e^{-\tau s}$$

$$Y_p \doteq -K_p(T_L s+1)(s-2/\tau)/(s+2/\tau)$$

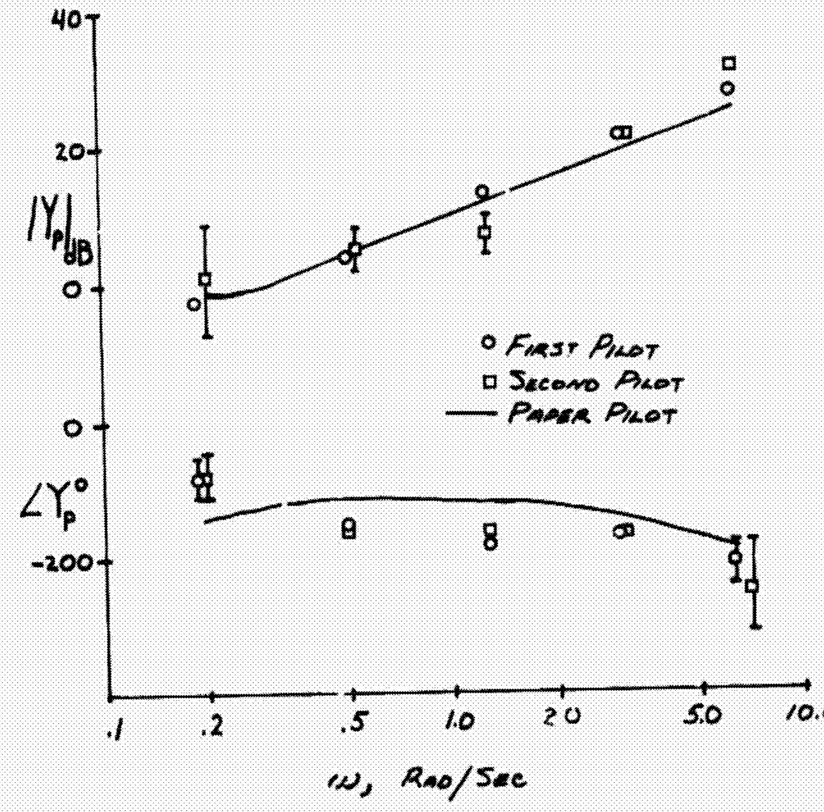
PITCH TRACKING TASK

FIGURE 1



TOTAL IN-FLIGHT SIMULATOR (TIFS)

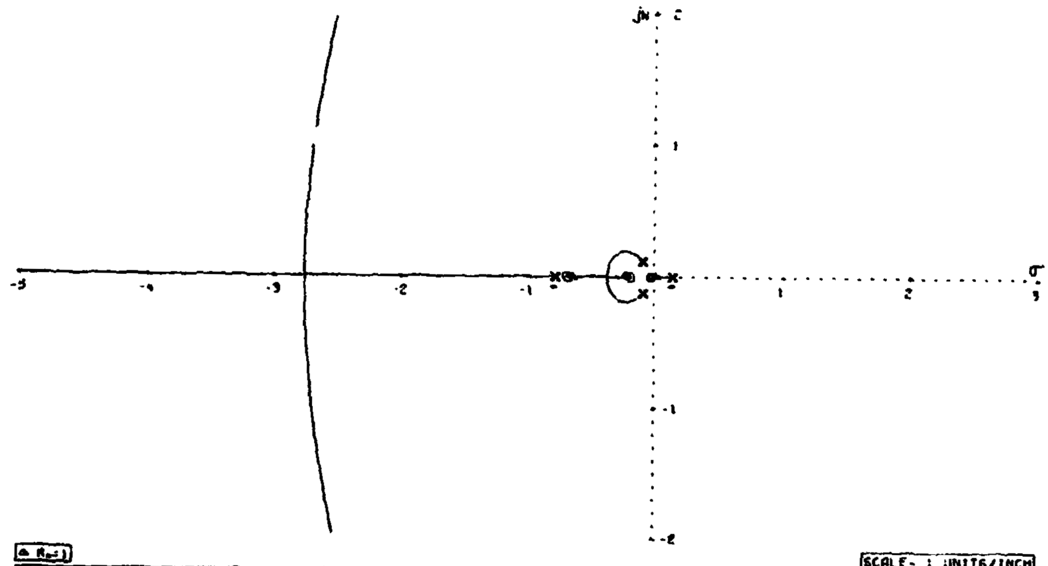
FIGURE 2



PILOT MODELS

FIGURE 3

SST BASELINE CONFIGURATION



$$G(S)H(S) = \frac{-K(S-6.67)(S+0.2)(S+0.004)(S+0.694)}{(S+6.67)(S-0.139)(S+0.784)(S^2+0.182S+0.022)}$$

FIGURE 4 - ROOT LOCUS