N75 19133

PITCH PAPER PILOT REVISITED

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ABSTRACT

Two methods are described for predicting the handling qualities of an aircraft in pitch. Both methods are based on minimizing a pilot rating expression with respect to free pilot parameters. In one case the pilot rating expression was developed from a set of moving base simulation data. In the other case, the pilot rating expression was developed from a set of fixed base simulation data. In both cases pilot rating is primarily a function of pitch attitude and pitch rate; however, in the moving base case, the pilot rating is more sensitive to pitch rate than in the fixed base case. For each method, predicted pilot ratings and performance measures agree well with the measured data corresponding to that case. Both methods are used to predict pilot ratings for a set of flight test configurations and the results of the two methods agree to within one half a rating unit. The predicted ratings in both cases correlate well with the actual pilot ratings from the flight tests.

INTRODUCTION

The paper pilot concept for predicting aircraft handling qualities in a specified piloted task is based on the following hypothesis.

1. For a well defined task, the pilot rating is a function of the closed loop performance and the pilot workload. This function is called the pilot rating expression.

2. The predicted pilot rating can be obtained by minimizing the pilot rating expression with respect to free pilot parameters in the closed loop pilot-vehicle model. (The lower the rating--the better the handling qualities.) The minimal value of the pilot rating expression corresponds to the pilot rating for the task.

The paper pilot concept was successfully used to develop a method of predicting the longitudinal handling qualities of a VTOL aircraft in a precision hover task (Refs 1 and 2). In this case the pilot rating expression is a function of rms pitch rate, rms longitudinal hover error and two pilot lead time constants in the pilot model. The predicted pilot ratings agree well with actual pilot ratings from a fixed base flight simulation study (Refs 3 and 4).

The paper pilot concept was next applied to a pitch tracking task (Ref 5). The pilot rating expression, for the commanded pitch tracking task was taken to be a function of the rms tracking error and the pilot lead time constant in the pilot model. In this application, the predicted pilot ratings did not compare well with actual ratings for certain cases. For those cases where the short period approximation to the aircraft dynamics has a high natural frequency and is lightly damped, the predicted rating tends to be well below the actual ratings (Ref 5).

Two new methods for predicting aircraft handling qualities in pitch have been developed to correct the deficiencies in the original pitch paper pilot (Ref 5). They were developed independently; however, both methods are based on the paper pilot concept. In one case the pilot rating expression was developed based on an existing set of data from a moving base simulation. In the other case a set of fixed based simulation data was generated and used to develop the pilot rating expression. The two methods are described and compared in this paper.

PILOT VEHICLE MODEL

The piloted task considered was that of maintaining a nominal or zero pitch attitude in the presence of a vertical gust disturbance. The closed loop system is represented by the block diagram of Fig. 1.

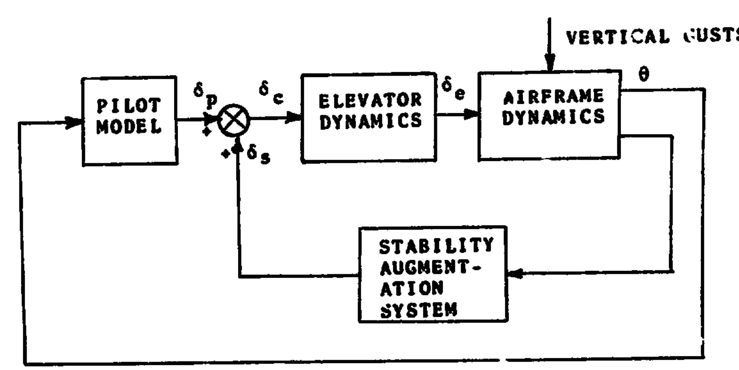

Fig. 1. Pilot-Vehicle Model.

The form of the pilot model used is based on the crossover model of Ref 6 and is

$$\frac{\delta_p}{\theta} = \frac{K_p(T_L s+1)}{T_I s+1} e^{-\tau s}$$

where K_p is the pilot gain, T_L is the pilot lead time constant, T_I is the pilot lag time constant, and $e^{-\tau s}$ is a pure time delay.

The elevator dynamics are modeled by a first order lag with a relatively high band width.

The airframe dynamics are modeled by linearized longitudinal equations of motion (Ref 5).

The vertical gusts are modeled by shaped, Gaussian amplitude, noise. In each method, a different form for the shaping filter is used; however, in both cases the power spectral density of the gust approximates that of the Dryden model (Ref 7).

The stability augmentation system that was considered included linear feedbacks on pitch rate, pitch acceleration, and normal acceleration.

RBJ PITCH PAPER PILOT

The data used to develop the RBJ pitch paper pilot was taken from a report by Onstott, Salmon, and McCormick (Ref 8). This report includes data from a moving base simulation of the F-5 and A-7 aircraft. Eight configurations for each aircraft were simulated. The simulation studies included the task of holding the pitch attitude to zero in the presence of a vertical gust disturbance. Pilot ratings and rms pitch angles are reported for a variety of rms gust intensities for each aircraft configuration. For each of the 16 aircraft configurations, two cases were selected corresponding to low and high turbulence levels. These 32 cases of different gust/aircraft configurations were then used to determine the pilot rating expression.

The resulting pilot rating expression is

$$J = PERF + .5T_L + 1$$

where

$$PERF = \sigma_\theta + 4\sigma_q$$

and σ_θ and σ_q are the closed loop rms values of pitch attitude and pitch rate, respectively.

The pilot lag time constant is taken to be .1 sec corresponding to a typical neuromuscular lag (Ref 9). The pilot time delay is taken to be τ = .32 sec. The values of K_p and T_L in the pilot model are selected to minimize the value of J.

The predicted pilot rating is then given by

$$PR = R_1(PERF) + .5T_L + 1$$

where

$$R_1(PERF) = \begin{cases} PERF, & 0 \le PERF \le 5.5 \\ 5.5, & PERF > 5.5 \end{cases}$$

The upper limit on R_1 is based on the assumption that there is some limit to the degradation of pilot rating due to poor performance. The $.5T_L$ is a measure of pilot work load. The addition of the constant 1 insures that the predicted pilot rating is greater than 1, which is the minimum (or best) rating on the Cooper pilot rating scale.

The correlation between the predicted pilot rating and the actual pilot ratings from Ref 8 is shown in the scatter diagram of Fig. 2. Good agreement was obtained between the actual and predicted ratings in those cases. In addition the predicted rms values of pitch attitude agree well with the measured values as indicated by Fig. 3.

Details of the RBJ pitch paper pilot are contained in Ref 10.

JDA PITCH PAPER PILOT

A fixed base simulation was conducted to develop the data base from which the JDA pitch paper pilot was developed. The flight tests of the USAF/CAL variable-stability T-33 aircraft (Ref 11) were used as a basis for the fixed-base simulation. These tests were chosen because a full range of aircraft dynamics and pilot ratings were presented. In particular, several configurations had a high short-period natural frequency and were lightly damped. The pilot ratings given in the report were for overall pitch handling qualities, although tracking tasks were accomplished during the flights. The fourteen base configurations described in Ref 11 were selected to simulate. A rms gust intensity (w_g) of 10 ft/sec was used in the simulation. This level of gust intensity was selected as the one which resulted in the best agreement in

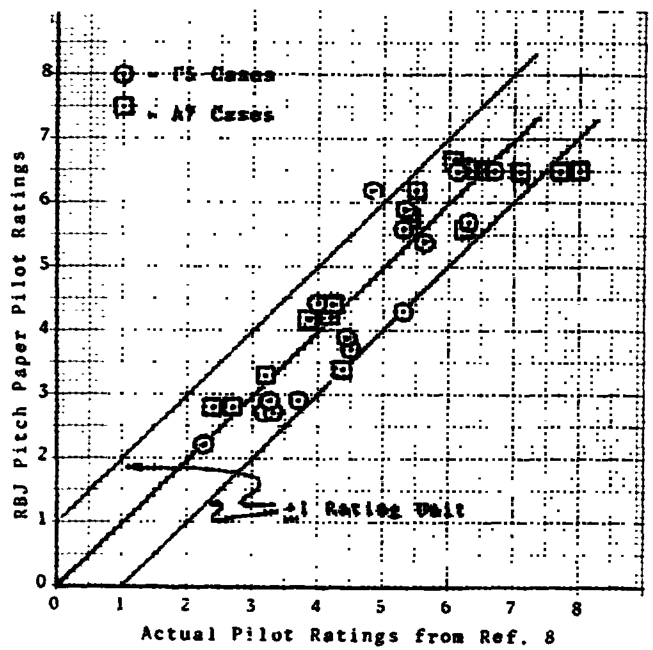

Fig. 2. Comparison of Predicted Pilot Rating and Simulation Pilot Ratings

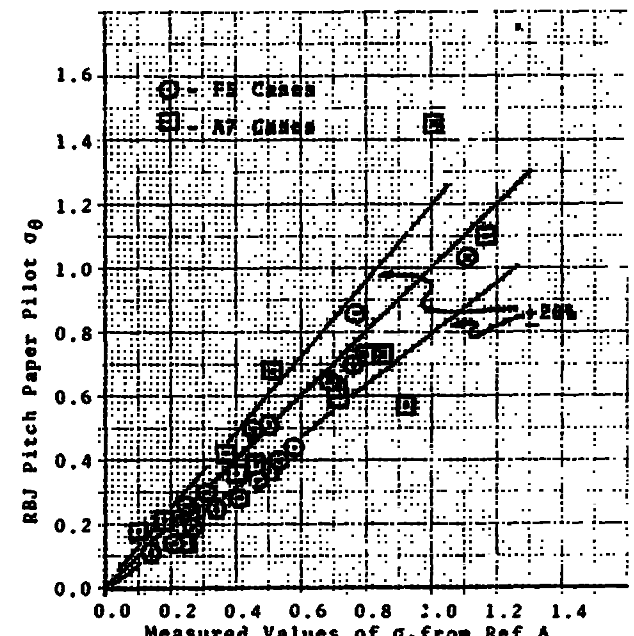

Fig. 3. Comparison of Measured and Predicted σ_θ

pilot ratings between the fixed base simulation and Ref 11. Pilot ratings were given and the rms values of pitch attitude, pitch rate, pitch acceleration, aerodynamic angle of attack, and stick output were measured for seven to twelve runs for each configuration.

The average pilot ratings given during the simulation compare fairly well with the average ratings of the flight tests (Ref 12). The differences in ratings are primarily due to the fact that the flight tests rated overall pitch handling qualities, while the simulation ratings were based only on pitch tracking ability. The results of the simulation were used to determine a pilot rating expression.

The resulting pilot rating expression is

$$J = PERF + .43T_L + 1$$

where

$$PERF = 5.8\sigma_\theta + .43\sigma_q$$

The pilot time delay, τ, was taken to be .3 sec based on an analysis of the simulation data. The values of K_p, T_L and T_I in the pilot model are selected to minimize the value of J.

The predicted pilot rating is then given by

$$PR = R_1(PERF) + .43T_L + 1$$

where

$$R_1(PERF) = \begin{cases} PERF & , 0 \le PERF \le 5.5 \\ 5.5 + .5(PERF - 5.5), & PERF > 5.5 \end{cases}$$

The definition of R_1 is based on the assumption that once the performance deteriorates beyond a certain point, a further deterioration of performance is not as consequential in the pilot rating. The $.43T_L$ is a measure of pilot work load. The addition of the constant 1 insures that the predicted pilot rating is greater than 1.

The correlation between the predicted pilot ratings and the actual pilot ratings from Ref 12 is shown in the scatter diagram of Fig. 4. Excellent agreement was obtained between the actual and predicted ratings in those cases. In addition, the predicted rms values of the system states agree well with the measured values as indicated in Figs. 5 through 8.

Details of the JDA pitch paper pilot are contained in Ref 12.

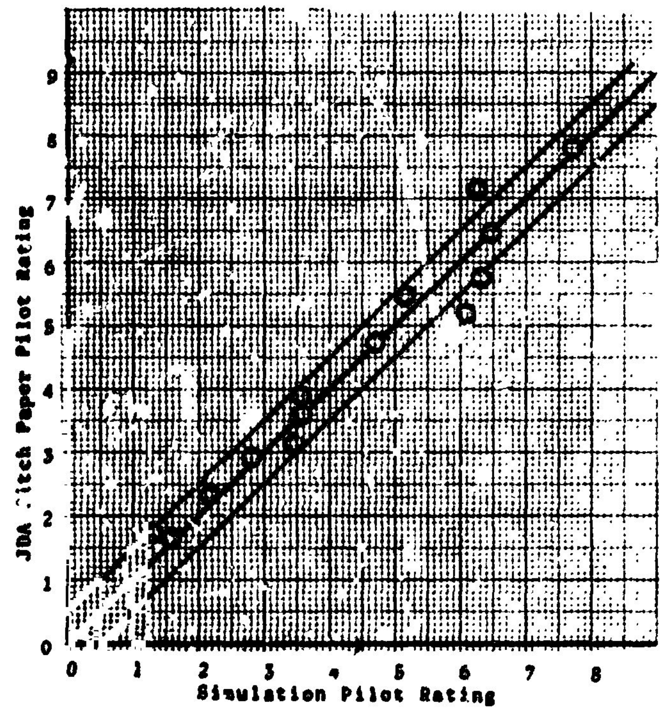

Fig. 4. Predicted Pilot Ratings vs Simulation Pilot Ratings

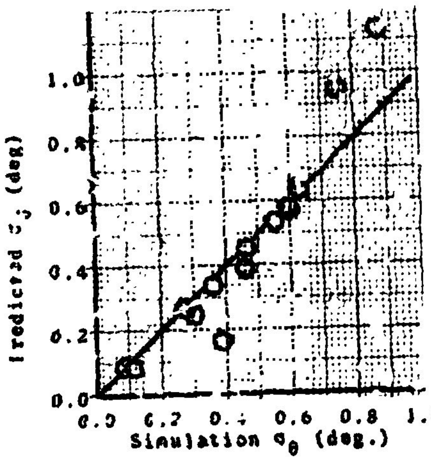

Fig. 5. Predicted vs Simulation σ_θ

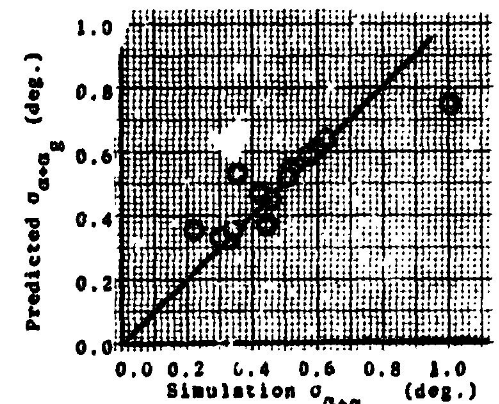

Fig. 7. Predicted vs Simulation $\sigma_{\alpha+\alpha_g}$

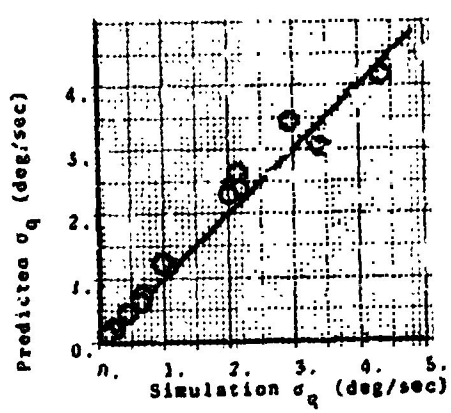

Fig. 6. Predicted vs Simulation σ_q

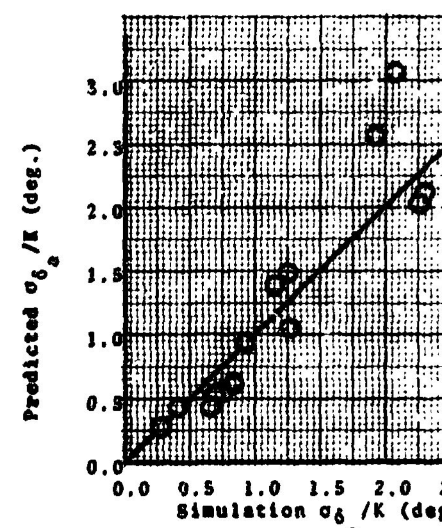

Fig. 8. Predicted vs Simulation σ_{δ_e}/K

COMPARISON OF THE TWO METHODS

Although the two methods of predictin^ pilot rating are very similar, there are differences in the details. The two major differences are as follows:

• J is function of σ_θ, σ_q, and T_L in both c.ses. Howe\ in the RBJ method the dominate weighting is on $\sigma_q(\sigma_\theta+\sim\sigma_q)$, where in the JDA method, the dominate weighting is on $\sigma_\theta(5.8\sigma_\theta + .43\sigma_q)$.

2. In the JDA method, pilot lag, T_I is considered as a free parameter in the pilot model and thus in the minim'zat:on proce.lure. There was no indication, however, that the lag term is a significant pilot opinion factor.

In order to det.rmine which method is best, a flyoff was performed. Data from a low altitude, high speed, flight test study (Ref 13) was used in attempt to determine which method would work the best. It was this data that caused the old pitch paper pilot to crash and burn. An rms gust intensity of 10 ft/sec was used in the JDA method. This was the level used in the fixed base simulation used to develop the pilot rating expression. An rms gust intensity of 6.5 ft/sec was used in the RBJ method. This level resulted from finding the rms gust intensity that would give the best agreement between the predicted pilot ratings using the RBJ method and those given in Ref 11.

A comparison of actual pilot ratings and predicted pilot ratings are given in Table I. Predicted ratings are shown

Table I

Comparison of Predicted and Actual Pilot Ratings

Case (Ref 13)	Pilot Rating			
	Actual (Ref 13)	Old Pitch Paper Pilot (Ref 5)	RBJ	JDA
LA	4.	2.18	1.94	2.25
LB	2.5	2.25	1.74	1.97
LC	2.25	2.42	1.47	1.70
LD	4.	2.17	3.50	3.80
LE	3.6	2.18	3.24	3.57
LF	2.63	2.24	2.84	3.21
LG	1.33	2.34	2.42	2.[illegible]1
LH	5.33	2.83	6.05	6.64
LJ	4.	2.66	5.23	5.27
LA	4.	2.63	4.78	5.01
LL	4.1[illegible]	2.62	4.28	4.80

for the old pitch paper pilot (Ref 5), the RBJ method and the JDA method. This comparison is shown graphically in Fig. 9.

CONCLUSIONS

In both methods, the predicted ratings generally agree well with the rating data that was used to develop the pilot rating expression for that method. Better agreement was obtained with the JDA method, but fewer cases were considered.

In addition both methods give rms performance values that agree well with the actual data that was available for comparison. In particular, the JDA method resulted in predicted rms values that agreed well with measured values for all of the significant states in the pitch task.

When both methods were used on an independent data set (the flight test data of Ref 13), they both resulted in answers that were quite close. There is good correlation between the actual ratings and those predi:ted by the RBJ and JDA methods. The greatest exception is in the LA case where there is a difference in the order of two rating units. It is of course possible that the actual rating for this case is incorrect.

It is clear from Table I that a great improvement has been realized over the old pitch paper pilot and that the "low damping-high natural frequency" problem of pitch paper pilot has been fixed.

YOU DONE GOOD PAPER PILOT!

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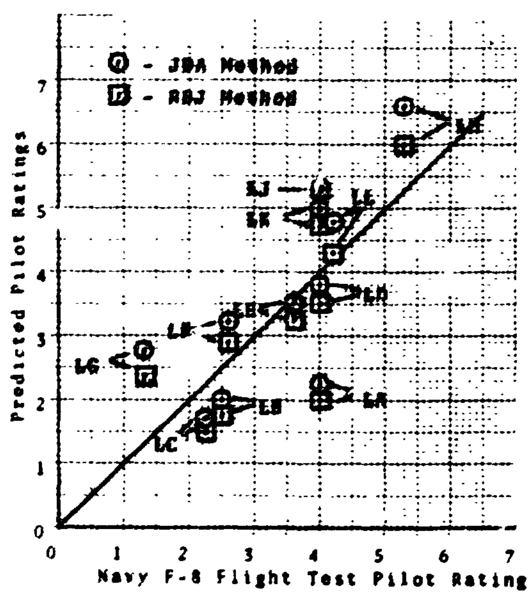

Fig. 3. Comparison of Predicted Pilot Rating and Actual Pilot Ratings from Flight Test Study

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