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EFFECTS OF VISUAL FLIGHT DISPLAY DYNAMICS ON ALTITUDE TRACKING PERFORMANCE IN A FLIGHT SIMULATOR

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ABSTRACT

A study of the effects of visual display dynamics on pilot tracking performance in a simulator has been performed. The tracking task consisted of maintaining the piloted aircraft at the same altitude as two aircraft positioned three-hundred feet ahead, as would be required in level formation flying. The two leading aircraft were represented symbolically along with the horizon on a CRT display. Vertical position of these aircraft with respect to the horizon indicated the altitude of the subject's aircraft, which was disturbed by atmospheric turbulence. Various bandwidths of second-order dynamics were interposed between the true aircraft altitude and the displayed altitude, whereas no dynamics were interposed in the attitude display. Experiments were run using two experienced pilots and two substantually different longitudinal dynamics for the piloted aircraft. Preliminary results indicate a significant decrease in altitude tracking performance for display dynamics with natural frequencies below ten radians per second.

Introduction

Both fixed-base and moving-base simulators are often used to simulate flight by visual reference to objects outside of the cockpit. Often, these visual displays are generated by a TV camera moving with respect to a scale model. However, in many cases, the multiple degree of freedom TV camera servo drives exhibit appreciable dynamic lags, especially in their response to translational commands. These display dynamics may have natural frequencies as low or lower than the short-period dynamics of the simulated aircraft. This paper presents some of the results of a study of the effects of vertical axis translational servo dynamics on the tracking performance of a pilot in a rudimentary fixed-based simulator.

Experimental Set-Up

The longitudinal equations of motion of an airplane were simulated on a hybrid computer. The pilot/subject controlled the simulated airplane with a side-stick controller which provided elevator commands to the airplane. The CRT display provided the visual cues to the pilot. Figure 1 shows the block diagram representation of the simulation. The tracking task consisted of a simplified *formation flying* task. The two lead aircraft were positioned three hundred feet ahead of the piloted aircraft and maintained a constant altitude. The pilot/subject flew in the trailing position and was instructed to simply maintain the same altitude as the lead aircraft. However, the piloted aircraft was disturbed by a simulated vertical gust spectrum. This spectrum was essentially the one-dimensional Dryden model with break frequencies at

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1-radian/sec and 10 radians/sec , and was produced by analog filtering of a pseudo-random binary noise generator.

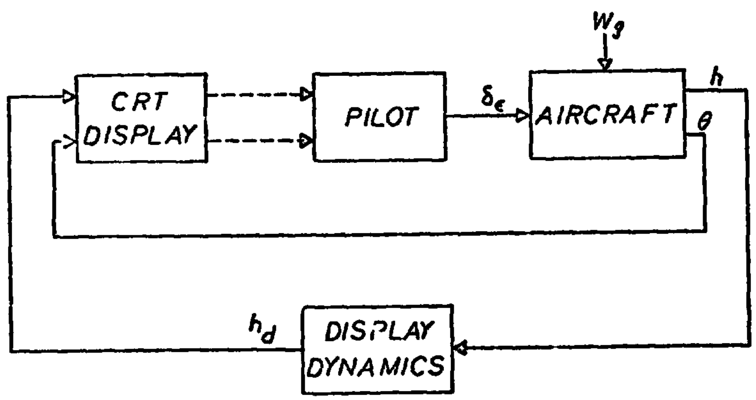

Fig. 1, simulation block diagram

The CRT display was an inside-out display and showed both pitch angle and altitude displacement. A horizon line positioned at infinity provided a reference for the pitch attitude of the piloted aircraft. This angle was displayed directly with no external dynamics. The display is illustrated in Figure 2.

The altitude deviation away from nominal was represented by the displacement between the horizon line and the aircraft symbols. The nominal flight condition of level flight at the same altitude as the lead aircraft is illustrated by Figure 2c. Level flight, but below the nominal altitude, is shown by Figure 2a. A nose up pitch angle, but still below nominal altitude situation is depicted by Figure 2b. The planform of a delta-wing appeared whenever the piloted aircraft was above or below the nominal altitude. The amount and shape of the planform observed was proportional to the amount of altitude displacement and to the direction of displacement, respectively.

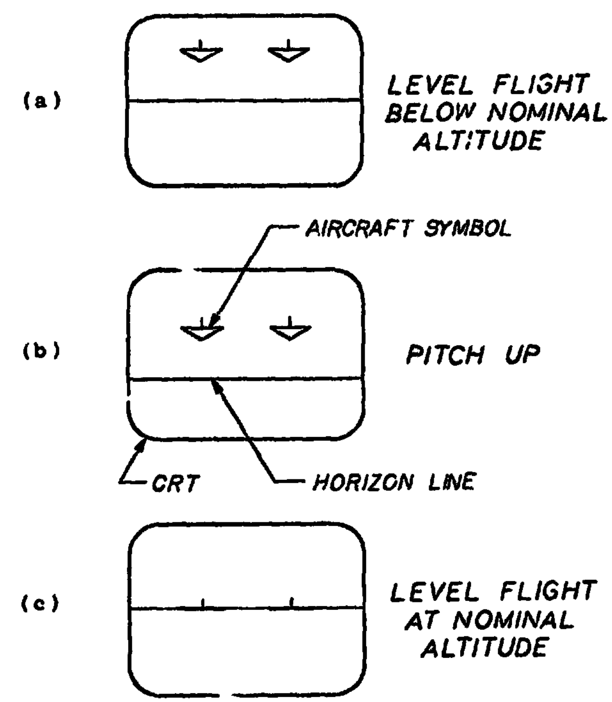

Fig. 2, typical visual display scenes

The altitude displayed on the CRT was not necessarily the true altitude of the aircraft. Various bandwidths of second order dynamics were interposed between the true altitude of the airplane and the altitude displayed to the pilot. The natural frequencies of the display dynamics were varied from infinity, (i.e., no dynamics) to 3 radians/second. The damping ratio of the display dynamics was held constant at 0.707. These dynamics are representative of TV camera servo drives which have both inertia and damping. This simulation represented vertical axis (z-axis) translational visual display dynamics only.

Two different types of aircraft longitudinal dynamics were simulated. These represented fairly different handling qualities. The dynamic characteristics are presented in Table 1. Airplane #1 has a rather high short-period natural frequency and a rather low short-period damping ratio. By comparison, airplane #2 has a lower short-period natural frequency and a larger short-period damping ratio. Airplane #1 exhibited a quicker response to elevator commands than did airplane #2. The elevator coefficients for the two airplanes were adjusted so that the elevator gains in the region of open-loop unity gain crossover frequency were approximately equal.

AIRCRAFT DYNAMICS

Aircraft	Short period		Phugoid	
	ω_{sp}	ζ_{sp}	ω_p	ζ_p
	4.8 r/s	0.38	0.07 r/s	0.09
2	2.6 r/s	0.54	0.11 r/s	0.06

Table 1

Experimental Conditions

Twelve different experimental configurations were examined for each of two subjects. These twelve conditions consisted of six different display dynamics natural frequencies for each of the two airplanes. Fifteen runs of two minute duration were made at each condition. The two subjects who participated in the experiment were both experienced pilots. Subject #1 was a military pilot with both fixed and rotary-wing experience. The second subject was a commercial airline first officer with only fixed-wing experience.

Experimental Data

Each run was recorded on-line with a digital computer. At the termination of each of these 2 minute runs, the mean square altitude deviation and the mean square vertical gust velocity (noise disturbance) were also recorded. These two quantities were employed to define a performance rating, designated as PR.

$$PR = \frac{\text{mean-square altitude deviation}}{\text{mean-square vertical gust velocity}}$$

This quantity is proportional to the mean-square altitude but normalized to remove some of the effects of the variability of the noise input from run to run. To further facilitate comparisons between the various conditions, a normalized performance rating was defined as follows:

$$\text{Normalized PR} = \frac{\text{mean PR (with display dynamics)}}{\text{mean PR (without display dynamics)}}$$

This measure was defined for each combination of pilot and aircraft. The data for these four combinations are shown in Figures 3 and 4. The data points represent the mean of fifteen runs at that particular display dynamics natural frequency. The 95% confidence levels of the mean are indicated by the bars above and below each data point. The results for both subjects' performance with airplane #1 are shown in Figure 3. For this airplane, on the basis of t-tests, all the differences are statistically significant at the $P < .001$ level with the exception of the 8.5 radian/second condition for subject #1, which was still significant at the $P < .01$ level.

Figure 4 shows the means for both subjects controlling aircraft #2. For subject #1, only the condition for display dynamics at 3 rad/sec has differences statistically significant from the no display dynamics condition. Performance differences for the remaining four display dynamics frequencies are not statistically significant. For the second subject, same airplane, the first three points, 3.0, 5.0, and 8.5 radian/second, have differences significant at $P < .001$ level, but the remaining two points are not statistically different from the no dynamics condition. These data seem to indicate a

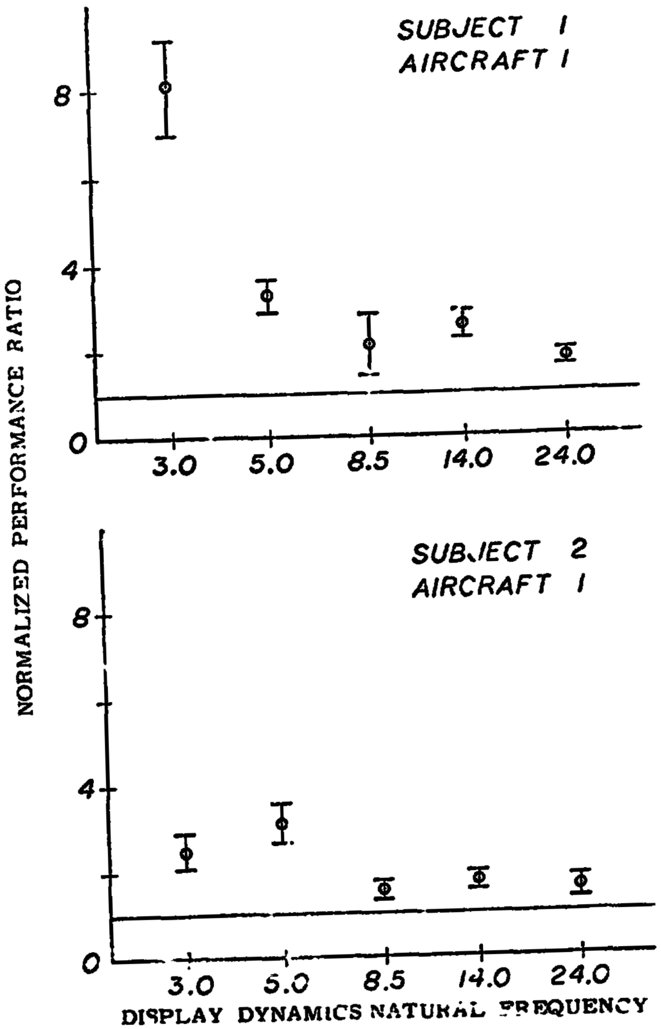

Fig. 3, effects of display dynamics natural frequencies on tracking performance for aircraft 1

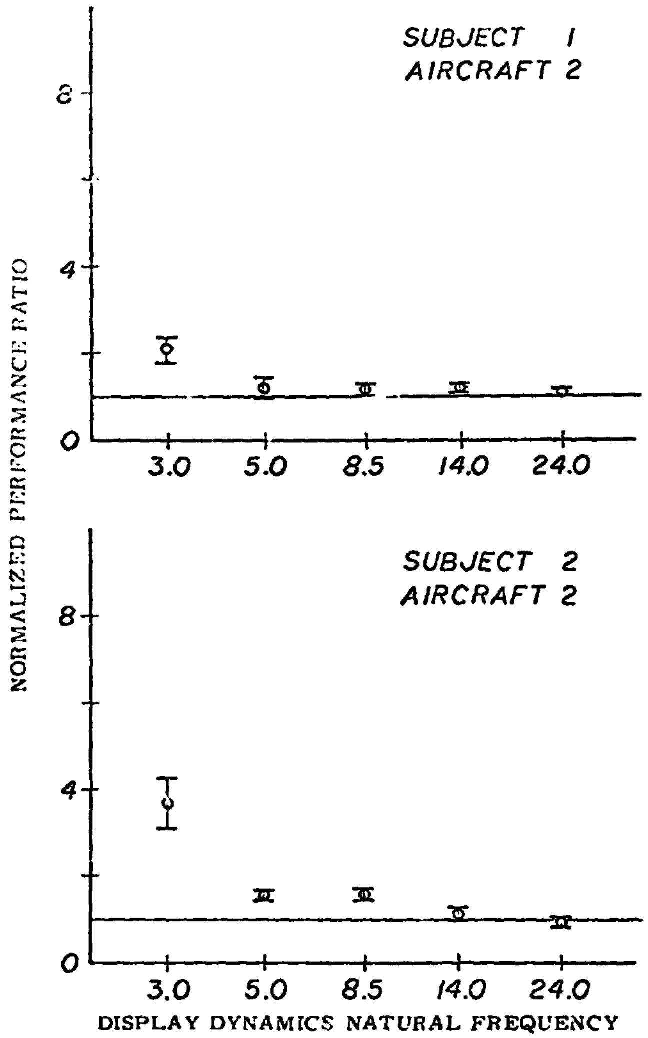

Fig. 4, effects of display dynamics natural frequencies on tracking performance for aircraft #2

relationship between display dynamics and the short-period dynamics of the simulated aircraft.

The second subject, when controlling airplane #1 with display dynamics natural frequency of 3.0 rad/sec, exhibited a level of performance which appeared to be inconsistent with his trends for other display dynamics and also inconsistent with the performance and trends of the first subject. In the frequency domain, the closed loop transfer function relating vertical gusts as the input and altitude deviation as the output shows a substantial change in characteristics for this particular experimental condition as compared to the general form exhibited for all other configurations. It is interesting to note that this second subject flies one specific type of aircraft almost exclusively, an aircraft whose pitch dynamics may be similar to airplane #1 in this study.

The two independent parameters which seem to best characterize these data are:

a) the short-period damping ratio

b) the relationship between the display dynamics and the short-period natural frequency.

Figure 5 shows the means of the Normalized PR plotted vs the ratio of display dynamics natural frequency to short-period natural frequency. The blocked points represent airplane #1 and the open points represent airplane #2. In general, the data for the same airplane flown by both subjects seems to group rather well. The means for airplane #1 are generally higher than for airplane #2. However, a single curve appears to represent the mean data fairly well.

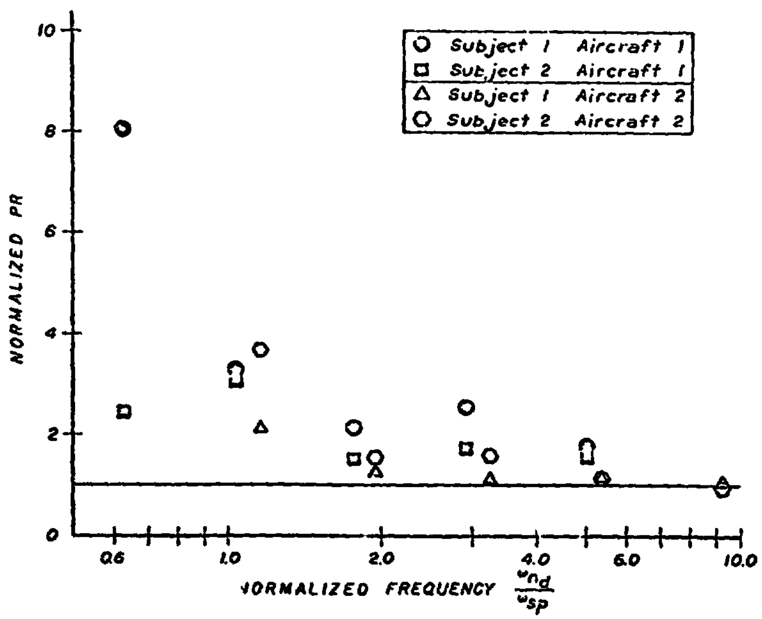

Fig. 5, normalized PR v.s. normalized frequency, two subjects-two airplanes

Conclusions

There are two conclusions which can be drawn from these data:

1) for this type of altitude tracking task, if the simulated aircraft is lightly damped the presence of display dynamics with natural frequencies as high as 5 times the short-period natural frequency causes significant degradation of altitude tracking performance.

2) when the simulated aircraft is more heavily damped, the presence of display dynamics is not significant until the ratio of display dynamics natural frequency to short-period natural frequency is approximately two or less.

In summary, whether dynamical display lags will cause degradation of altitude tracking performance depends on both the short-period damping ratio, and the ratio of the display dynamics natural frequency to the short-period natural frequency of the s lated aircraft.