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USE OF THE TILT CUE IN A SIMULATED HEADING TRACKING TASK*

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ABSTRACT

An experimental and analytical study was undertaken jointly by the Aerospace Medical Research Laboratory and Bolt Beranek and Newman Inc. to explore the effects of the tilt cue on pilot/vehicle performance in a simulated heading tracking task. The task was performed with subjects using visual-only cues and combined visual and roll-axis motion cues. Half of the experimental trials were conducted with the simulator rotating about the horizontal axis; to suppress the tilt cue, the remaining trials were conducted with the simulator cab tilted 90° so that roll-axis motions were about earth vertical.

The presence of the tilt cue allowed a substantial and statistically significant reduction in performance scores. When the tilt cue was suppressed, the availability of motion cues did not result in significant performance improvement. These effects were accounted for by the optimal-control pilot/vehicle model, wherein the presence or absence of various motion cues was represented by appropriate definition of the perceptual quantities assumed to be used by the human operator.

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INTRODUCTION

One of the problems associated with ground-based motion simulation is the introduction of unwanted or "false" cues that are not present in three dimensional flight. The particular set of such false cues present in a given simulation depends both on the nature of the flight task and the degrees of freedom of the moving-base simulator.

This paper reviews the results of a recent experimental and analytical study to explore the pilot's ability to use the "tilt cue" (i.e., the deviation of the effective "gravity vector" from the usual head-to-seat orientation). Such a cue is "false", for example, if it is present in the simulation of a constant rate coordinated turn. This study was performed as part of a multi-year collaborative effort between Bolt Beranek and Newman and the Aerospace Medical Research Center to develop a model of the pilot's use of roll-axis motion cues. Results obtained in the preceding phases of this program have been reported in References [1-5]; documentation of the study reviewed below is in preparation.*

DESCRIPTION OF EXPERIMENTS

Preliminary model analysis was conducted using the optimal-control pilot/vehicle model to search for an experimental task for which performance would be sensitive to the presence or absence of the tilt cue. This analysis revealed that simple roll-axis tasks of the type explored previously would not be sufficiently sensitive. When the addition of another integration to the system dynamics was found to provide the desired predicted sensitivity, the heading tracking task diagrammed in Figure 1 was adopted for this study. In all experimental trails the subject was provided with a visual display of heading error as sketched in Figure 2.

Motion about the roll axis was provided by the Dynamic Environmental Simulator (DES). When the roll axis of the simulator was in the normal horizontal orientation, a roll displacement provided the subject with a tilt cue. The tilt cue was suppressed by rotating the DES 90 degrees so that the pilot was in the supine position. In this position gravity acted normally to the plane of rotation and could not provide the pilot with information related to the tracking task. Motion was provided only in the roll axis; yaw motion was absent.

Vehicle dynamics were of a higher order than those explored in the preceding study. The DES itself provided approximate dynamics of a single pole

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* Levison, W. H. and A. M. Junker, "Modeling the Pilot's Use of a Roll-Axis Tilt Cue", BBN Report No. 3802, Bolt Beranek and Newman Inc., Cambridge, Mass. (in preparation).

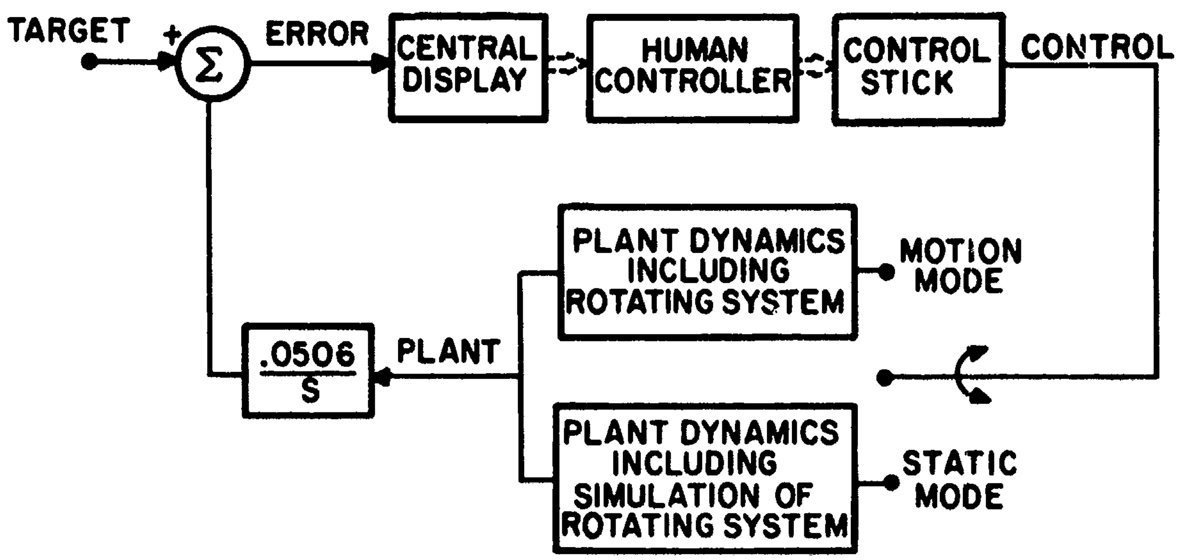

Figure 1. Block Diagram of the Tracking Task

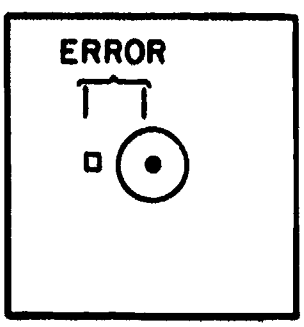

Figure 2. Sketch of the Central Visual Display

at 2 rad/sec and a complex pole pair having a natural frequency at about 10 rad/sec. "Target" motion was provided by a sum of sinusoids designed to approximate a second-order noise process.

Subjects were instructed to minimize a weighted sum of mean squared heading error and mean squared roll acceleration and were trained to near asymptotic performance on each of the four experimental conditions.

SUMMARY OF RESULTS

The comparison between predicted and measured rms performance scores presented in Figure 3 shows that the model predicted the major trend of the experiment: namely, that motion cues would benefit performance to a greater extent when the tilt cue was present (i.e., horizontal roll axis). This comparison is perhaps better illustrated in Figure 4 in which static-motion <u>differences</u> in rms scores are shown for all performance measures. For the most part, predicted differences were within one standard deviation of the difference scores obtained experimentally. For roll axis horizontal, the model predicted a smaller decrease in the error score and a greater decrease in the acceleration score than revealed by the data. Predicted static/motion performance differences were generally less than observed experimentally for roll about the vertical; however, observed differences were largely not statistically significant.

Model predictions shown in Figures 3 and 4 were obtained with pilot-related parameters selected as indicated in Table 1. On the basis of results obtained in a study of simulator washout effects [3], a "residual noise" of 15 degrees was associated with perception of plant roll angle from the tilt cue. Because of the relatively large roll rates and accelerations required to perform the tracking task, perceptual thresholds and residual noise terms for other motion-related cues were considered negligible.

The informational analysis adopted in previous studies was used to account for the presence or absence of motion cues. For roll about the horizontal axis, moving-base simulation was assumed to provide the pilot with information related directly to vehicle roll angle, roll rate, roll acceleration, and roll acceleration rate. We further assumed that attention would be shared between visual cues as a group and motion cues as a group and that the pilot would allocate attention between these two sets of cues in a way that would minimize the objective performance cost. A similar treatment was adopted for roll about the vertical axis, only in this case the pilot was assumed to obtain no cue related directly to plant position, and zero attention was ascribed to this variable. The model for static tracking was

* The reader is directed to References 1-5 for a review of the optimal-control model and its treatment of motion cues.

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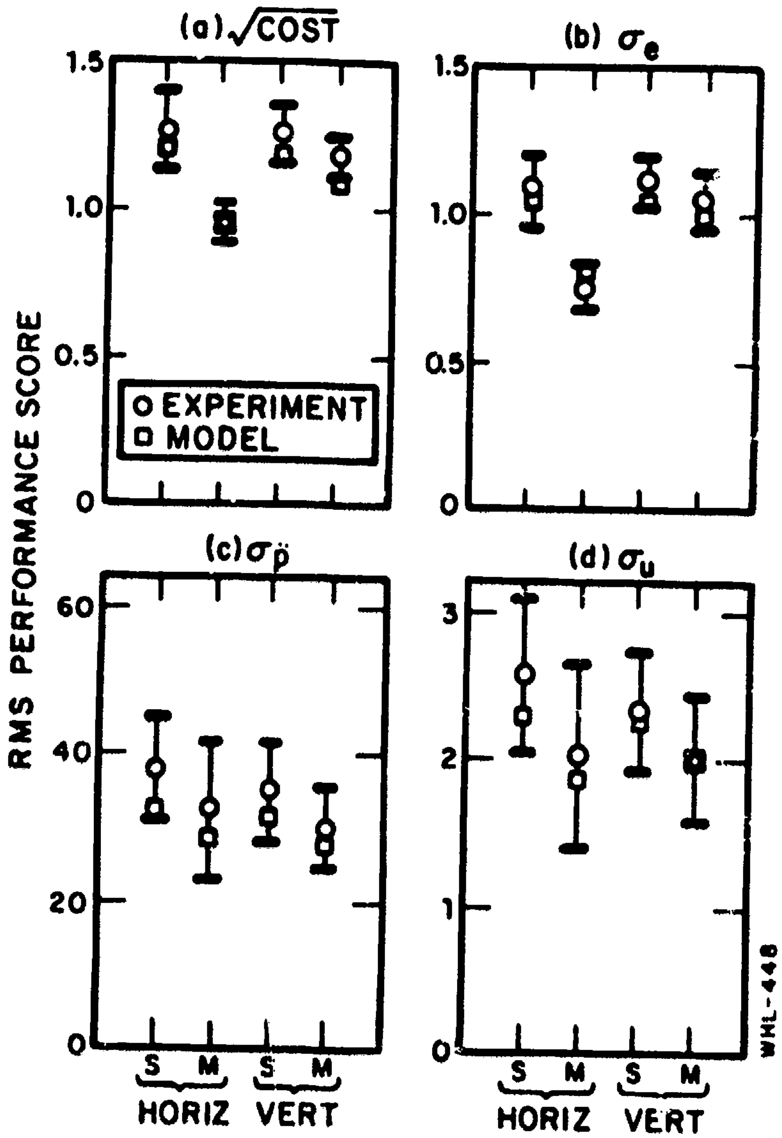

Figure 3. Comparison Between Model and Experimental Performance Scores, Nominal Parameter Values

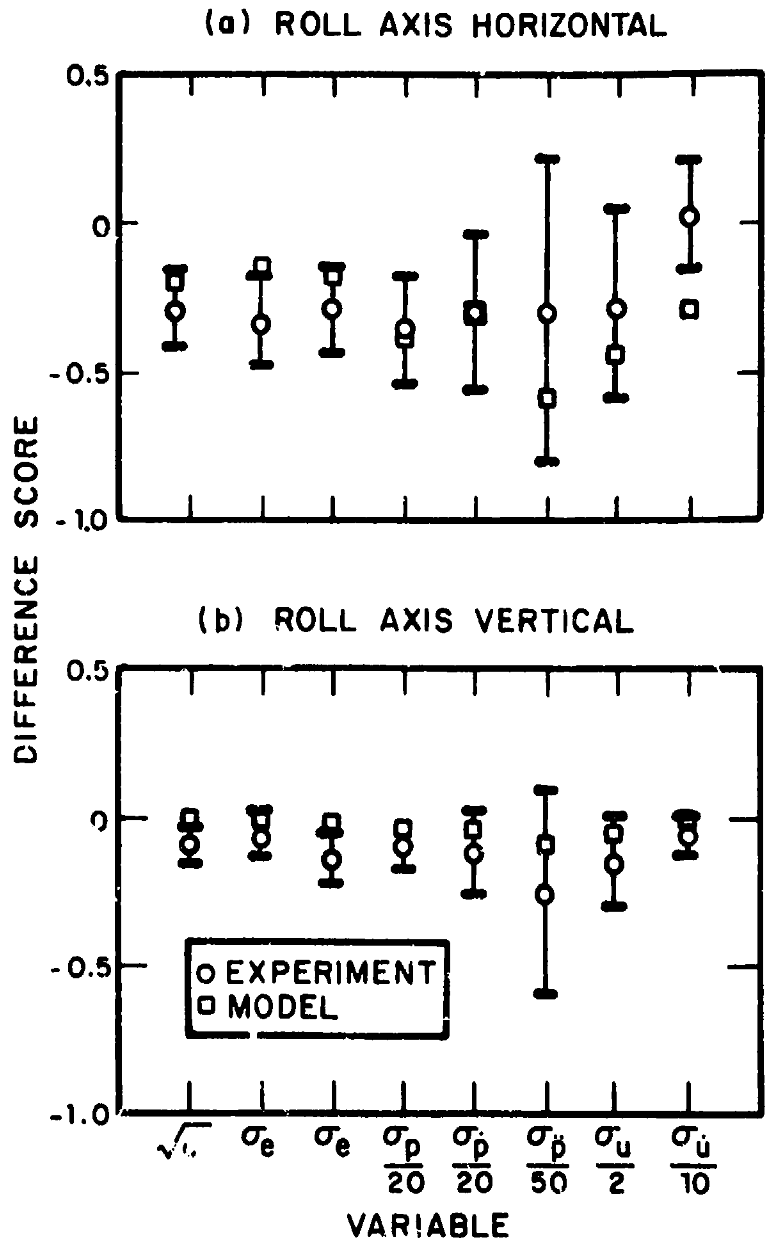

Figure 4. Differences Between Motion and Static Performance Scores

identical for the pilot in the upright and supine positions. Relative attentions of 0.5 and 0.2 to motion variables were predicted, respectively, for the cases of tilt cue present and tilt cue absent.

Table 1

Nominal Values for Pilot-Related Model Parameters

Motor time constant	0.1 seconds
Time delay	0.2 seconds
Driving motor noise/ signal ratio	. (negligible)
Pseudo motor noise/ signal ratio	-35 dB relative to control variance
Observation noise/signal ratio for "full attention"	-20 dB relative to signal variance
Perceptual threshold, indicator displacement	0.05 degrees visual arc
Perceptual threshold, indicator velocity	0.05 degrees/second visual arc

Figure 5 shows that the model correctly predicted many of the detailed changes in pilot response behavior induced by the moving-base simulation. For roll about the horizontal, the model showed a substantial increase in low-frequency phase shift, a small decrease in amplitude ratio, and a decrease in input-correlated control power at low frequencies. For vertical-axis roll, the model correctly predicted a small increase in low-frequency phase and, in general, no appreciable changes in other frequency-response measures.

The model also predicted the following effects that were not observed experimentally: decreased input-correlated and remnant-related control power at high frequencies for horizontal-axis roll, and increased low-frequency remnant power for roll about the vertical. Errors in predicting the effects of motion simulation on low-frequency remnant power arose primarily from the tendency of the model to predict considerably less remnant in the static case than was observed experimentally.

The subjects used in these experiments were instructed only to minimize total "cost"; they were not instructed as to the desired control strategy. One might, therefore, expect the subjects to have adopted strategies different from that predicted by the model, provided such non-optimal behavior had neglible effect on total cost.

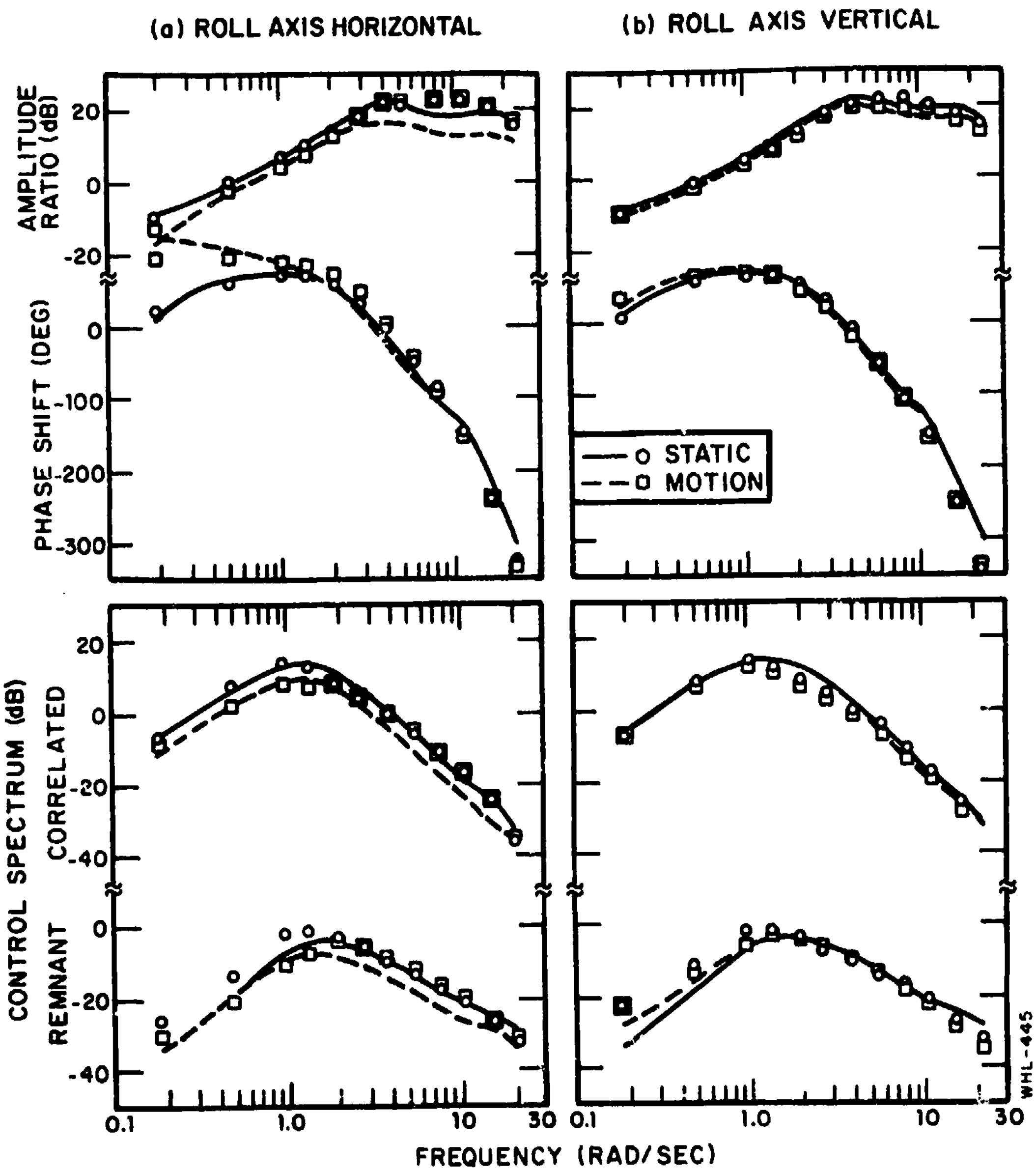

Figure 5. Comparison Between Model and Experimental Frequency-Response, Nominal Parameter Values

Selected pilot-related parameters were varied to determine the extent to which matching errors could be attributed to performance insensitivity. Specifically, time delay and cost weightings were modified in such a way that total cost was virtually unchanged (an increase of less than 3%.) Figure 6a shows that the ability of the model to match pilot response behavior at high frequencies was substantially improved by this procedure. To this extent, differences between predicted and observed measurements can be attributed to "pilot preference" of the type that does not noticeably affect performance.

Errors in modeling low-frequency aspects of response behavior could not be attributable to pilot preference, however. Low-frequency remnant power for static tracking was matched only by an increase in observation noise - specifically, noise associated with perception of heading error. The match to low-frequency phase shift for the motion case was improved by assuming less than optimal attention to motion cues. The resulting improvement in model-matching capability is demonstrated in Figure 6b.

DISCUSSION OF RESULTS

The results of this study indicate that a simple informational analysis is sufficient to account for much of the influence of the tilt cue in tasks involving roll-axis motion. Specifically, one assumes that the pilot directly perceives the bank angle of the (moving) vehicle if the tilt cue is present; otherwise, this element is omitted from the pilot's "display vector". The remaining motion-related cues of roll rate, roll acceleration, and roll acceleration rate are assumed available in both situations.

One should not interpret the results of this study as indicating that the tilt cue will generally be of significance in a task involving roll-axis motions. On the contrary, the degree to which the tilt cue provides usable information to the pilot depends on the details of the tracking task. (In fact, considerable pre-experimental model analysis was required to design an experimental task in which performance would be significantly influenced by the presence or absence of the tilt cue.)

The "residual noise" of 15 degrees associated with perception of the tilt cue is not to be interpreted as a detection threshold, but rather as a measure of uncertainty associated with this perceptual variable in the context of a continuous tracking task. Since a "residual noise" is roughly equivalent to a "threshold" of one-third the value in terms of the optimal-control pilot model [6], the residual noise of 15 degrees is consistent with an indifference threshold of about 5 degrees recently obtained in an experiment requiring simultaneous detection of tilt and continuous roll-axis control [7].

To some extent, insensitivity of performance to pilot response strategy appears to have allowed the subjects to "trade" acceleration score for error score when performing the tracking task with roll motion about the

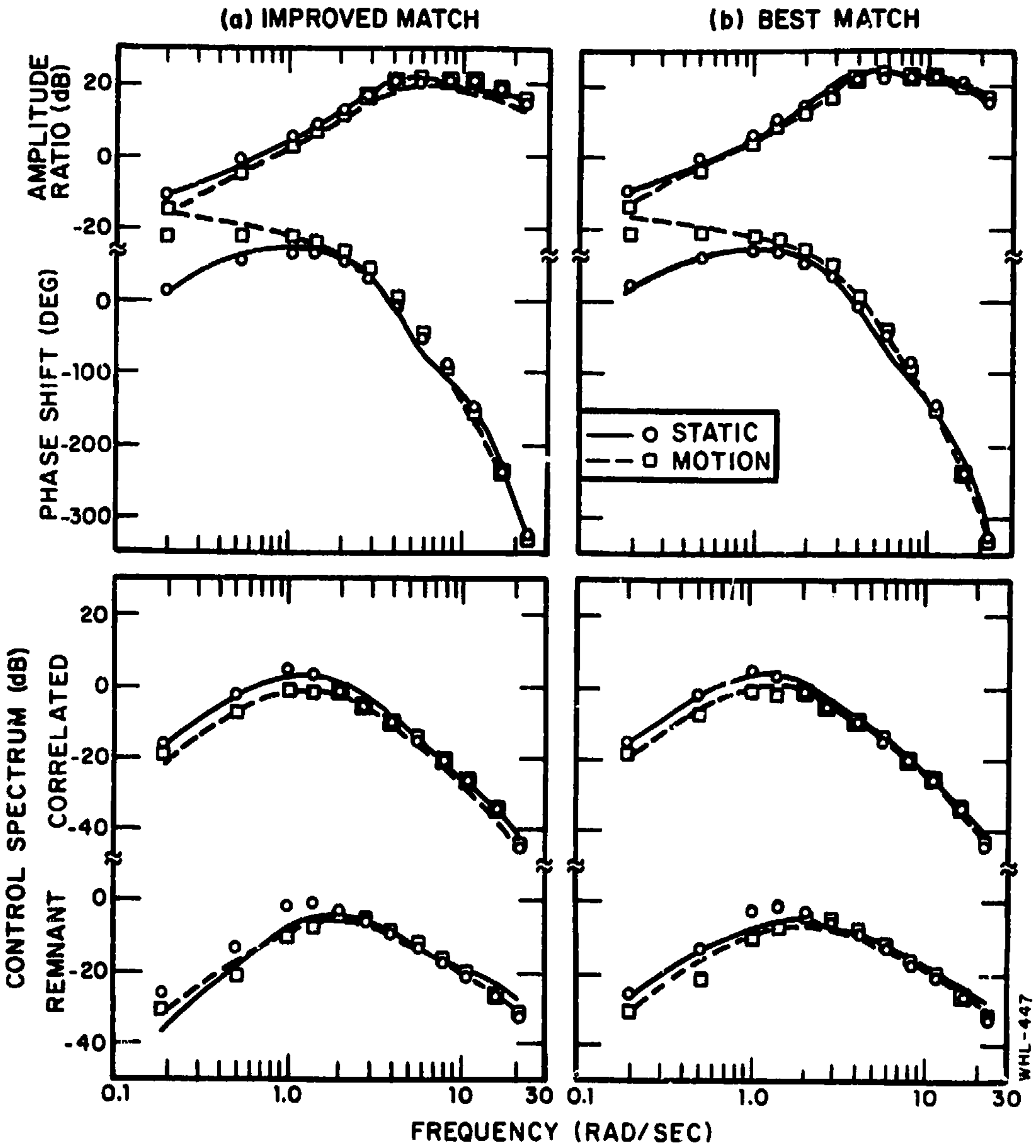

Figure 6. Comparison Between MOdel and Experimental Frequency Response, Parameter Values Adjusted for Better Match

horizontal axis. However, performance insensitivity does not explain the relatively large noise/signal ratio (equivalently, low attention) associated with perception of heading error in the fixed-base tracking task. Increasing this parameter from the nominal -20 dB to -5 dB to provide the best match to the experimental results increased the predicted total cost by about 20% - an increase too large to ascribe to pilot indifference.

A more consistent explanation of these results is that the high noise level may have reflected increased uncertainties about vehicle response characteristics caused by the relatively high order of the plant dynamics (two pure integrations plus additional lags to represent the dynamics of the rotating simulator). When motion cues were present, the controllers may have obtained sufficient additional information about the state of the controlled plant to minimize this uncertainty; hence, the ability to match moving-base response behavior with nominal noise levels. Improved modeling of pilot response behavior in situations involving high-order dynamics is a possible area for future research.

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