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TRANSFER OF TRAINING WITH SIMULATED AIRCRAFT DYNAMICS:

II. VARIATIONS IN CONTROL GAIN AND PHUGOID CHARACTERISTICS

F. A. MUCKLER, R. W. OBERMAYER, W. H. HANLON, F. P. SERIO

AVIATION PHYSCOLOGY LABORATORY
UNIVERSITY OF ILLINOIS

ASSISTED BY THE STAFF OF THE TRAINING RESEARCH BRANCH,
AEROSPACE MEDICAL RESEARCH LABORATORIES

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FOREWORD

Work covered by this report was initiated under contract by the Training Research Branch, Behavioral Sciences Laboratory, Aerospace Medical Research Laboratories of Aeronautical Systems Division. This work was part of a general program documented under Project 7197, "Human Factors in the Design of Operator Trainers," with Dr. R. L. Morgan acting as Project Scientist. Dr. M. R. Rockway was the Air Force initiator and technical monitor for this study under Task No. 71635, "Simulation Requirements of Training Equipment." The original research upon which the report is based was completed at the Aviation Psychology Laboratory of the University of Illinois under Air Force Contract No. AF 33(616)-2725, entitled "Survey and Research to Determine Simulation Requirements of Synthetic (Ground) Flight and Fire Control Training Devices." During the course of the contract Dr. A. C. Williams, Jr. and Dr. L. I. O'Kelly served as Principle Investigators.

A number of individuals contributed to the early phases of the present program, and the authors wish to extend their gratitude to Dr. A. C. Williams, Jr., Dr. M. Adelson, and Dr. J. E. Nygaard. In particular, appreciation is extended to Dr. M. R. Rockway and Dr. L. I. O'Kelly for their guidance throughout the program.

Mr. Obermayer and Mr. Muckler are currently members of The Martin Company of the Martin-Marietta Corporation, Baltimore 3, Maryland. Mr. Hanlon is a member of the Human Factors Group of Convair, a Division of General Dynamics Corporation, San Diego, California. Mr. Serio is a member of the Control Systems Laboratory, University of Illinois, Urbana, Illinois.

ABSTRACT

This report is the second in a series dealing with transfer of training as a function of simulated aircraft longitudinal dynamics. Subjects performed single dimension compensatory tracking with long period (phugoid) oscillatory control system dynamics. Three experiments are reported dealing with variations in control gain.

Increasing control gain resulted in equally high training and transfer performance for all oscillatory transient conditions studied, but at a lower gain level, significant differences were found.

If rate of onset of the transient conditions were not equated by adjusting control gain, significant negative relative transfer of training was elicited. Equalization of rate of onset, however, substantially reduced training performance differences and eliminated negative transfer effects.

PUBLICATION REVIEW

Walter F. Grether

WALTER F. GRETHER
Technical Director
Behavioral Sciences Laboratory
Aerospace Medical Research Laboratories

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

I. INTRODUCTION

This report is the second in a series describing exploratory experiments dealing with transfer of training as a function of simulated aircraft longitudinal dynamics. The purpose of these studies was to produce research data that may be applicable to design decisions concerning fidelity of simulation of flight training simulators. The initial studies (8) investigated some of the basic simulation parameters of aircraft longitudinal dynamics in terms of period and damping values of long-period (phugoid) oscillatory transients.

It is obvious, however, that in a complex man-machine system-simulator or aircraft, for example, many parameters must be specified for optimum training and transfer of training results. From previous experimentation, it seems reasonable that one of the most important parameters is control gain. Accordingly, the three studies reported here center on variations of control gain and various phugoid conditions.

From the point of view of the human operator, control gain is of interest in terms of control and display relationships; that is, variations in control gain result in variations in display movement characteristics, and the conventional terminology in discussing control gain for lower order systems is more adequately expressed in terms of control/display (C/D) movement ratios (e.g., 9). Changes in the C/D ratio are an indication of the sensitivity of the control; e.g., the lower the ratio the less control output required to produce display movement and hence the more sensitive the control.

There is concrete evidence that determination of C/D ratios is important for optimum man-machine system performance (e.g., 5). There is further evidence, however, that the optimal C/D ratio for a given man-machine system may be the complex resultant of the interaction of variables (e.g., 1, 9). Finally, it has been shown (10, 11) that transfer of training can be affected through variations of C/D ratios.

Most of the prior studies have been concerned with relatively simple system dynamics. The present studies are an attempt to examine the effect of control gain variations -- and hence control/display movement ratios -- in combination with higher order system dynamics. The specification of fidelity of simulation for flight training simulators in terms of system dynamics require that higher order systems be examined since these dynamics are an integral part of the flight control and flight display complex.

II. EXPERIMENT 3: VARIATIONS IN CONTROL GAIN AND PHUGOID CHARACTERISTICS*

In the previous studies (8) of performance with various long-period (phugoid) oscillatory transients, a constant low control-gain setting was used for all conditions. In the present study, these data are compared with data obtained with a uniformly high control gain setting.

Experimental Method

Experimental Task and Apparatus.** In all cases, the subject performed one-dimension (vertical) compensatory tracking. A horizontal stimulus line was displayed on a 5-inch oscilloscope. Using a conventional aircraft control stick the subject attempted to keep the stimulus line centered at all times.

The subject's control stick output was fed into a computer which generated simulated aircraft long-period (phugoid) oscillatory transients with period and damping values as designated by the particular experimental conditions. At this point, it was possible to vary the control gain of the subject's stick output. Two control gain settings were selected, a low-gain setting which had been used in all previous experimental conditions (8), and a high gain which was double that of low gain. Variations in control gain, therefore, provided the primary experimental variable under study in the present investigation. Increasing control-gain results in decreasing the C/D movement ratio, since with higher control gain less operator control output is required for display movements.

The signal from the computer was mixed with a signal generated by a cam, and the result was displayed to the subject on the face of the oscilloscope as an error signal. The frequency of the cam forcing function signal was a saw-tooth function very closely approximating a simple sine wave of 6 cycles per minute. Given a trial with no stick input, the stimulus movement was ± 0.3 inch on the scope face at maximum amplitude of the simple sine wave pattern. With no stick input, time-on-target (TOT) scores of 15 seconds were obtained for the forcing function per trial.

The Oscillatory Transients. In the original study in this series (8) a total of nine phugoid oscillatory transients representing wide variations in period and damping values were studied. From this set of nine, five were selected for investigation in the present study:

1. Condition 1: Period = 18 seconds: Damping = 17 seconds
2. Condition 3: Period = 71 seconds: Damping = 17 seconds
3. Condition 5: Period = 35 seconds: Damping = 33 seconds
4. Condition 7: Period = 18 seconds: Damping = 66 seconds
5. Condition 9: Period = 71 seconds: Damping = 66 seconds

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*Experiments 1 and 2 are discussed in WADD TR 60-615 (I).

**A detailed technical description of the experimental apparatus, simulation techniques, and experimental procedures may be found in the first report in this series (8).

Damping is expressed in terms of time-to-damp-to-half-amplitude.

Experimental Design. To investigate the training and transfer effects of variations in control-gain and simulated phugoid transient conditions, ten experimental conditions were selected, as shown in Table 1.

TABLE 1.

Experiment 3: Experimental Design and Groups*

Control Gain	Phugoid Condition				
	1	3	5	7	9
Low Gain	1.1	1.3	1.5**	1.7	1.9
High Gain	3.1	3.3	3.5**	3.7	3.9

**Transfer Conditions

Ten independent subject groups were trained on the individual experimental conditions. For transfer, all groups shifted to or remained on one transfer condition (either 1.5 or 3.5).

Subjects. A total of 100 male University of Illinois under-graduate students provided data for this experiment. Half of the subjects had served previously on conditions 1.1, 1.3, 1.5, 1.7, and 1.9 as part of the basic experiment in this series (8). The remainder of the subjects (N = 50) were specifically assigned to this study for conditions 3.1, 3.3, 3.5, 3.7, and 3.9. Assignment of subjects was at random, with the exception that they were equally divided between conditions. Each experimental group, therefore, consisted of ten subjects.

Procedure. Every experimental trial was 30 seconds in length. An inter-trial interval of 30 seconds was used. Each subject was given 30 training trials on one of the experimental conditions. After a 5-minute rest each subject was then transferred to either condition 1.5 or 3.5 and given 10 transfer trials. The detailed instructions given to each subject may be seen in the first report in this series (8). Particular care was taken to insure that all procedures were identical for the various groups.

Response Measure. The response measure was time-on-target (TOT) for each training and transfer trial. A tolerance band of ±0.2 inch was allowed from

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* Report Notation. Consistent with previous studies in this series, a decimal notation has been adopted to indicate the particular experiment and the phugoid condition. The number preceding the decimal is the experiment number; the number after the decimal is the phugoid condition. It may be seen in Table 1 that half of the conditions were derived from Experiment 1, while the remainder are specific to this study.

the null, or center, line. The maximum possible TOT score was 30 seconds, the length of the individual training and transfer trial.

Results

The major findings of this experiment are shown graphically in figures 1 through 6. Note should be made of the fact that on each figure theoretical performance with no subject stick input is shown; that is, if the subject had done nothing he could have achieved a 15-second TOT score.

The figures are grouped to make the following comparisons:

1. Figures 1 and 2 show period variations with damping held constant. Figure 1 shows conditions 3.1 and 3.3, with damping held constant at 17 seconds and period varied from 18 seconds (condition 3.1) to 71 seconds (condition 3.3). Training and transfer performance is compared with the control group (3.5) performance. Figure 2 shows conditions 3.7 and 3.9, with damping held constant at 66 seconds and period varied from 18 seconds (condition 3.7) to 71 seconds (condition 3.9). All groups performed under the high control-gain setting.

2. Figures 3 and 4 show damping variations with period held constant. Figure 3 shows condition 3.1 and 3.7, with period held constant at 18 seconds and damping varied from 17 seconds (3.1) to 66 seconds (3.7). Figure 4 shows conditions 3.3 and 3.9, with period held constant at 71 seconds, while time to damp to half amplitude is varied from 17 seconds (3.3) to 66 seconds (3.9). In both cases, training and transfer performance is compared with that of the appropriate control group (3.5). All groups performed under the high control-gain setting.

3. Figures 5 and 6 show training and transfer performance under both high and low control-gain settings. Figure 5 shows performance with low gain settings for conditions 1, 5, and 9. Figure 6 shows performance with high control-gain settings for the same phugoid conditions (1, 5, and 9).

Training Trials. A number of separate analyses are possible for the training trials data. The basic analytic technique used was a distribution-free method (12). Due to extreme inter-trial variability, the data were blocked and examined in groups of five trials, means and standard deviations of which may be seen in the Appendix. The 1% level of statistical significance was accepted throughout.

1. Previous experimentation (8) had shown that performance differences between groups 1.1, 1.3, 1.7, and 1.9 were statistically significant throughout training. In addition, a 2 x 2 statistical analysis showed a significant period effect but no damping effect.

2. Analysis of performance scores for high control-gain setting conditions 3.1, 3.3, 3.7, and 3.9 revealed no statistically significant differences in performance. As may be seen in figures 1 through 4, training performance was essentially equivalent for all high control-gain conditions.

3. Figures 5 and 6 show the comparison of training performance for a set of low-gain conditions (1.1, 1.5, and 1.9) and a set of high-gain conditions (3.1, 3.5, and 3.9). A 2 x 3 statistical analysis produced significant total and column

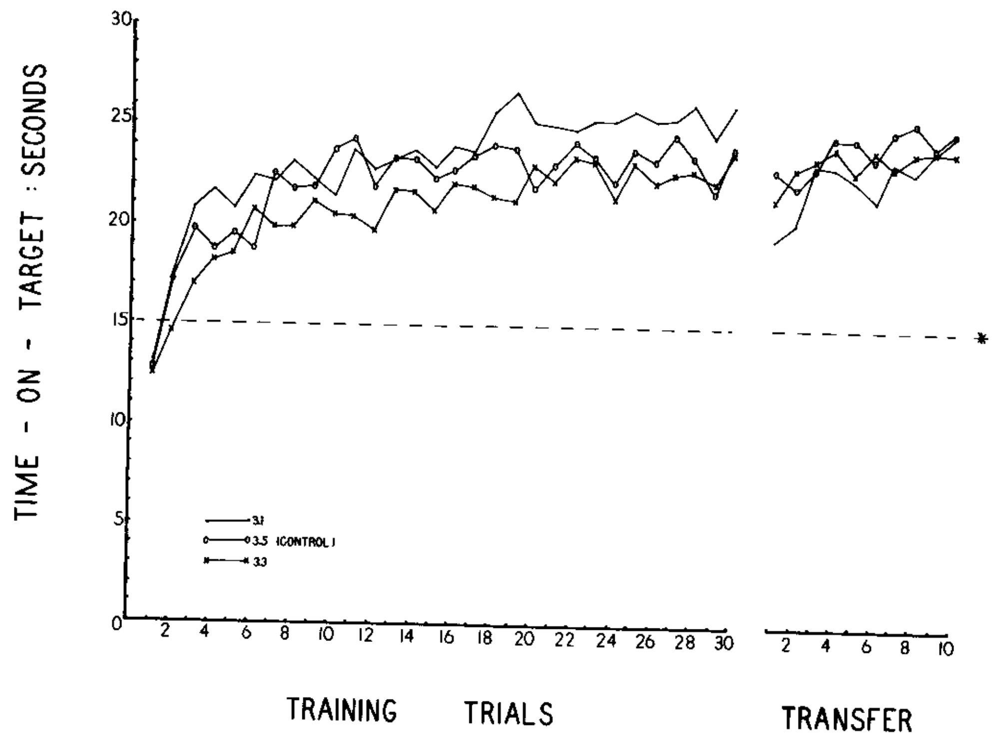

Figure 1. Experiment 3: Training and transfer performance for groups 3.1, 3.5, and 3.3.

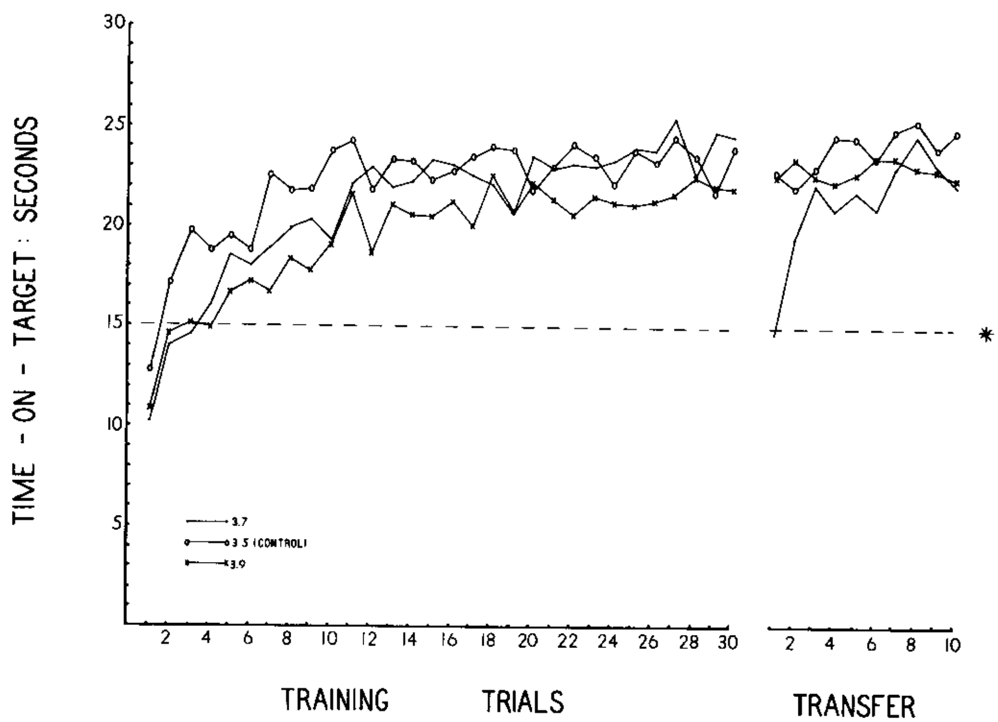

Figure 2. Experiment 3: Training and transfer performance for groups 3.7, 3.5, and 3.9.

* Theoretical "performance" with no subject response.

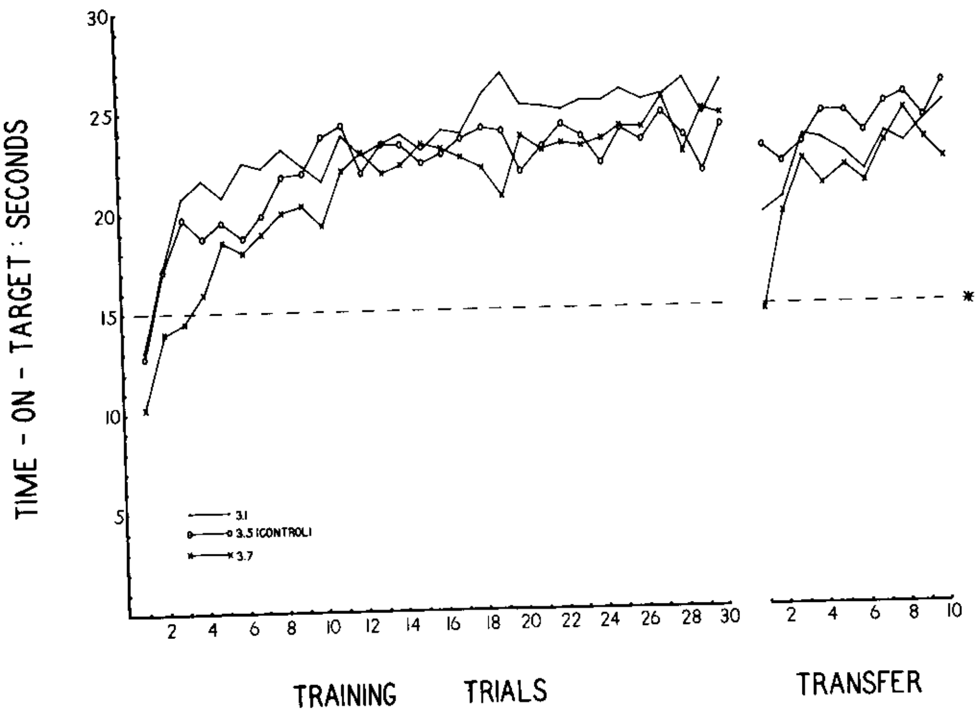

Figure 3. Experiment 3: Training and transfer performance for groups 3.1, 3.5, and 3.7.

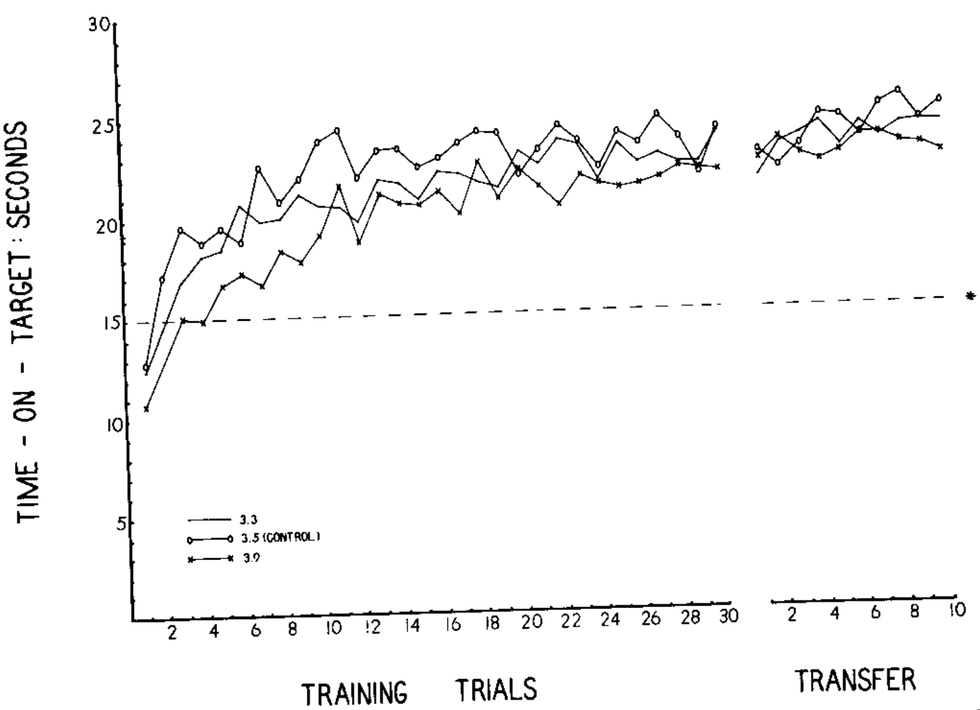

Figure 4. Experiment 3: Training and transfer performance for groups 3.3, 3.5, and 3.9.

* Theoretical "performance" with no subject response.

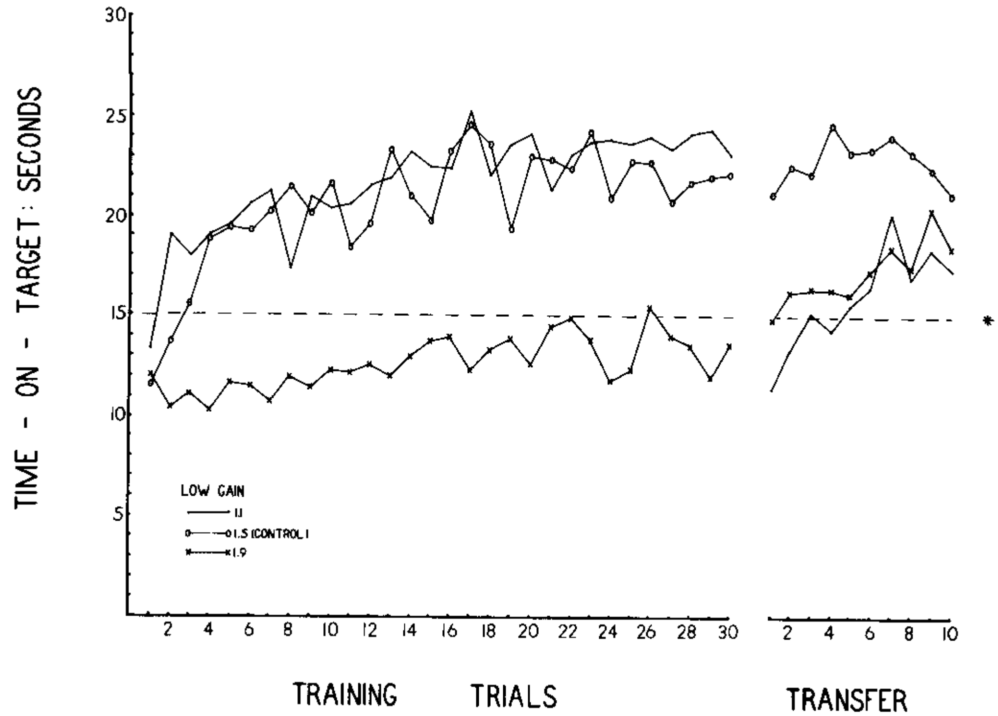

Figure 5. Experiment 3: Training and transfer performance for low control gain settings (conditions 1.1, 1.5, and 1.9).

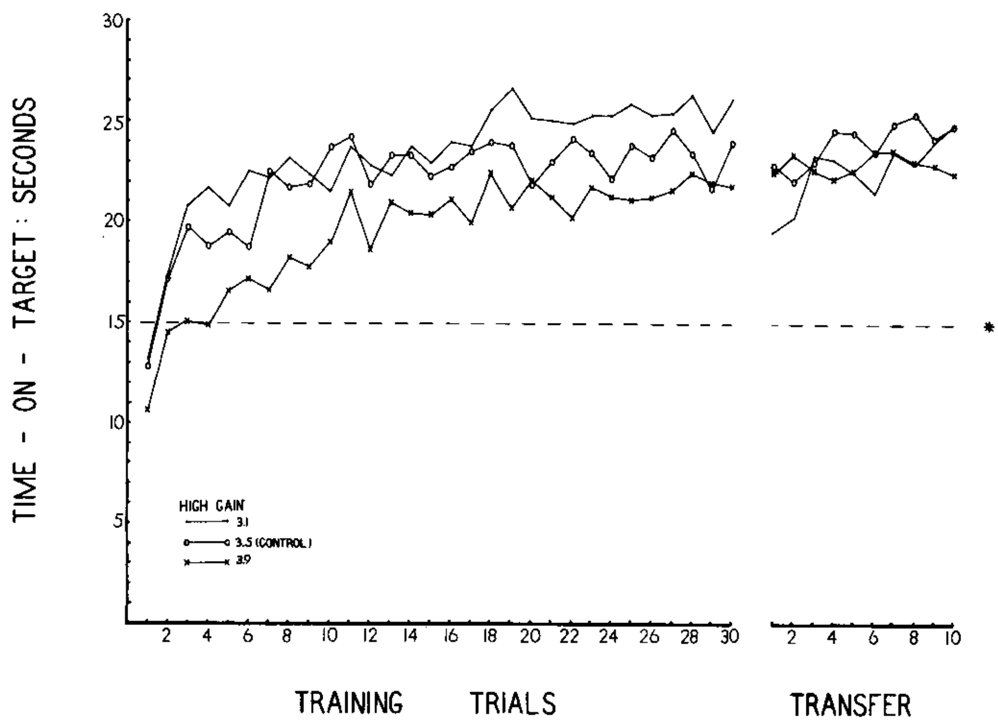

Figure 6. Experiment 3: Training and transfer performance for high control gain settings (conditions 3.1, 3.5, and 3.9).

* Theoretical "performance" with no subject response.

(phugoid conditions) chi-square values. The row (control-gain) chi-square approaches but does not reach statistical significance, except for the last five training trials. These findings strongly suggest a significant interaction effect, but analysis did not confirm this expectation. Further, the differences between groups 1.1, 1.5, and 1.9 were statistically significant throughout training (see figure 5). Figure 6 supports the finding that there were no significant performance differences between groups 3.1, 3.5, and 3.9.

Transfer Trials. Statistical analysis of the transfer performance of groups 3.1, 3.3, 3.5, 3.7, and 3.9 showed no statistically significant differences. This result is supported by visual examination of the transfer data shown in figures 1 through 4. A single exception is the initial transfer trial performance of condition 3.7, which was found to be statistically significantly different from control group (3.5) performance on the first transfer trial only. Thus, performance on the transfer condition was essentially equivalent for all high control-gain setting experimental conditions. Previous experimentation (8) had shown that with the same phugoid transients under low-gain settings, transfer performance was significantly poorer than that of the control group (1.5).

In the preceding studies in this series, a distinction was made between "absolute" and "relative" transfer effect. By the term "absolute transfer effect" is meant the effect of learning a task on the initial learning of a second, subsequent task. This is the classical question asked in most transfer-of-training studies. The term "relative transfer effect" refers to a quite different transfer question, and means a comparison of the performance of the experimental groups with the control group after all groups have received an equivalent number of training trials. This distinction between absolute and relative transfer effect will be maintained in the discussion of the transfer data which follows.

1. Computation of absolute transfer effect is based on the equation proposed by Gagne, Foster, and Crowley (2):

$$\text{Per Cent Absolute Transfer Effect} = \frac{\text{Transfer Group Score} - \text{Control Group Score}}{\text{Total Possible Score} - \text{Control Group Score}} \times 100$$

Per cent absolute transfer effect is based on a comparison of the early transfer performance of the experimental groups with the early training performance of the two control groups (1.5 and 3.5). Table 2 shows these percentages computed separately for the first and second blocks of five trials for each comparison.

TABLE 2

Experiment 3: Per Cent Absolute Transfer Effect

High-Gain Groups	Transfer Trials 1-5	Transfer Trials 6-10	Low-Gain Groups	Transfer Trials 1-5	Transfer Trials 6-10
3.1	34	20	1.1	-12	-21
3.3	44	26	1.3	30	9
3.5	47	34	1.5	50	25
3.7	18	11	1.7	6	-13
3.9	41	17	1.9	0.3	-20

Under the high control-gain setting, positive transfer was obtained for all phugoid conditions. Under the low-gain setting, substantial positive transfer effect was obtained only for condition 1.3. For the remaining conditions low positive or negative transfer was found, particularly as the course of transfer progressed.

2. The computation of relative transfer effect is based on a comparison of the experimental and control groups after all groups had received an equivalent number of training trials. Equation 3, as presented by Gagne, Foster, and Crowley (2) expresses this comparison:

$$\text{Per Cent Relative Transfer Effect} = \frac{\text{T score (trial x) - C score (initial)}}{\text{C score (trial x) - C score (initial)}} \times 100$$

Since the control group was given direct practice without change, the performance of this group is used as the base. With this equation, 100 per cent relative transfer means that the transfer gain was equal to the direct practice gain over an equivalent number of trials. Negative transfer values mean that there was a transfer loss relative to the direct practice gain over the trials block. In Table 3, per cent relative transfer effect is shown for all high control gain and low control gain experimental conditions. The 100 per cent values for the two control groups (3.5 and 1.5) are derived simply by a comparison of the control group score against itself.

TABLE 3

Experiment 3: Per Cent Relative Transfer Effect

High-Gain Groups	Transfer Trials 1-5	Transfer Trials 6-10	Low-Gain Groups	Transfer Trials 1-5	Transfer Trials 6-10
3.1	72	82	1.1	-23	37
3.3	94	91	1.3	59	78
3.5	100	100	1.5	100	100
3.7	39	75	1.7	12	48
3.9	88	79	1.9	3	39

It is apparent that under the high control gain setting, relative transfer effect is comparable for the experimental conditions with that of the control group with the initial exception of condition 3.7. On the other hand, the low-gain groups do not appear to benefit by an equivalent number of training trials as compared with direct practice. Again, there is a single exception in the performance of condition 1.3.

In summary, these data appear to show that variations in control-gain setting affects both absolute and relative transfer. High positive transfer is produced under most of the high-gain conditions. Low positive or negative transfer is produced by many of the low-gain conditions. To secure facilitative transfer effects, therefore, it would seem that high control-gain would be useful for the phugoid transient conditions used as complex system dynamics in these studies.

Discussion

Transfer of Training. As just noted, it would appear that increasing control-gain had a marked effect on transfer of training with various long period (phugoid) oscillatory transients. High control gain appears to produce a facilitatory effect. This finding is in marked contrast to the transfer performance of the same phugoid transients under low control gain settings. For the most part, the transfer performance of these groups was poor.

Application of these findings to man-machine system design, and particularly to the design of flight training simulators, is extremely hazardous. Control gain in aircraft and their associated simulators varies radically as a function of the particular flight condition, and as aircraft performance extends into the hypersonic range, the variance between control gain for high and low speed and altitude is often remarkable. It does not follow necessarily that simply increasing control gain will insure high transfer effects. Data are needed comparing transfer from high to low control gain and vice versa; the following experiment attempts to examine this problem. The results would seem to indicate, in support of previous studies, that in the design of flight training simulators -- or for that matter any complex man-machine system -- a great deal more attention can profitably be directed to the problem of control gain and the associated variations in control/display movement ratios.

Training Trials. Increasing control gain for the phugoid transients under investigation removed differences in training performance that were evident under the low control-gain setting. Most of the improvement was restricted, however, to the longer period conditions which possibly accounts for the lack of a pronounced interaction effect. No period and damping effects were noted under the high-gain setting, while period differences were marked under the low-gain setting for the same phugoid conditions.

During pre-experimental work it was suspected that a higher control-gain setting might result in a significant damping effect. As control gain is increased, damping is usually a definite aid in controlling rapid frequency phenomena which can occur with the poorly damped phugoid transients. However, as was the case with the low-gain settings, no damping effect was found.

The high control-gain condition in this study represented the maximum available gain with the present equipment. It might be concluded that even higher gain levels would not affect tracking performance, but there is every reason to suspect that this is not the case. Prior investigations with similar aircraft pitch dynamics have shown clearly that, after a certain point, increasing control-gain results in marked decrement in pilot tracking performance (6, 7). It would seem reasonable that Helson's (3) "U" hypothesis is applicable and that increased control gain would eventually result in performance decrement as did decreasing control gain. Certainly a broader range of gain settings than those used in the present study should be investigated.

III. EXPERIMENT 4: TRANSFER BETWEEN CONTROL GAINS

As noted on the preceding page, the critical question concerning fidelity of simulation of control gain is transfer between different control-gain settings. This information is necessary to determine the possible transfer effect that might result if the control-gain settings differ between the aircraft and the simulator.

The present study is designed to give a preliminary look at transfer from high to low gain and from low to high gain. A single long-period oscillatory transient condition is used.

Experimental Method

Experimental Task and Apparatus.* As before, the subject performed single-dimension (vertical) compensatory tracking. A horizontal stimulus line was displayed on a 5-inch oscilloscope face. Using a conventional aircraft control stick, the subject attempted to keep the stimulus line centered at all times.

The subject's control stick output was fed into a computer which generated simulated aircraft long-period (phugoid) oscillatory transients with period and damping values as designated by the particular experimental conditions. For the present study, one transient condition was selected -- condition 5 -- with a period of 35 seconds and a time-to-damp-to-half-amplitude of 33 seconds. The signal from the computer was mixed with a forcing function signal generated by a cam, and the resultant error signal was displayed to the subject on the face of the oscilloscope. The forcing function was a saw-tooth function closely approximating a simple sine wave of 6 cycles per minute: The displayed amplitude on the scope without stick input was ± 0.3 inch at maximum amplitude. With no subject response, TOT scores of 15 seconds per trial could be obtained with the forcing function alone.

Experimental Design. The purpose of the present experiment was to study transfer of training from a high to a low control-gain setting and from a low to a high-gain setting using a single long-period transient condition. The basic experimental design then becomes a classical AB-BA transfer-of-training paradigm, and four experimental groups may be distinguished:

TABLE 4

Experiment 4: Experimental Design and Groups

Groups	Experimental Conditions**
4.5H	High Control Gain to Low Control Gain
4.5L	Low Control Gain to High Control Gain
3.5	High Control Gain (Exp. Control)
1.5	Low Control Gain (Exp. Control)

**Phugoid Condition 5: $P = 35''$; $T_{\frac{1}{2}} = 33''$

* A detailed technical discussion of the experimental apparatus, procedures, and simulation techniques may be found in the first report in this series (8).

Four independent groups of subjects were assigned to the experimental conditions.

Subjects. A total of 40 male University of Illinois under-graduate students served as subjects in this experiment. Half of the subjects had previously served in Experiment 1 (group 1.5) and Experiment 3 (group 3.5), and their data provides experimental control conditions for this study. The remainder of the subjects were specifically assigned to this study and were assigned at random to the two experimental conditions (4.5H and 4.5L). Each of the four groups had 10 subjects.

Procedure and Response Measure. The same basic procedure was used in this study as that described for the preceding experiments. Specifically, for each of the four groups in Table 4, the procedure was as follows: (a) Group 4.5H was given 30 training trials on phugoid condition 5, with the same high control-gain setting as was used in the preceding experiment; this was followed by 10 transfer trials on the low control-gain setting; (b) group 4.5L was given 10 training trials on the low-gain setting, followed by 10 transfer trials on the high setting; (c) control group 1.5 had 40 trials with low-gain setting.

The response measure was again TOT for each of the 30 training trials and the 10 transfer trials.

Results

The basic findings of this study are shown graphically in figures 7 and 8. Figure 7 shows training and transfer performance from a high control-gain setting to a low setting. Figure 8 shows training and transfer performance from a low-gain setting to a high setting.

Training Trials. The basic comparison of interest concerns the training performance of groups 4.5H and 4.5L. Analysis of blocked training trials (means and standard deviations are shown in the Appendix) showed no statistically significant differences throughout the 30 training trials, using a distribution-free method (12).

Transfer Trials. A number of comparisons are possible for the transfer trials, each of which substantiate the implications of the data presented graphically in figures 7 and 8.

1. A comparison of transfer performance between group 4.5H and the appropriate control group 1.5 showed that the differences were statistically significant throughout the 10 transfer trials. As figure 7 shows, the performance difference appears to be considerable.

2. A comparison of transfer performance between group 4.5L and the appropriate control group, 3.5, showed no statistically significant differences during the transfer trials. As figure 8 shows, there is very close agreement in the transfer performance scores.

Computation of absolute and relative transfer effect confirms these findings:

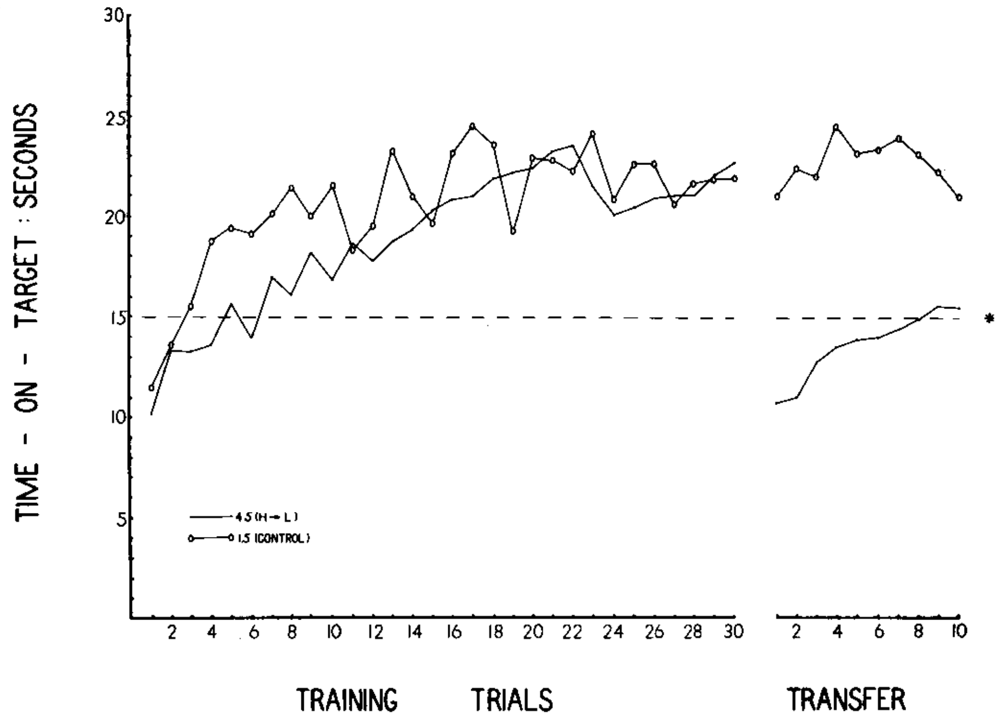

Figure 7. Experiment 4: Transfer from high to low control gain settings.

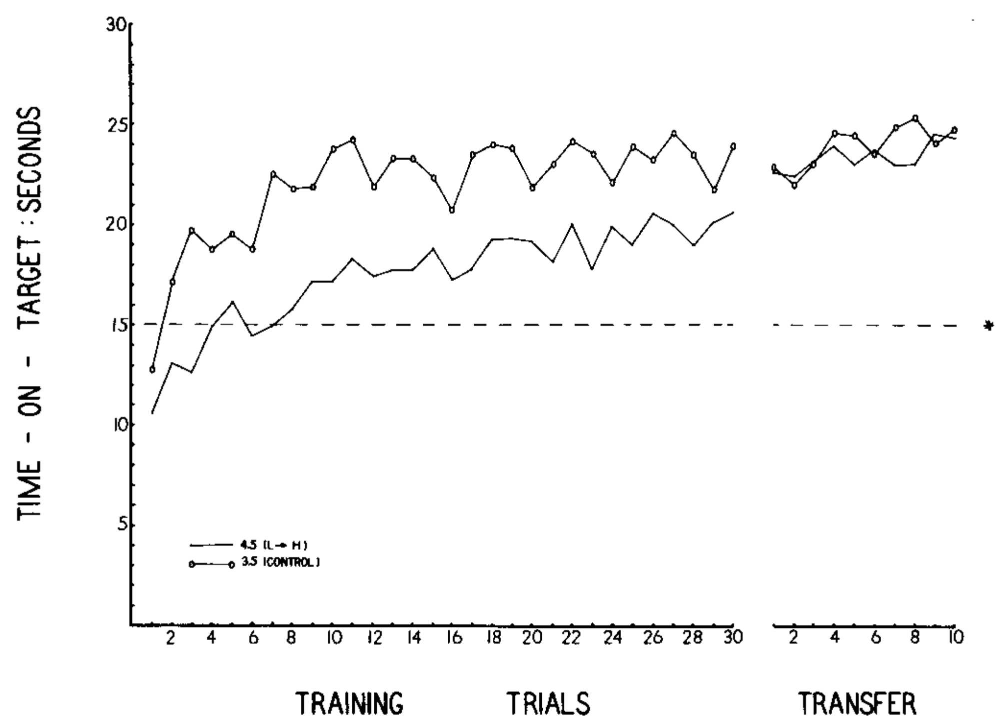

Figure 8. Experiment 4: Transfer from low to high control gain settings.

* Theoretical "performance" with no subject response.

Blocked Transfer Trials	Absolute Transfer Effect - Per Cent 4.5H	4.5L	Relative Transfer Effect - Per Cent 4.5H	4.5L
1-5	-20	44	-44	94
6-10	-55	44	-10	88

It would appear, then, that transfer from a low to high-gain setting is positive, while transfer from high to low-gain is negative. The finding that group 4.5H showed negative absolute transfer is of interest since it is often extremely difficult to demonstrate this type of interference effect in continuous tracking tasks.

Discussion

There are a few published studies in the literature that may have some relationship to the present study (e.g., 10, 11). Unfortunately, however, these studies differ from the present one in almost every specific detail of experimental task, apparatus, and procedure, and comparison is obviously difficult.

The studies of Rockway (10) and Rockway, Eckstrand, and Morgan (11) are of particular interest, since they represent systematic transfer variations from high to low C/D ratios and from low to high ratios. In a general way, this corresponds to the present technique of changes from high to low control-gain and low to high gain.

Rockway (10) trained three groups of subjects with C/D training ratios of 1:3, 1:9 and 1:27. The groups then transferred to the lowest ratio, 1:3. Transfer for all groups was positive. Allowing for the many differences between Rockway's study and the present one, this is in effect a change from high to low gain. Since in the present study substantial amounts of negative relative transfer occurred, it might be conjectured that negative transfer effects might be obtained as the complexity of system dynamics is increased. Experimental verification of this hypothesis is obviously required.

Rockway, Eckstrand, and Morgan (11) also investigated transfer to the highest ratio (1:27) from the lower ratios (1:3 and 1:9). Here significant positive transfer was obtained throughout the transfer trials. In a similar change in the present experiment, the same general result was obtained.

However, these comparisons can only be conjecture at the present time. It is obvious in the present context that a great deal more empirical information is needed. Investigation of the transfer interaction between gain settings and various transient conditions would be perhaps the most immediate possibility.

One of the most frequent complaints concerning flight simulator performance is that the simulator is too "sensitive". It has been extremely difficult to delimit specifically the causes of this complaint. A number of hypotheses have been advanced with the objective of localizing the problem in such variables as control gain, specific C/D movement relationships, lack of adequate small-motion resolution by the computer (e.g., 4), etc. A literal interpretation of the present experiment would be that simulator gain control should be less than the aircraft; such a conclusion, however, would be quite unwarranted on the basis of this very scanty evidence. This fact is specifically mentioned at this point to avoid any possibility that such a conclusion would be made.

IV. EXPERIMENT 5: RATE-OF-ONSET VARIATIONS

By manipulation of control gain it is possible to exert some influence over the initial rate of response of the various long-period oscillatory transients. Although initial rate of onset can be equated only over a very short range for these widely disparate transients, some recent evidence (1) would seem to indicate that this type of equalization may strongly affect training performance levels. The present study provides evidence to support this hypothesis, and, in addition, shows that equating initial rate of onset can also affect transfer of training.

Experimental Method

Experimental Task and Apparatus. The experimental task and apparatus variables remain the same as has been described in the previous studies. The major experimental variable concerns the use of control-gain setting to achieve various rate-of-onset conditions.

Rate of Onset Variations. For this study, three long-period (phugoid) transient conditions were selected with widely varying period and damping terms:

(1) Condition 1: Period = 18 seconds; damping = 17 seconds
(2) Condition 5: Period = 35 seconds; damping = 33 seconds
(3) Condition 9: Period = 71 seconds; damping = 66 seconds

As before, damping is expressed in terms of time-to-damp-to-half-amplitude. Training and transfer data have already been obtained for these conditions under both high control-gain and low control-gain settings; these data have been shown in figures 5 and 6.

By manipulation of control gain at the subject's stick output, it is possible to equate the initial rate of onset for these three conditions, although this equalization is only possible over a very short time range. To a standard step input, it was found that by varying the control-gain setting to initial rate of onset could be equalized over a .5 second time range. Under high gain settings (Experiment 3), a unit step produced a given steady-state level for each condition. Holding the gain constant for condition 9, the gains for conditions 1 and 5 were adjusted so that the responses agreed closely to condition 9 during the first .5 second, again for a unit step. After this time interval, the responses diverged considerably due to different period and damping characteristics. While the average rate of onset agreed during this time, the rate is always dependent upon the magnitude of control input.

Experimental Design. The purpose of the present investigation is to study training and transfer performance with the three transient conditions with (a) low control gain and initial rate of onset uncontrolled, (b) high control gain and initial rate of onset uncontrolled, and (c) initial rate of onset equated. Thus, a basic 3 x 3 experimental design was used. Nine independent groups of subjects were trained on the experimental conditions.

TABLE 5

Experiment 5: Experimental Design and Groups

Rate-of-Onset Variations	Phugoid Conditions 1	5	9
Low Gain: Rate-of-Onset Uncontrolled	1.1	1.5*	1.9
High Gain: Rate-of-Onset Uncontrolled	3.1	3.5*	3.9
Rate-of-Onset Equated	5.1	5.5*	5.9

* Transfer Conditions

Subjects. A total of 90 male University of Illinois under-graduates provided the data for this experiment. One-third of the subjects served on conditions 1.1, 1.5, and 1.9 as part of the basic experiment in this series (8). A second third of the subjects served on conditions 3.1, 3.5, and 3.9 as part of Experiment 3. A final group of 30 subjects was assigned at random to conditions 5.1, 5.5, and 5.9 for the present study. It should be understood that the data presented for groups 1.1, 1.5, 1.9, 3.1, 3.5, and 3.9 is derived from previous Experiments 1 and 3.

Procedure and Response Measure. The same basic procedure was used in this study as in the preceding four experiments. Each experimental trial was 30 seconds in length. An inter-trial interval of 30 seconds was used. After a 5-minute rest, each subject was then transferred to either 1.5, 3.5, or 5.5 and given 10 additional trials. Particular care was taken to insure that all procedures were identical for the various groups. The response measure was again TOT for each of the 30 training trials and the 10 transfer trials.

Results

The basic findings of this study are shown graphically in figures 9, 10, and 11. Figures 9 and 10 compare training and transfer performance for phugoid conditions 1, 5, and 9 under (a) low gain with rate of onset uncontrolled, and (b) rate of onset equated. Figures 10 and 11 compare training and transfer performance for phugoid conditions 1, 5, and 9 under (a) high gain with rate of onset uncontrolled and (b) rate of onset equated.

Training Trials. A number of separate analyses are possible for the training trials. The basic analytic technique used was a distribution-free method (12). Due to extreme inter-trial variability, the data were blocked and examined in groups of five trials, means and standard deviations for which may be seen in the Appendix, Table 9. The 1% level of statistical significance was accepted throughout.

1. A 2 x 3 analysis was conducted comparing low-gain, rate-of-onset-uncontrolled groups (1.1, 1.5, and 1.9) against rate-of-onset-equated groups (5.1, 5.5, and 5.9). Total chi-square values were significant throughout the 30 training trials, as were column (phugoid variations) values. Row (rate of onset) and interaction terms were not significant. Figures 9 and 10 show graphically the training

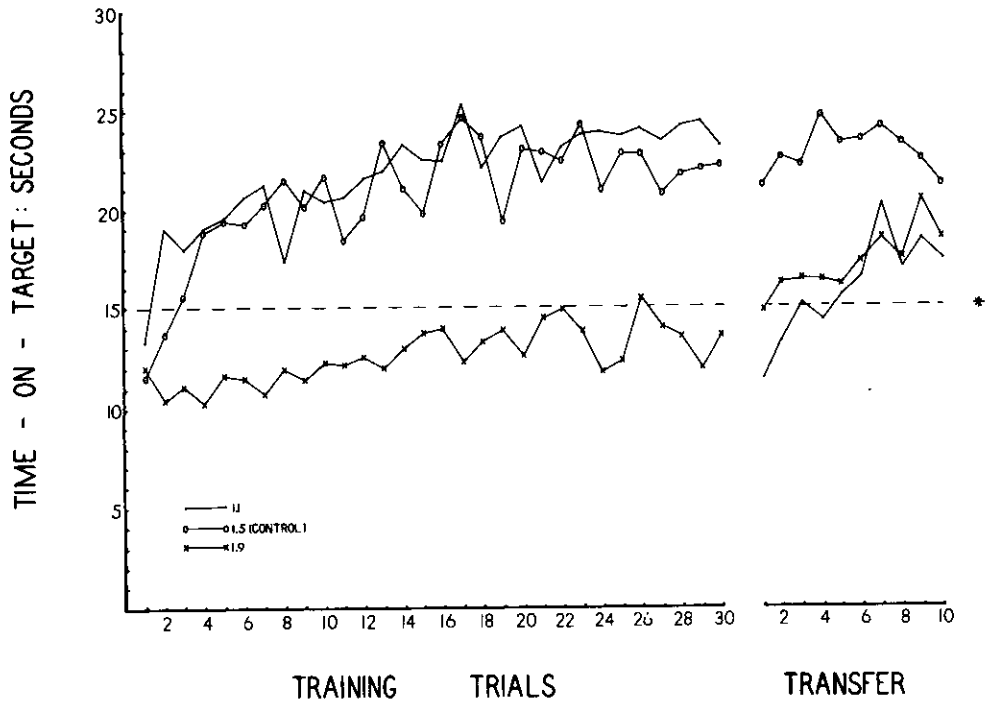

Figure 9. Experiment 5: Training and transfer performance for phugoid conditions 1, 5, and 9; low control gain with rate of onset uncontrolled.

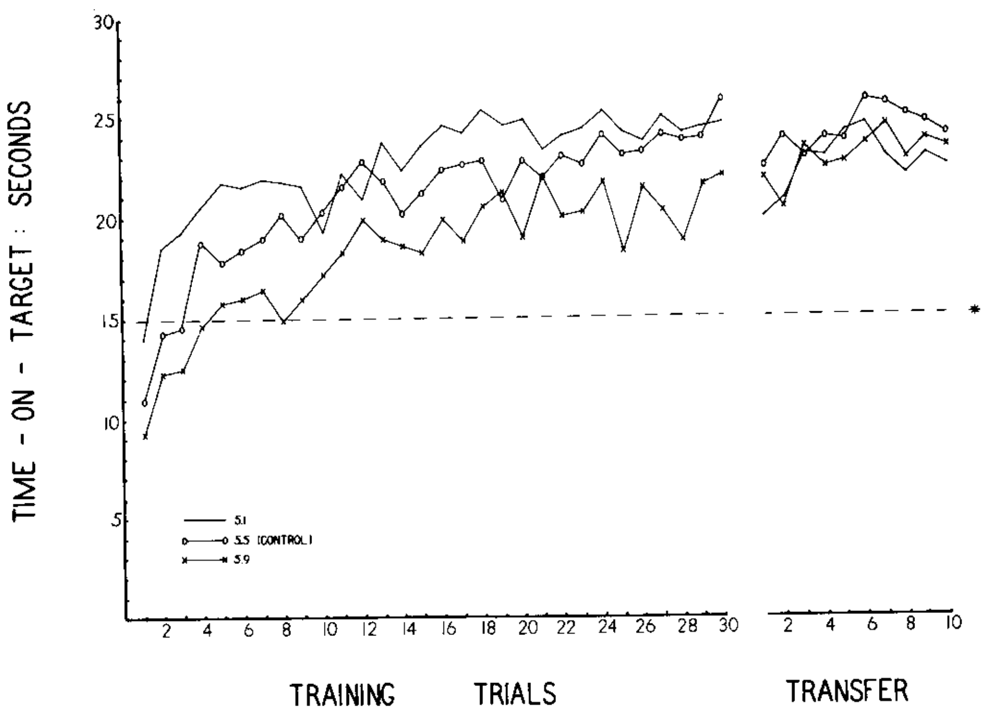

Figure 10. Experiment 5: Training and transfer performance for phugoid conditions 1, 5, and 9; rate of onset equated.

* Theoretical "performance" with no subject response.

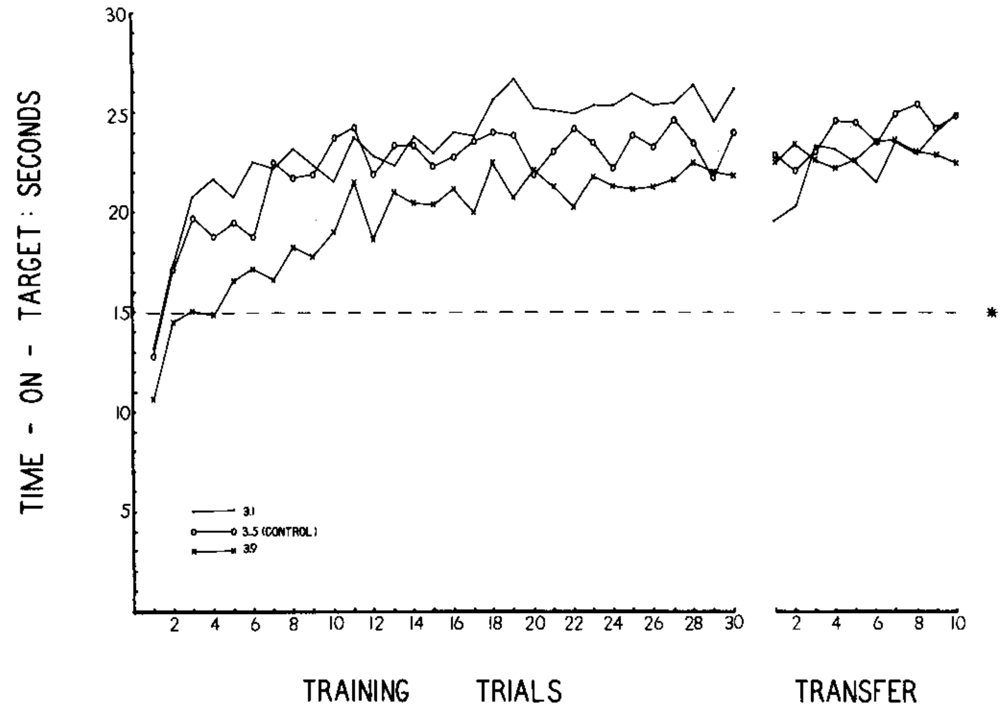

Figure 11. Experiment 5: Training and transfer performance for phugoid conditions 1, 5, and 9; high control gain with rate of onset uncontrolled. (* Theoretical "performance" with no subject response)

performance of these groups

2. A 2 x 3 analysis was conducted comparing <u>high</u>-control-gain, rate-of-onset uncontrolled groups (3.1, 3.5, and 3.9) against rate-of-onset equated groups (5.1, 5.5, and 5.9). Through trials 1-10 and 26-30, total chi-square and column values were significant; on the remaining training trials these values approached significance closely. Row and interaction terms were not significant.

3. Previous experimentation (8) had shown that the differences between the low-control-gain, rate-of-onset-uncontrolled groups (1.1, 1.5, 1.9) were statistically significant throughout training. Training performance may be seen again in figure 9.

4. A 1 x 3 analysis compared training performance for the rate-of-onset-equated groups (5.1, 5.5, and 5.9). These performance differences were statistically significant for the 1-10 and 26-30 training trials, approaching significance on the remaining training trials. As may be seen in figure 10, training performance differences are of relatively small magnitude.

5. A previous study in this report (Experiment 3) had shown no statistically significant differences in training performance for the high-gain, rate-of-onset-uncontrolled groups (3.1, 3.5, and 3.9). Figure 11 above may be examined.

Transfer Trials. A parallel set of separate analyses are also possible for the transfer trials.

1. A 2 x 3 analysis comparing low gain (1.1, 1.5, and 1.9) and rate-of-onset-equated groups (5.1, 5.5, and 5.9) showed total, row (rate-of-onset variations), and column (phugoid conditions) values to be statistically significant. There was no significant interaction effect. As may be seen in figures 11 and 12, transfer performance for the two conditions was quite different.

2. A 2 x 3 analysis comparing high gain (3.1, 3.5, and 3.9) and rate-of-onset-equated groups (5.1, 5.5, and 5.9) showed no statistically significant differences throughout the transfer trials. As figures 12 and 13 show, transfer performance for these six groups was in general equivalent.

3. Previous experimentation (8) had shown that transfer performance differences for groups 1.1, 1.5, and 1.9 are statistically significant. In Experiment 3, it was shown that there were no significant performance differences during transfer for groups 3.1, 3.5, and 3.9. Finally, in this study, no significant differences in transfer performance were found for groups 5.1, 5.5, and 5.9. Transfer data as shown in figure 12 support this finding.

Per Cent Transfer. Per cent relative and absolute transfer may be computed for all groups in the present study.

TABLE 6

Experiment 5: Per Cent Absolute and Relative Transfer

Rate-of-Onset Variations	Absolute Transfer 1-5	Absolute Transfer 6-10	Relative Transfer 1-5	Relative Transfer 6-10
Low Gain: Rate Uncontrolled				
1.1	-12	-21	-23	37
1.5	50	25	100	100
1.9	0.3	-20	3	39
High Gain: Rate Uncontrolled				
3.1	34	20	72	82
3.5	47	34	100	100
3.9	41	17	88	79
Rate-of-Onset Equated				
5.1	47	34	85	79
5.5	55	53	100	100
5.9	47	41	86	87

In general, these data are interpreted to mean that transfer performance is high and substantially equivalent for transfer groups where (a) rate of onset has been controlled and (b) high control-gain, rate-of-onset-uncontrolled conditions are used. For low control-gain groups, however, where rate of onset is uncontrolled, transfer is in general negative.

Discussion

Transfer of Training. It would appear that equating rate of onset by differential control gain settings can influence transfer-of-training data obtained with these oscillatory transient conditions. Perhaps the most interesting finding was that equivalent and high transfer performance could be obtained in two different ways, either by high control gain or by control of rate of onset.

Although these results are preliminary and exploratory and need substantiation, it is possible that they may have some implications for future research in the design of flight training simulators. A great deal of concern has been directed toward the fidelity of response of flight simulator computers to small stick motions (4). Much of the pilot's output may be small amplitude movements, and it has not been easy to obtain accurate computer response for these pilot movements. Among other things, this may mean that initial rate of onset to pilot control movements can be substantially unlike the corresponding aircraft response to identical pilot movements. How this might effect transfer of training is not known.

In the present study, initial rate of onset was equated, although this was possible over a very limited range of response in terms of time and amplitude. Yet this equalization resulted in transfer performance as high as the control group and as high as had been obtained with high control-gain settings with rate of onset uncontrolled.

Due to the scanty nature of the data, no generalizations are possible. However, it is suggested as a topic for future research the short-term, low-amplitude simulator response to pilot control movements should be given much closer attention. It is further suggested that transfer effects derived from flight training simulators in so far as continuous flight tracking tasks are concerned may rest in large part on the events occurring at the lower normal limits of amplifier response. These are subjects for future research.

Training Trials. The tracking performance data are by no means clear. Even with rate of onset equated, there were statistically significant performance differences for the three transient conditions although the absolute magnitude was small.

An interesting analogue to the present study has recently been reported by Feddersen (1). On the basis of the findings of Rockway (9) that there is an interaction between C/D ratio and exponential time delay of system response, Feddersen reasoned that the critical variable, in so far as operator performance is concerned was the rate of movement of the display element, regardless of the variation of C/D ratio and time delay used to obtain a given display movement rate. This hypothesis was confirmed experimentally for negatively accelerated ("stable") functions but not for positively accelerated ("unstable") functions.

Equalization of rate of onset in this study is analogous to the technique used by Feddersen to achieve a given rate of display movement. However, the conditions of the present study are considerably complicated by the existence of the oscillatory transients which were not present in Feddersen's experiments; it is doubtful that rate of display movement was equated except for very short time periods. Nevertheless, the results showed a similar effect of deriving very small differences in performance, despite very large differences in the transient conditions.

The conventional approach to the study of man-machine systems is to select a set of physical parameters associated with machine response, vary these parameters, and record operator performance changes. The results are usually complex functions, and change in operator performance is seldom a monotonic function of the physical parameters. The suspicion frequently arises that the selected physical parameters may not be the most direct independent variables in determining operator performance, but rather that the pertinent stimulus variables for the operator may be a resultant of those being varied. The results of Feddersen and of the present study certainly cannot be used to dismiss this suspicion.

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APPENDIX: Means and Standard Deviations by Blocked Trials

TABLE 7

Experiment 3: Means and Standard Deviations by Blocked Trials

	Blocked Trials	Experimental Groups 3.1	3.3	3.5	3.7	3.9
Training Trials	1-5	93.58* 26.13**	80.56 14.64	87.89 19.33	72.97 24.46	71.84 19.09
	6-10	111.40 19.77	102.18 9.37	108.57 13.93	96.20 23.78	88.69 11.39
	11-15	116.44 21.21	104.35 12.28	115.03 15.40	112.14 21.50	102.20 13.56
	16-20	125.18 13.52	109.95 9.76	115.92 14.86	117.77 21.17	106.49 14.93
	21-25	126.43 15.18	113.83 10.99	116.73 12.32	116.36 20.36	105.76 10.52
	26-30	127.76 13.63	114.30 8.71	117.06 10.89	121.29 16.19	109.31 10.53
Transfer Trials	1-5	108.67 20.88	115.23 14.31	116.96 13.12	99.18 26.53	113.35 18.12
	6-10	116.65 16.34	119.47 10.92	122.78 9.47	114.03 23.24	115.40 15.72

* Means in Seconds
** Standard Deviations in Seconds

TABLE 8

Experiment 4: Means and Standard Deviations by Blocked Trials

	Blocked Trials	Experimental Groups			
		High to Low		Low to High	
		4.5H	1.5	4.5L	3.5
Training Trials	1-5	65.93* 25.85**	77.87 10.70	67.43 10.10	87.89 19.33
	6-10	83.86 24.45	101.35 14.68	79.41 11.86	108.57 13.93
	11-15	94.79 20.25	101.72 11.97	89.79 10.89	115.03 15.40
	16-20	108.24 14.43	114.40 9.28	93.61 15.48	115.92 14.86
	21-25	108.67 11.23	112.64 14.77	94.83 13.37	116.73 12.32
	26-30	107.79 11.80	111.18 16.15	100.47 13.65	117.06 10.89
Transfer Trials	1-5	61.84 11.07	114.17 13.68	115.29 10.22	116.96 13.12
	6-10	74.38 13.24	113.64 11.20	118.70 12.32	122.78 9.47

* Means in Seconds
** Standard Deviations in Seconds

TABLE 9

Experiment 5: Means and Standard Deviations by Blocked Trials

	Blocked Trials	Experimental Groups 5.1	5.5	5.9
Training Trials	1-5	94.12* 13.62**	76.21 21.35	64.32 15.79
	6-10	105.99 16.92	96.66 19.72	80.51 13.52
	11-15	112.53 18.56	107.13 12.83	93.87 13.00
	16-20	123.11 10.22	111.12 15.24	99.62 14.75
	21-25	120.88 13.26	114.49 12.41	102.25 10.96
	26-30	121.70 16.45	120.49 11.54	105.31 12.12
Transfer Trials	1-5	110.78 18.79	116.82 10.93	111.15 12.91
	6-10	114.80 17.32	124.96 9.23	118.45 12.11

* Means in Seconds
** Standard Deviations in Seconds