A STUDY OF ADAPTIVE TRAINING USING AN OPERATIONAL FLIGHT TRAINER SIMULATOR (1)

MESSRS N. C. ELLIS, A. L. LOWES AND W. G. MATHENY
Life Sciences, Inc.

BACKGROUND

Adaptive training is essentially a technique whereby the complexity and/or the difficulty of a task to be learned is adapted to the skill level of the trainee during the progress of training. As a training technique, it has roots: (a) in the self-adaptive technique which has received considerable study and development for application in the field of flight control system design; and (b) in psychological learning theory which has, in the past, served as an appropriate basis for training program planning. Conceptually, the latter of the two is perhaps the most important. A long accepted tenet in learning theory, other things being equal, is that learning can best be accomplished when the two following criteria are met: (a) The difficulty of the task being learned is varied along some continuum of simple to complex during the process of learning; and (b) The variations along this continuum are made dependent upon the trainee's progress in learning the assigned task.

Despite an almost overwhelming desire to indicate that the adaptive training technique is a fresh approach to training problems, the authors frankly admit from the outset that the principles underlying this technique are by no means new to seasoned instructors. In the training situation, the good instructor, as a matter of fact, applies these basic principles at least to the best of his ability. For example, the instructor will, during the course of training, assess trainee performance at particular stages of progress to establish the trainee's readiness to move on to a more difficult task. Should the instructor determine that a task is too difficult for the trainee, he will "drop back" to a less difficult task and progress the trainee less rapidly. Instructors know that properly utilizing these principles will, over the long run, produce high task proficiency at a savings in effort on the part of both the instructor and the trainee.

At this point, it is quite easy to understand that one requirement for using adaptive training principles depends upon making valid decisions regarding a trainee's readiness to progress. In simple tasks, these decisions can usually be handled by the instructor. As training tasks increase in complexity (e. g., acquiring aircraft flight skills), the amount and type of data upon which these decisions are made frequently exceed the instructor's information processing capability. In these cases, some provision should be made for automating this decision or at least summarizing the data such that it can be handled by the instructor. Automating this decision process utilizing weapon system computers, in the opinion of the authors, is the crux of applying the adaptive training technique in operational flight training situation.

PROBLEM AREAS

Despite the utility of the self-adaptive technique in flight control design and the existing knowledge concerning the principles underlying adaptive training, there has been little systematic study of the adaptive concept for human operator training. Some initial work has been accomplished by Kelley (1962) (2) in which he described the concept of a "self adjusting vehicle simulation," and further discussed its applications to training, system design and human performance. Since this time, however, Kelley (1966 and 1967) (3) (4) has primarily been interested in applying the adaptive concept to manual control design.

(1) This paper presents a portion of the results of a study supported by the Naval Training Device Center under Contract N61339-1889. Complete study results are currently being prepared as a technical report, NAVTRADEVCEN 1889-2. (Lowes, Ellis, et al., In Preparation)

When one considers the magnitudes of the problems associated with the development of the adaptive training technique for human operator training and then extending this technique to operational training situations, it is easy to understand the present sparseness of study data. The three major problems are: (a) the definition of a meaningful parameter(s) of task difficulty applicable to complex operator tasks; (b) the incorporation into operational training situations (e. g., Operational Flight Trainers) of the necessary sensing and logic which will determine the trainee's readiness to receive an increase in task difficulty; and (c) the determination of the magnitude and the rates of step changes which are compatible with human learning rates.

Several approaches to resolving this first problem exist in research literature related to the adaptive concept. For example, it has been suggested that task difficulty can be varied by: (1) changing the level of the control order (Hudson, 1962); (5), (2) shifting the system from a quickened one to its normal response state (Birmingham, et al, 1962), (6), and (3) other such means as changing the complexity of the external forcing function, altering the information content of displays, modifying the control system or instituting changes in the dynamic characteristics of the system (Kelley, 1962).

In considering the latter problems, namely the adaptive logic and its incorporation into operational training situations, the literature is less helpful. There does appear to be a consensus of opinion among investigators that rate of learning is the important parameter upon which changes in task difficulty must depend; however, there are no hard data on such things as when to make changes along the difficulty continuum and what the magnitudes and rates of these changes should be. Kelley (1966) again is the most useful source; he has pointed out the importance of this latter factor, suggesting that the rate of change should neither be so slow as to retard a trainee's progress nor be so fast as to cause the system to oscillate about the desired rate.

SCOPE AND HYPOTHESIS

Since current thinking supports the utility of incorporating adaptive techniques into task training programs, defining specific training situations in which these techniques can be introduced is presently receiving increased attention in military settings. One of these areas is pilot training. An extension of adaptive techniques into complex pilot training situations, such as those employing flight simulators, would certainly represent a significant step forward for the training state-of-the-art. The present study is aimed at determining the feasibility of this extension.

A general hypothesis in this type of study would be that the incorporation of the adaptive technique into an OFT is feasible. In addition, the resulting combination should operationally provide a training technique superior to conventional techniques in training time, quality, economy or any combination thereof. Although the purpose of the present study was to investigate the feasibility of incorporating the adaptive principle into flight simulators, it was necessary to reduce the scope of the experimental hypothesis to a more manageable form. It was hypothesized for study purposes that adaptively trained pilots would be more proficient when transferred to a flight simulation representative of an aircraft than would pilots who were transferred to the same task after having been trained under conventional flight simulator techniques.

METHOD

SUBJECTS

Eighteen instrumented-rated pilots without jet experience served as subjects. Some of the pilots were recently hired flight engineers with the commercial airlines, but the majority were private pilots. The average flight time per pilot for the sample was approximately 500 hours. These pilots were thoroughly familiar with the flight characteristics and cockpit layput of the UDOFTT complex since they had participated in a previous study conducted by LSI (NAVTRADEVCEN 0034-1: Ellis, Lowes, et al, In Press). (7)

CONDITIONS OF SIMULATION

Operational Flight Trainer (OFT)—The Universal Digital Operational Flight Trainer Tool (UDOFTT) served as the OFT. The UDOFTT is a high-speed stored-program digital computer with two fixed base simulator cockpits. There are no visual attachments. A complete description of the facility is given in a Sylvania (1963) (8) report. The aircraft simulated was a current high performance, swept wing, single engine jet fighter. Simulation was accomplished using the equations of motion developed for this particular aircraft by the OFT manufacturer.

Turbulence (G)—Turbulence (G) was simulated by disturbing the aircraft with continuous angle of attack and pitch rate gusts. The gusts are representative of a stationary random variable with frequency and amplitude distributions matched to atmospheric gust structure data. Preliminary pilot studies established for the present study task a G range from 0 to 32 fps. The value of G represents the largest possible magnitude of any gust within the series. The rms (ft/sec) of the gust disturbance may be computed simply by multiplying the value of G by 0.177. (A complete discussion of turbulence will be available in NAVTRADEVCEN 1889-2). Although air turbulence is a multi-channel disturbance, only the longitudinal mode was employed. The authors felt that only complexity and little basic insight into the adaptive technique could be gained by using two turbulent modes. In this study, G was the parameter used to define task difficulty. Assuming that task difficulty is directly proportional to the magnitude and probability of task error, and understanding that larger G intensities will increase the magnitude of piloting error, it follows then that increases in G represent increases in the difficulty of the flight task.

Adaptive Logic—Three of the more important factors which control the synthesis of an adaptive logic scheme are: (a) an appropriate error measure (i.e., rms error, mean absolute error, median absolute error, etc.) for assessing performance; (b) a criterion error score which can be used for making changes in task difficulty; and (c) the manner and rate in which variations in task difficulty can be accomplished. The adaptive formulas derived from these considerations were:

$$G_{i+1} = G_i + K(h_c - |h_a - h_r|)^2 \quad \text{If } h_c - |h_a - h_r| > 0$$

$$G_{i+1} = G_i - K(h_c - |h_a - h_r|)^2 \quad \text{If } h_c - |h_a - h_r| < 0$$

Where: G_i is the turbulence intensity at time t_i;
h_c is the criterion error score;
h_a is the indicated altitude of the simulated aircraft;
h_r is the prescribed reference altitude; and
K is the factor which determines the amount by which the intensity is incremented (or decremented) during each successive program cycle.

This logical scheme can be compared to the adjustment formula derived by Kelley (1966) and can be shown to resemble closely a digital analog of the formula he proposes for the analog computer. From the results of preliminary investigations, the criterion error score (h_c) was established as a 125 ft deviation from the prescribed altitude, and the optimum rate (K) for regulating difficulty was determined to be $\sqrt{\pi} \times 10^{-5}$

STUDY TASK

The task required of the subjects was to hold the aircraft as close as possible to the trim altitude (25,000 feet) using only fore and aft stick control. In order to restrict the experiment to a single dimension, the simulation of the lateral mode of motion of the aircraft was not functional. This was accomplished by a "roll lock mode" in which roll acceleration, yaw acceleration, and rate of change of sideslip angle were held at zero. Since the aircraft was trimmed before each trial so that roll angle and slip angle were zero, it followed that these angles remained zero throughout the trial and that heading remained at a constant value. The only instruments that were necessary for the pilot to watch were those indicating motion in the plane of symmetry of the aircraft. A tolerance of ± 50 feet of altitude deviation was suggested.

EXPERIMENTAL DESIGN

Experimental Paradigm—The experimental design and transfer of training paradigm is presented in Table 10. Each pilot received a total of 30 200 sec. simulator trials. Trials 1-25 were used as training time, and trials 26-30 served as the transfer task. The Adaptive Group received training under conditions in which changes in turbulence were dependent upon each individual pilot's continuous performance. Turbulence was permitted to vary continuously from 0 to 32 G during any one training trial. If the pilot were flying the simulator within criterion limits, turbulence was increased, but if out-of-tolerance conditions existed, turbulence was decreased. The Control Group, on the other hand, was given constant amounts of practice on 5 different levels of turbulence as shown in Table 10. The transfer task employed an intermediate level of turbulence which was held constant during the task.

TABLE 10

EXPERIMENTAL DESIGN

ADAPTIVE GROUP

Training Trials	Conditions	Transfer Trials	Conditions
1 - 25	Adaptive Program	26 - 30	Gust Level = 16

CONTROL GROUP

Training Trials	Conditions	Transfer Trials	Conditions
1 - 5	Gust level = 6	26 - 30	Gust level = 16
6 - 10	Gust level = 10		
11 - 15	Gust level = 16		
16 - 20	Gust level = 19		
21 - 25	Gust level = 22		

Scoring—Objective measurements of the pilots' inputs, the system outputs and the intensity of the turbulence were obtained during the trials. These measurements included: (1) the mean and variance of the fore and aft stick position, (2) average absolute altitude error, (3) average absolute Mach number error, and (4) the mean and variance of turbulence intensity. Two "back-to-back" one-hundred second scoring intervals were used. The scores from both intervals were averaged to obtain the scores for the entire trial. Data samples for altitude and Mach errors were taken every second; data samples for stick position and turbulence intensity were taken every one-half second. Continuous recordings of the following were made with an on-line CEC recorder: (1) altitude error, (2) indicated rate of climb, (3) pitch angle, (4) stick position, (5) Mach number error, (6) angle of attack gust, (7) pitch rate gust, (8) scaled (i. e., amplified by level of turbulence intensity) output of the random number generator, (9) normal acceleration, and (10) level of turbulence intensity.

Procedure—Performance data from a previously conducted study (NAVTRADEVCEN 0034-1; Ellis, et al., In Press) in which these same pilots participated were used to form two matched groups. One was designated as the Adaptive Group and the other the Control

Group. Prior to transferring to a pre-defined transfer task, both groups received practice on identical simulated maneuvers; however, the former group practiced under adaptive conditions and the latter, under conditions representative of conventional training techniques.

Each pilot was scheduled for two experimental sessions. He was required to fly 15 trials per session, giving a total number of trials equal to thirty. Rest periods were provided to combat fatigue, for loss in motivation, and so forth. Task instructions were provided in the form of a maneuver briefing. For both groups the computer was retrimmed before the onset of each trial to the criterion flight condition, 1.1 Mach at 25,000 feet. Before releasing controls to the pilot the trim button was disabled so that the stick and throttle were the only operating controls. For the control group, the level of turbulence was preset to the designated value for each trial and held constant throughout the trial. For the adaptive group the level of turbulence was set at zero at the beginning of the first trial of each session. For each succeeding trial of each session, exclusive of the last five (transfer trials) of the second session, the turbulence level at the beginning of each trial was set at the last instantaneous value it had assumed in the immediately preceding trial.

RESULTS AND DISCUSSION

Before discussing the findings of this study, one limitation of the data should be made clear. A programming error led to the omission of the equation describing the motion of the air mass. As a result, it is not known whether or not these data represent absolute values for the parameters (e.g., altitude error, control stick input, etc.) used to assess performance; however, the establishment of absolute values was not the objective of the study. It should be recalled that this investigation was a feasibility study in which an adaptive training technique was to be studied relative to a more conventional training technique. Since the omission occurred in the programs for both groups of pilots, then the authors feel that the validity of the study results is not compromised.

The results reported in this paper have been organized for discussion under the headings of: (a) Training Performance, and (b) Transfer Performance.

TRAINING PERFORMANCE

The term training is being used here in a rather restricted sense. In this context, training simply represents twenty-five practice trials in flying the UDOFTT under the study conditions of turbulence. Figure 117 was prepared to provide a visual basis for comparing the performances of the Adaptive and Control Groups during the training trials.

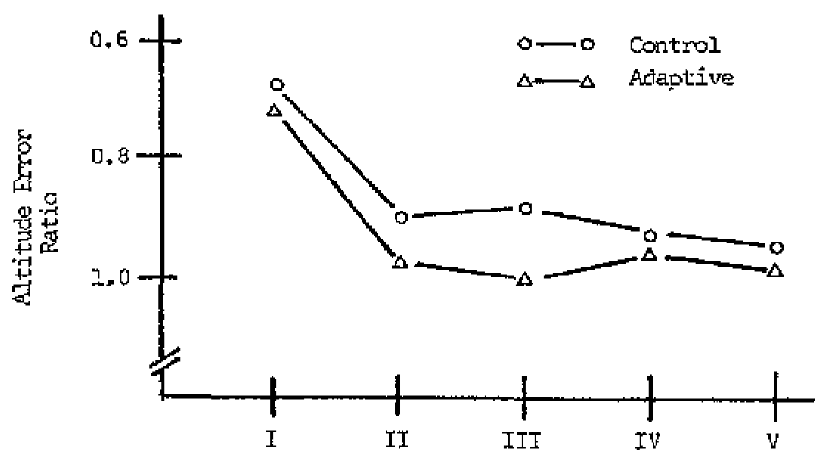

Figure 117. Altitude Error Ratio for Each of Five Trial Blocks

Figure 117 is a plot of Altitude Error Ratios across blocks of training trials. Each block is a summary representation of five training trials. The Altitude Error Ratio represents a derived measure of control skill. It is the ratio of the minimum standard altitude error estimated for a known level of simulated turbulence (G) to the pilot's actual altitude error in flying that level of G in the UDOFTT. Learning in this case can be defined in terms of the rate at which the pilot's altitude error approaches the minimum standard error, or in terms of the Altitude Error Ratio, learning can be expressed as the rate in which this Ratio approaches unity. The plots in Figure 117 show that the rate of learning for the Adaptive Group is faster and perhaps more stable than that of the Control Group. More importantly, the data in this figure appear to suggest that the Adaptive Group could be transferred to the transfer task at some point in training prior to the end of the Block V trials. As a matter of fact, the data indicate that transfer for the Adaptive Group could be accomplished at the end of Block III trials. This being the case, considerable savings in training time might well be effected.

TRANSFER PERFORMANCE

Although it has no known basis in fact, one serious indictment which has been leveled at the utility of adaptive training is that the artificiality of the training situation will not prepare a trainee for real situational tasks. For example, in the present context this would essentially mean that giving a trainee practice in an aircraft simulator on a task which gets "easier" when he is in "trouble" will not prepare him for handling "trouble" in the real aircraft. Aside from the general question regarding the utility of aircraft simulators in flight training, this criticism is basically a question of transfer of training. Therefore, to provide an initial data base for discussing this problem, a transfer task was provided in the present study. Because limitations placed upon the study did not permit using a real aircraft, the transfer task consisted of five additional trials in the simulator. In these sessions, the pilots were subjected to a constant turbulence level of moderate difficulty.

The average absolute altitude errors and the corresponding error variances during the transfer task for the Control Group and Adaptive Group pilots appear in Figures 118 and 119 respectively. It is obvious that there is a consistently smaller altitude error ($p < .03$ on basis of Sight Test) across the trials for the adaptively trained pilots. In addition to evaluating directional consistency, the magnitudes of the differences in absolute altitude error for the groups were also tested statistically. The results of a t test for a matched group design revealed that differences in altitude errors between matched pairs of pilots comprising the Adaptive and Control Groups were statistically different ($p < .05$). It is also apparent from observation of the variances that there is more consistency of performance among members of the Adaptive Group than amont members of the Control Group ($p < .03$ on basis of Sign Test).

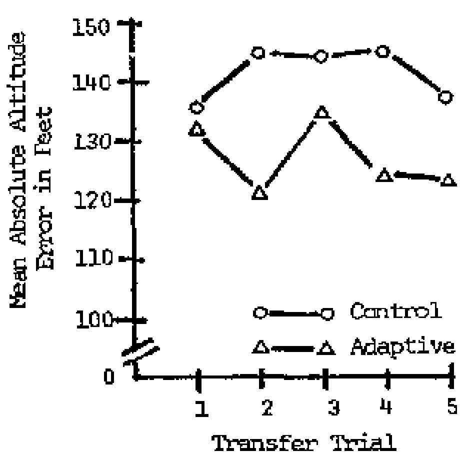

Figure 118. Altitude Error During Transfer

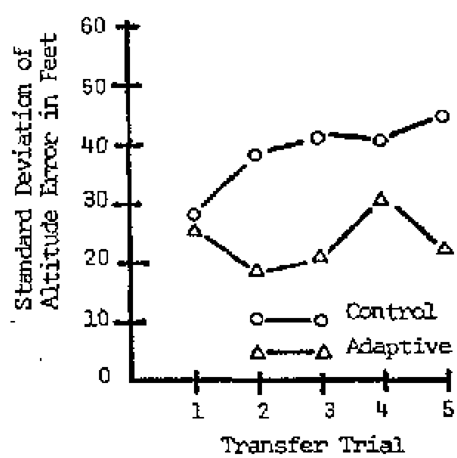

Figure 119. Altitude Error S. D. During Transfer

Although the pilots in the Adaptive Group demonstrated greater proficiency in the control of altitude, one question worth exploring is: Did the adaptive nature of the training decrease pilot proficiency in some other system parameter? The present investigation does not permit an in-depth study of this question; however, some data are available. Note that Figures 120 and 121 illustrate that Mach number and Mach variance are also smaller for the adaptively trained group so that it is definitely not the case that the control strategy learned by the Adaptive Group to produce smaller altitude errors potentially causes a secondary error (which in this study would be Mach number deviation) to become larger. Consequently, the control strategy developed with adaptive training appears also to reduce other measurable system errors.

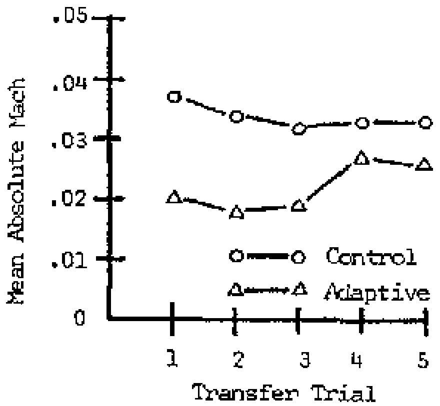

Figure 120. Mach Number During Transfer

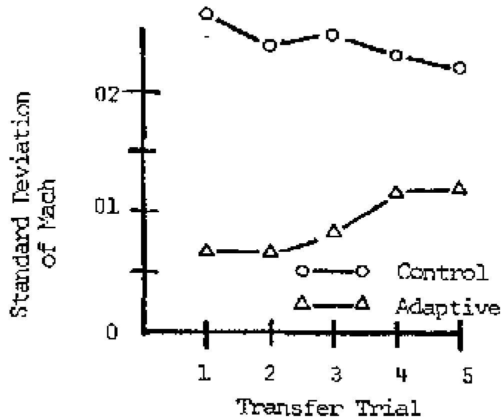

Figure 121. Mach Number S. D. During Transfer

CONCLUSIONS AND RECOMMENDATIONS

An investigator must always guard against the tendency to overstate his case at the conclusion of a feasibility study, but overcoming this tendency is even more difficult when the results of that study exceed his highest expectations. Therefore, it is from this background of guarded optimism that the authors offer the following conclusions:

(1) The adaptive training technique can be feasibly incorporated within a defined framework of an OFT training situation.

(2) The adaptive training technique, when compared with the more conventional training technique, did, in fact, better prepare the pilots for a simulator transfer task designed within the limitations of the equipment to be representative of an operational task.

(3) The adaptive training technique did not inherently lead to the development of a secondary error in system control.

(4) The adaptive training technique may potentially result in a savings in training time.

With regard to recommendations, the authors feel that the adaptive approach to training merits a great deal more investigation. Further research should be accomplished with regard to: (a) adapting individual learning rates, (b) adapting the aircraft system to effect changes in task difficulty, (c) supplying multi-channel variations in task difficulty, and (d) developing appropriate criteria for selecting error measures for assessing performance.

(1) This paper presents a portion of the results of a study supported by the Naval Training Device Center under Contract N61339-1889. Complete study results are currently being prepared as a technical report, NAVTRADEVCEN 1889-2, (Lowes, Ellis, et al., In Preparation).

(2) Kelley, C. R. Self Adjusting Vehicle Simulators. Paper presented at International Congress on Human Factors in Electronics, Long Beach, California, 1962.

(3) Kelley, C. R. Adaptive Simulation: Design Applications of Self-Adjusting Simulators. Engineering Psychology Branch, Psychological Sciences Division, Office of Naval Research. Contract Nonr4986(00) NR 196-050, August, 1966.

(4) Kelley, C. R. Further Research with Adaptive Tasks. Engineering Psychology Branch, Psychological Sciences Division, Office of Naval Research. Contract Nonr4986(00)NR196-050. August, 1967.

(5) Hudson, E. M. An Adaptive Training Simulator. Papre presented at International Congress on Human Factors in Electronics, Long Beach, California, 1962.

(6) Birmingham, H. P., Chernikoff, R.and Ziegler, P. N. "The Design and Use of 'Equalization' Tracking Machines." Paper presented at The International Congress on Human *Factors in Electronics, Long Beach, California, 1962.*

(7) Ellis, N. C., Lowes, A. L., Matheny, W. G. and Norman, D. A. Pilot Performance, Transfer of Training and Degree of Simulation: III. Performance of Non-jet Experienced Pilots Versus Simulation Fidelity. NAVTRADEVCEN 0034-1, Naval Training Device Center; Orlando, Florida, In Press.

(8) Sylvania Electric Products,Inc. The UDOFTT Flight Simulation System, Final Report, AMRL Tech. Docum. Rept., Wright-Patterson AFB, December, 1963.