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ABSTRACT

The study investigates the potential utility of a predictor instrument in the training of manual control operators in aircraft simulators. Various predictor display design configurations were presented to subjects during training trials on an aircraft approach to landing task. Subsequently, subjects were tested on trials devoid of the predictor instrument to determine transfer effects. Each of the predictor display configurations was contrasted with a control or baseline display which did not include the predictor. Results of the study indicated that transfer from a predictor to a nonpredictor display was dramatic; learning was greatly accelerated, and the difference between predictor trained and nonpredictor trained subjects appeared permanent, in view of a rather stable asymptotes observed during the last 24 test trials. It was concluded that the predictor display accelerated learning through its ability to provide immediate feedback to operators regarding the unique response of the system to control actions. Such feedback enabled operators to learn the complex dynamics of the vehicle much more rapidly than was possible without it. Implications for use of the predictor instrument in wide variety of operational and training applications are discussed. Appended materials include a bibliography, a report on exploratory research, computer simulations, and subject instructions. (Author/BP)

EFFECT OF A PREDICTOR INSTRUMENT ON LEARNING TO LAND A SIMULATED JET TRAINER

Final Report on Contract F44620-73-C-0014

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I. INTRODUCTION

A. PURPOSE

Use of a predictor display has been shown to virtually transform the difficulty of a variety of complex, manual control, pursuit tracking tasks to the level of those having relatively simple control requirements. Within 15 minutes practice, naive operators have been able to perform some complex tasks with a predictor display at accuracy levels previously achievable only after extensive training without a predictor display (Kelley, 1968).

The purpose of the present study was to explore adaptive use of a predictor display to promote rapid and accurate learning on conventional tracking tasks, i.e., transfer of training.

The study consisted of two phases. The remainder of this chapter presents a review and theoretical discussion of the problem (Section B), a summary of exploratory research conducted in Phase I (Section C), and a brief description of and underlying rationale for the experiment conducted in Phase II (Section D). Chapters II through IV describe the Phase II experiment in detail.

B. BACKGROUND

1. Introduction

The more complex and difficult a manual control task, the more inaccuracies in system response will result. Such an effect results from man's limited capabilities to simulate the ideal servomechanism and to predict near future system control needs. An excellent example illustrating his limitations is a flight task. A large part of learning to fly involves learning to make appropriate control inputs in response to information in the visual world outside the cockpit and to information contained in the flight instruments. The task is uniquely complex under IFR conditions, where system status information is, for the most part, restricted to flight instruments alone.

In principle, to maintain appropriate aircraft control the pilot continously determines the present status of the aircraft, extrapolates its near future status and then formulates and executes responses that will hopefully maintain or bring the status of the aircraft within acceptable tolerances. Inherent in this control process are several sources of time lags which contribute to the instability of the control system and difficulty of the control task.

2. Time Lags

One primary set of lags is inherent in the control dynamics of the aircraft. A step function input to the stick, for example, is integrated over time and appears several seconds later as an accelerating change in attitude (e.g., Etkin, 1958). The aircraft is a high inertia system and cannot respond immediately to control commands.

A second set of lags is associated with the perceptual and motor processes of the pilot. Changes in positions, velocities, accelerations and other parameters varying in time must exceed certain threshold values before they are perceived as having changed. If any of those rates of change are low, delays in detecting the changes will occur (Osgood, 1953). Moreover, regardless of detection lag time, the pilot's minimum muscular reaction time represents a significant system lag as well.

Finally, a third set of lags is associated with human information processing time. The amount of processing time required in any particular situation depends on the amount and complexity of information to be processed. Human information processing is relatively slow at best and when the operator's limited capacity is exceeded, delays occur and errors build up rapidly (e.g., Knowles, Garvey & Newlin, 1953).

To maximize system response accuracy, it is necessary to compensate for lags characteristic of both control dynamics and human performance. Without such compensation, the system will be annoyingly oscillatory at best or fatally unstable at worst (Etkin, 1958).

3. Lag Compensation

In normal flight, the pilot provides some degree of compensation, a capability he develops through training and experience in simulators and in actual flight. However, while discussions of prediction in manual control tasks in the literature often seem to suggest that operators do employ predictions with some degree of success, the evidence supporting such suggestions seems nonexistent. In fact, what evidence there is suggests the opposite conclusion. For example, in a series of early studies employing a one-dimensional pursuit display, Gottsdanker (1952ab, 1955) observed no predictive capability whatsoever on the part of his Subjects. Moreover, Smith and Lyman (1967) found similar results using a high inertia, two dimensional tracking mount. Thus, it may well be that the human operator functions almost entirely as a slow servomechanism, as suggested long ago by Craik (1947, 1948). That is, the operator inputs a control action only after he perceives an error. Precision manual control, therefore, is not possible in conventional systems because operator and system lags cannot be rapidly compensated for by the human operator.

Compensation may be provided in other ways. Autopilot and stability augmentation control systems provide compensating lead terms automatically through servomechanisms tailored to the flight dynamics of the aircraft. Quickened displays, which apply the principles of stability augmentation to the display system, represent a technique used to provide compensation to the system by preconditioning the input to the pilot (Birmingham and Taylor, 1954). Predictor displays which utilize fast-time analogs of the control system dynamics, also provide compensation by processing current aircraft status and integrating system dynamics equations to form predictions of the future state of the aircraft (Kelley, 1962).

Regardless of how compensation is provided, its purpose is to stabilize control of the aircraft so that it can be flown more easily, smoothly and safely through desired maneuvers. For systems which require, for one reason or another, manual control by the human operator, predictor instruments appear to hold unique promise for achieving control precision.

4. Predictor Displays

It has been amply demonstrated that predictor displays can enable operators to control systems in which the dynamics are so complex that they are virtually impossible to control with feedback from conventional displays (Kelley, 1962). It has also been demonstrated that the efficacy of predictor displays is a function of several parameters such as prediction span, repetition rate, operator response model, or display format that can potentially serve as variables to be adapted during training to effect transfer from a predictor instrument to conventional instruments (Pitrella, Prosin, Kelley & Wulfeck, 1971).

As noted in Section 3, a predictor instrument utilizes a fast-time model of control dynamics to compute the future course of the system output, given the present state of the system and given certain assumptions about the operator's behavior. Since the real state of the system is sampled and the prediction calculations are repeated several times a second, the models for the control dynamics and operator performance can be crude but yet quite effective. For example, the dynamics of a pitch control system may be computed by sampling relations between deflections of the stick and control surfaces, changes in angle of attack, and changes in attitude. The predictor model incorporates the same elements scaled to operate many times faster and arranged so that the prediction is interrupted, reset, and restarted at a rate determined by the desired prediction span and display refresh requirements.

The output of a fast-time, repetitive model can be displayed in a number of ways. For present purposes, a simple display showing present position and predicted trajectory of an aircraft relative to a glideslope and a 0.5° tolerance envelope above and below the glideslope is used (see Figure 1).

The strategy is to control the aircraft such that present position remains within the tolerance envelope and, as much as possible, superimposed upon the glideslope. Since the predictor trace is generated in fast-time, it responds to the control inputs several hundred times faster than the actual aircraft or aircraft symbol and gives the pilot virtually instantaneous feedback with respect to the "long term" effects of his control actions. This feedback not only greatly simplifies the pilot's control task, it also gives him information that would seem useful as instructional feedback (Roberts & Taylor, 1972).

5. Predictor Instruments and Training

Novice pilots nearly always over-control and end up in a highly oscillatory mode of operation. In the pitch dimension, stick position information is available from kinesthetic and visual cues, as well as from stick force feedback. In actual flying, position information is also available through proprioceptive (body angle) cues. Angle of attack is sometimes presented directly, but more often it is presented indirectly via pitch angle. Attitude is presented directly and also indirectly as vertical velocity. Of course, none of this information is sufficiently precise or rapid. Consequently, over-controlling occurs when the pilot leaves in a stick deflection until he perceives a resulting change in pitch angle or vertical velocity and then tries to restore the stick to neutral.

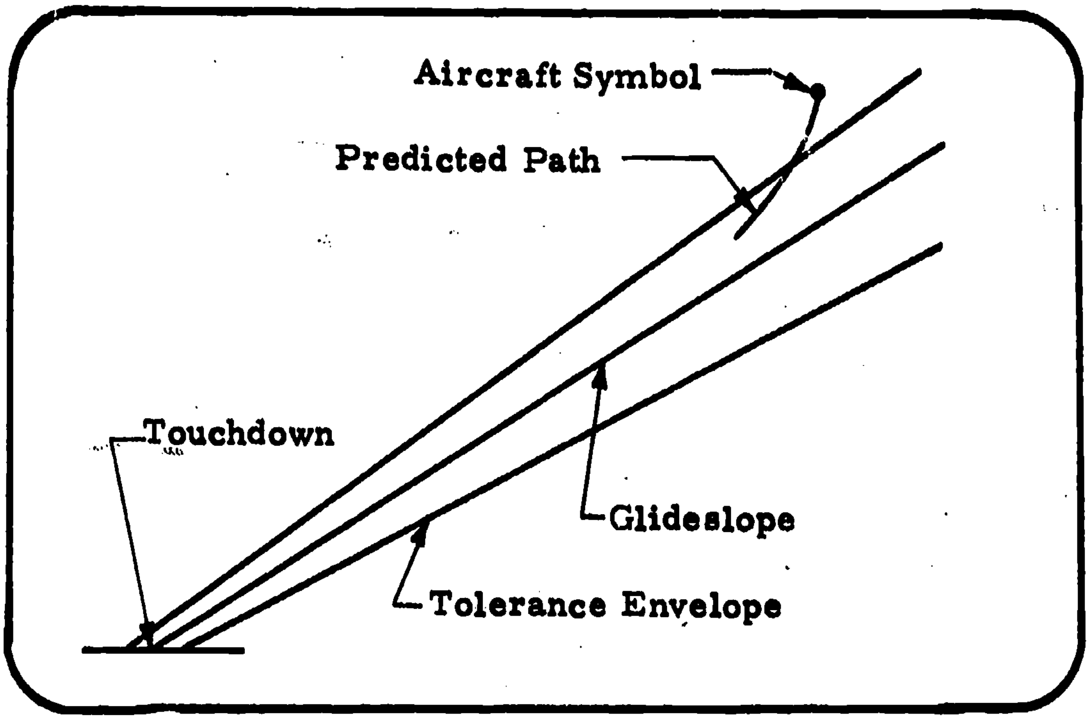


Figure 1. A cathode ray tube display showing an imprinted glideslope and tolerance envelope, and a simulated aircraft and its predicted trajectory.

However, the corrective action is usually too late and an opposite compensating control action must be introduced.

The fast-time predictor display reduces over-controlling by providing immediate feedback in terms of predicted outcome. And, as noted, it may also provide instructional cues to assist the student in learning to (1) understand the dynamics of his control system, (2) look for early derivative information, and (3) make small, intermittent step-function control movements. Early in training, the student usually controls the end of the predictor trace; with practice he learns also to control the shape of the trace, which depends on proper control of the derivative terms. Again, the fast-time feature of the predictor model provides the instantaneous feedback needed to facilitate his learning.

The evidence supporting the use of a predictor display for a wide variety of manual control systems is exceedingly powerful. However, its widespread implementation appears likely to be slow, although one is already flying in the DC-10. It awaits a thorough investigation in terms of the many parameters that constitute elements of its design, i.e., the various parameters need to be varied and evaluated for specific types of control tasks in order to establish design criteria for optimizing predictor displays for a wide range of systems. In the meantime, however, the question has emerged as to whether a current predictor instrument can be used fruitfully as an aid to facilitate learning on conventional displays.

6. Transfer of Training

Among the many variations in training methods, it is possible to distinguish three major strategies. At one extreme is the whole-task approach in which the student is required to practice the actual task in its entirety until he masters it. Since the learner must "sink or swim," this approach is best when (1) the task is already within the response capabilities of the learner when training begins, (2) the task is not particularly difficult, and (3) there are no overriding costs for errors and failures. Thus, this mode of training is useful in improving the efficiency with which a learner may perform a task he can already do, but is quite inappropriate in training situations in which the task far exceeds the learner's initial capabilities and the purpose of training is to develop new skills and capabilities that enable him to handle the task.

Two other general modes of training to develop new skills are those explicable in terms of the concepts of "transfer" and "shaping." In transfer modes, the learner is set to a task the mastery of which presumably will facilitate the subsequent mastery of a new task. For example, listening to lectures, reading books, and practicing in simulators are all activities which must be performed at a specified level, with the expectation being that there will be positive transfer from these tasks to the ultimate task of flying an aircraft. A number of theoretical explanations exist which account for reasons why transfer takes place (see, for example, Clark, 1972), but, for all practical purposes, determining whether the learning of one task will facilitate or inhibit subsequent learning of any given second task usually requires empirical investigation.

The concept of "shaping" describes what is really a special case of the transfer mode of training, although it is usually not considered as such. Shaping is training by eliciting and reinforcing successive approximations to the desired performance until the final desired performance is achieved. By making the steps between successive tasks very small, by programming the introduction of new task elements to capitalize on skills already developed, and by careful attention to the nature, contingencies and schedules of reinforcement, complex skills can be developed quite efficiently. Shaping is a special case of transfer since each trial is specifically designed to maximize the transfer from all the preceding trials (Gagne and Rhower, 1969).

C. EXPLORATORY RESEARCH

A literature review, development of rationale for a transfer of training experiment using the predictor instrument, and exploratory research constituted elements of Phase I of the project. Section B presented findings from the literature search. The present section discusses rationale and exploratory research.

1. Objectives and Rationale

It was originally proposed that an experiment be conducted to investigate the effects of using the predictor display on learning to master an IFR final approach to landing task in which simulated instruments represented the conventional primary displays. The predictor display was to be used in an adaptive or "as needed" mode to allow operators opportunities to relate changes in instrument readings with predictions generated by the predictor display. The purpose was to determine whether availability of the predictor display would significantly reduce the time to learn to perform a final approach task accurately using only the conventional instruments.

In brief, the reasons for believing that an adaptive predictor display would be useful in facilitating learning of such a complex flight control task were:

- The predictor display greatly simplifies the effective dynamics of the pilot's control task and, hence, allows him to attend to other features of the overall task such as interpreting and integrating information from the conventional instruments.

- The adaptive feature can be used to force a reduction in the pilot's dependence on the predictor display as a function of his proficiency in accomplishing normal control with conventional instruments.

In programmed learning terms, the adaptive predictor would be a "prompt" which could be "faded" to bring the desired behavior under control of the designated stimuli generated by the conventional instruments.

To illustrate the rationale underlying the first reason noted above, i.e., that the predictor trace facilitates learning of the aircraft's dynamics, consider Figure 2. In Figure 2 (a) the predictor trace shows that, at time zero (or T_0), the pilot was climbing slightly prior to inputting a brief, forward control movement (dive). The predictor trace shows the pilot how the aircraft will respond to his input over a continuous period of time. The pilot can clearly <u>see</u> the aircraft's response lag and can correlate the kind and degree of control input with the aircraft's behavior.

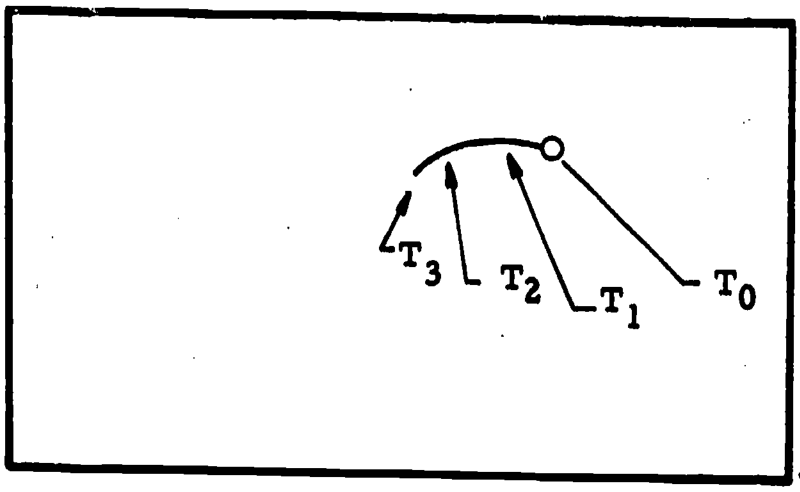
The same information is available with joint use of pitch and altitude indicators. However, these indicators are neither integrated, as is the case with the predictor trace, nor predictive of future states. At any given time, the pilot <u>cannot</u> see the aircraft's response lag or its future trajectory and he cannot easily correlate the kind and degree of control input with the aircraft's behavior. Obviously pilots <u>do</u> learn how their aircraft respond to control inputs. However, such learning occurs only after extensive, "brute force" training. We are suggesting, therefore, that learning the dynamics of any aircraft may be accelerated by use of a predictor display during training.

2. <u>Exploratory Research</u>

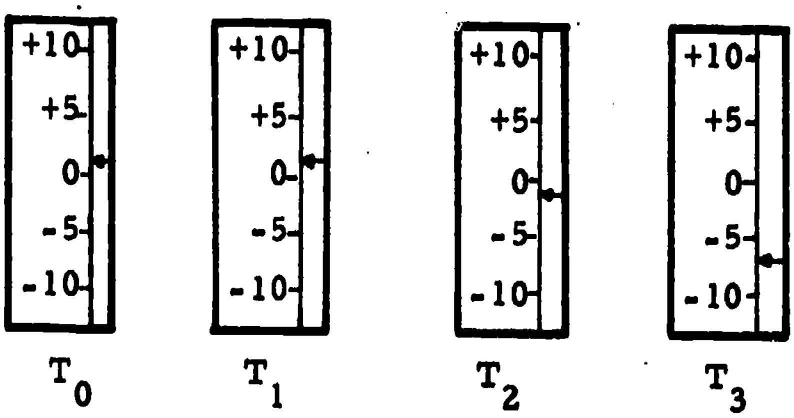
This section summarizes experimental research conducted during Phase I. A more detailed account is presented in Appendix A.

The research focused on determining transfer of training from a CRT side-looking display, having a predictor trace, to a set of conventional instruments. The instruments included altitude, pitch, glideslope, airspeed, percent power tachometer, and vertical velocity indicators. Control was accomplished with stick and power controls. The task was final approach to landing, as exemplified in the display shown in Figure 1. [illegible] aircraft simulated was a Cessna T-37.

Two groups of Subjects were used in the study. A Control Group of six Subjects learned to perform the final approach task without benefit



(a) CRT with Predictor trace



(b) Pitch indicator at four points in time

Figure 2. Modes of presenting pitch information and their effects on learning aircraft response to control movements.

of the predictor instrument, i.e., using only the conventional instruments. The predictor display was available, in an adaptive mode, to a Predictor Group of six Subjects during training trials but not during test trials in which both groups were tested on the conventional instruments. The adaptive feature involved the predictor appearing for five seconds, repetively, while the aircraft was out or about to go out of the tolerance envelope (five seconds into the future), as shown in Figure 1.

Performance measures were (1) percent of time within the $\pm 0.5^{\circ}$ glideslope envelope, and (2) percent of time within ± 6 knots airspeed tolerance about the 98 knot nominal airspeed. The criterion established for successful training performance on the task was three successive landings of 95 percent "within tolerance time" in terms of both glideslope and airspeed control.

Unfortunately, results of this exploratory research were apparently highly confounded. Differences in variability between the two groups were extremely large, criterion score distributions for both groups were bimodal, and it was found, after the study was completed, that the analog computer, which simulated the aircraft, had become intolerably unstable. Very importantly also, was the finding that the 5-second on/10-second off adaptive logic of the predictor instrument resulted in infrequent appearances of the predictor trace. In fact, its appearance was almost negligible, rendering the two experimental conditions more similar than different.

Despite the gross problems, most of the Predictor Subjects outperformed Control Subjects in terms of criterion scores and their variability was substantially lower. In addition, a great deal was learned that was applied to the full-scale experiment described in Sections II, III and IV.

D. RATIONALE FOR THE PHASE II EXPERIMENTAL DESIGN

In addition to specific problems encountered in our exploratory research, the study revealed that a full-scale experiment on the effects of the adaptive predictor instrument on transfer of training to conventional flight instruments was somewhat premature. In fact, such an experiment would be out of sequence with a systematic investigation of the predictor display's potential contribution toward facilitating learning. For example, the optimum adaptive logic for the final approach task, as well as for other related tasks, has yet to be determined empirically. The ON-OFF program selected for the exploratory study appears now to be inappropriate by virtue of its failure to provide a predictor trace of useful duration or frequency.

Similarly, the optimum prediction span for combination with an optimum adaptive logic also has not been determined empirically.

Since no adequate rationale existed for selecting appropriate adaptive logic or prediction span, it was believed that further arbitrary selection would be neither fruitful nor cost-effective. Thus, one major implication that emerged from our exploratory research was the requirement to optimize the predictor display parameters for our specific task. In particular, variations in adaptive logic and prediction spans needed to be evaluated.

Considerable time was allocated to mechanizing a fruitful simulation of T-37 aircraft dynamics and instrumenting simulated conventional controls and displays. Too little time and analog computer capacity were left to manipulate critical experimental variables effectively in a nine-month study.

All things considered, it was decided to run a 3 x 3 factorial experiment, having three levels of prediction span and three levels of adaptive logic. In addition, a tenth condition (control) was conceived for purposes of establishing baseline performance by which the nine experimental predictor conditions could be compared. All conditions were to include the side-looking CRT display (Figure 1) and exclude the conventional instruments. Given that one or more of the predictor instrument conditions substantially improved performance on transfer over the control condition, such a condition(s) would then be recommended as that condition to be used in a follow-on experiment employing conventional instruments.

Equipment was therefore modified to meet the requirements of the experiment described.

II. EXPERIMENTAL METHOD

A. EXPERIMENTAL DESIGN

The experimental design was a 3 x 3 factorial with a tenth (control) condition. Independent groups of five Subjects were randomly assigned to each of the 10 conditions.

Figure 3 shows examples of the display configurations for each of the nine experimental predictor conditions. The three rows of displays illustrate levels of prediction span, beginning with 5 second spans at the top, 10 second spans in the middle and ending with 20 second spans at the bottom.

The three columns reflect levels of adaptive logic. The left column illustrates that the predictor appears only when the aircraft symbol touches the tolerance envelope. The middle column shows that the trace appears when the aircraft symbol is predicted to touch the tolerance envelope 5 seconds into the future. Finally, the third column demonstrates that trace appearance occurs when the aircraft is predicted to touch the envelope 10 seconds into the future.

In all cases the predictor trace remained ON as long as the conditions specified above held true.

B. EQUIPMENT

Primary equipment for the study included a pilot's display/control station, an analog computer and a computer-calculator. The display/control station is shown in Figure 4. The main display was a side-looking, 16-inch diagonal CRT, mounted so that the center of the CRT was approximately at eye level. A glideslope of 4.3° and a ±0.5° envelope about it were drawn on the face of the CRT. The display was scaled to show a 6,666 foot or roughly 1-1/4 mile ground range, with an initial altitude of 500 feet at

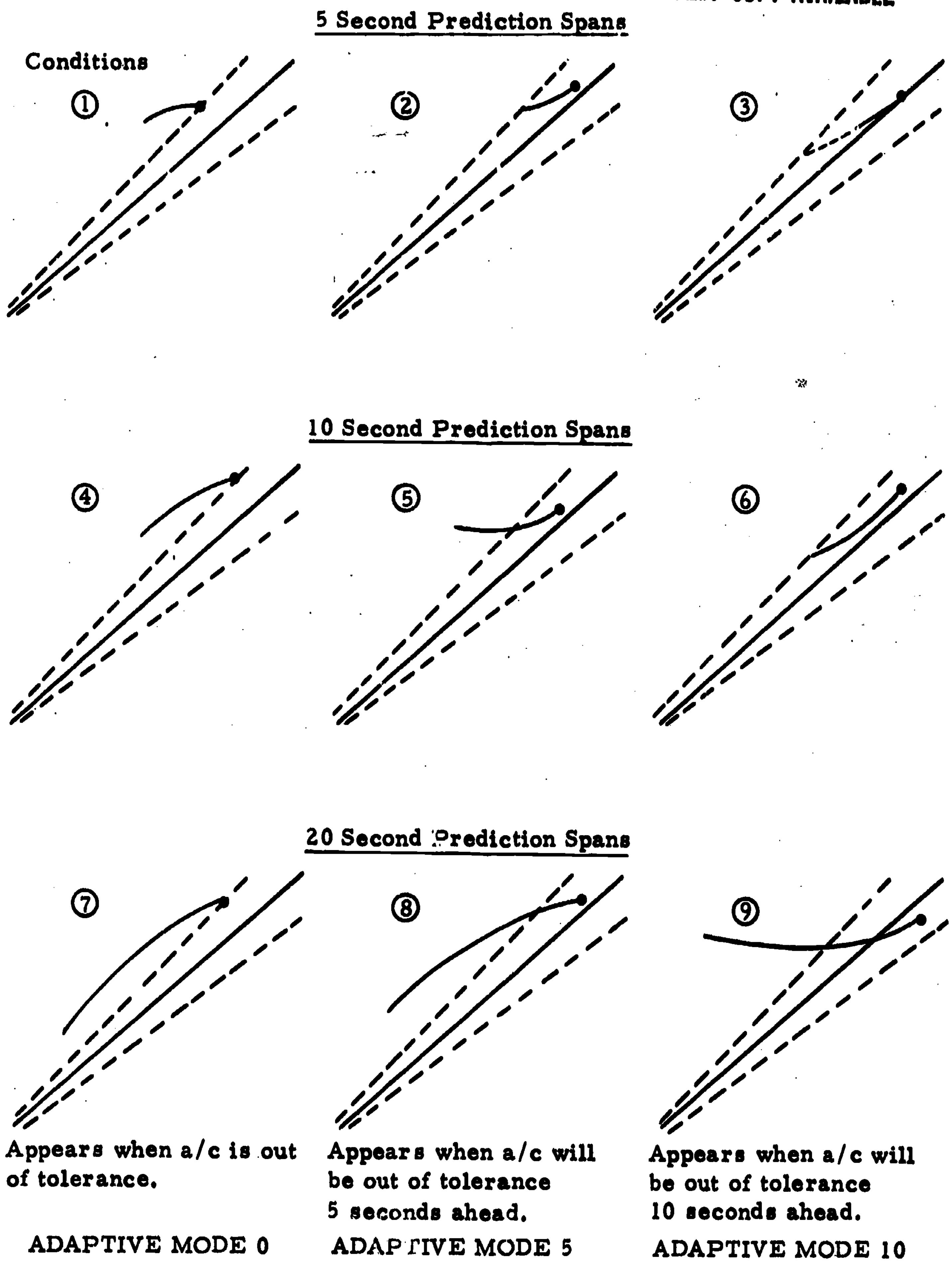


Figure 3. Predictor configurations for each of the nine experimental conditions.

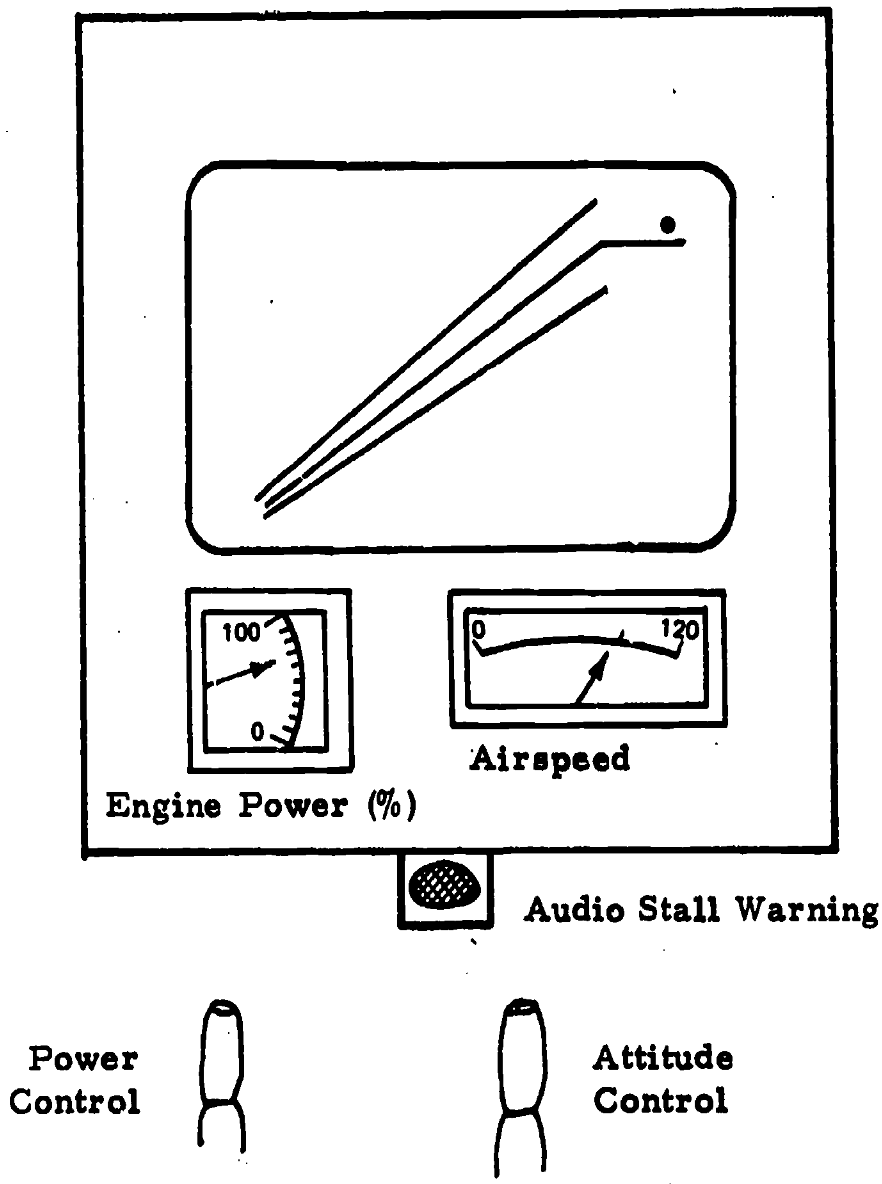


Figure 4. Operator's display/control station.

the upper right corner. Present aircraft position was represented on the CRT by an annular symbol.

Directly below the main CRT display were two indicators. A percent engine power indicator was located on the left and an airspeed indicator was positioned on the right. No other displays were employed.

Controls for the simulation consisted of a pedestal mounted joystick and a throttle mounted at elbow height. The joystick, adapted from an autopilot controller, was spring loaded, moderately self-centering, and traveled through an angular excursion of $\pm 20°$. The oil-damped throttle traveled through a total arc of 60°. Full-back position represented engine idle (50 percent RPM), while full-forward position constituted maximum power (100 percent). Normal trim power setting of 82 percent was achieved by a throttle position 8 to 10 degrees forward of vertical.

Generation of the predictor trace of future aircraft trajectory was accomplished by a fast-time, repetitively cycled analog model, based on a real-time T-37 aircraft model.[1] This model operated with a time scale 1000 times faster than the real-time model and was reset and operated 15 times per second. During each reset cycle, each integrator in the fast-time model sampled the output value of the corresponding integrator in the real-time model. The fast-time model operated under the assumption that the operator would hold whatever stick position he held at the start of any single prediction cycle for one second. Such an assumption is necessary for the generation of a usable prediction, but the selected value was somewhat arbitrarily, rather than empirically, based.[2]

[1] Equations used for the computer simulation may be found in Appendix B.

[2] Work currently underway in this Laboratory is systematically determining the effects on performance of different stick assumption values.

The model also operated under an identical assumption with respect to throttle control. If either of the controls were moved during a prediction cycle, the next cycle (occurring in 0.067 seconds) would display the effect of the control input changes. For all practical purposes, prediction changes were continuous in nature.

As indicated, the real and fast-time models of the T-37 aircraft were simulated by a special purpose G.A. Philbrick analog computer, the second major equipment used in the study. The third piece of equipment was an Olivetti Programma P102 computer/calculator whose function was to program the analog computer and print-out prescribed operator performance data on tape.

C. SUBJECTS

Subjects used in this study were Air Force and Navy ROTC students from the Universities of Loyola and California, Los Angeles. They were paid $10 for participating in the study. Their ages ranged from 18 to 24. All had little or no flying experience but met Air Force and Navy qualifications for flight training. The Subjects were distributed randomly across experimental conditions with the single constraint that each condition contained the same balance of flying experience.

D. PROCEDURES

Subjects participated in two experimental sessions of approximately one-hour duration each. The sessions occurred either on successive days or with no more than one day of separation.

Prior to performing the task, Subjects were given instructions which described the task and display-control equipment in detail (Appendix C). Any questions were answered. Two practice runs on the simulator, one with and without the predictor instrument, were given. If the task was not fully understood at that point, additional clarification was made until the Subject was completely satisfied.

Each test session consisted of sets of six runs on the simulator, followed by one-minute rest periods. At the end of the first half of a test session, Subjects were permitted a five-minute break.

With the exception of the control group, Subjects were given the following sequence of runs within a set of six:

Run 1: Training (with predictor instrument)
Run 2: Test (without predictor instrument)
Run 3: Training (with predictor instrument)
Run 4: Test (without predictor instrument)
Run 5: Training (with predictor instrument)
Run 6: Test (without predictor instrument)

Thus, odd and even runs were training and test trials, respectively, throughout a test session.

The task given to Subjects was essentially the same as that performed by a pilot, where the aircraft is flown by an autopilot in all axes except the longitudinal. In this situation the pilot's functions are to maintain airspeed within limits with the power control (loading task) and to track the glideslope with the attitude control (primary task).

The computer simulation for each trial was initiated with the aircraft symbol in level flight. After approximately eight seconds, the symbol reached a point where descent was required and, subsequently, a power change was necessary. The glideslope/airspeed tracking task continued until the aircraft symbol was at an altitude of approximately one foot (a simulator hardware limitation).

The simulator included an audio stall warning device which activated when airspeed decreased to within five knots of stall speed. The actuation of the device warned the Subject (and experimenter) that task sharing was not occurring to the desired extent.

It should be noted that performance measurements continued whether the aircraft stalled or not. On some occasions, in fact, the aircraft did stall and probably would have been lost were the situation real but continuance of the run maintained consistency in the performance measures.

The tracking task continued until the aircraft "touched down" on the "runway," at which time the trial was terminated. Subsequently, the symbol disappeared and the equipment was reset for the next trial. Time for one trial was approximately 60 seconds.

At the beginning and end of test sessions plots of simulator flight tracks were made with an x-y recorder using pre-set throttle and control inputs. Such calibration runs were all observed to be without non-linear anomalies.

E. PERFORMANCE MEASURES AND STATISTICAL ANALYSES

The primary measure of performance was integrated altitude error, i.e., altitude deviations about the ideal, 4.3° glideslope. A secondary measure was integrated airspeed error.

Two independent analyses of the data were performed. Of main interest was the analysis of the test trials which provided an indication of transfer effects. The second analysis was concerned with the training trials which permitted evaluation of the effects on performance of different design configurations of the predictor instrument.

Transfer effects were determined through use of the data from the second experimental session only, since nearly all conditions were at or near asymptotic levels at the start of that session. Had asymptotes not been reached until the last half of the second session, for example, analysis would then have been performed on the data from the last half session.

For both test and training trials three analyses of variance were conducted. Two evaluated the independent effects of prediction span and adaptive mode variables. The third analysis included all ten conditions. Duncan's range test was selected to determine the significance of differences between all conditions in both analyses of variance tests.

III. RESULTS

A. TEST TRIALS

1. General Learning Performance

Figure 5 shows altitude error learning curves of the 10 experimental conditions on test trials. Each point on a given curve represents the mean of 12 trials X five Subjects or 60 data points. With the exception of Condition 1, all curves appear to have asymptoted on the last 24 trials.

A striking feature of these learning curves is the fact that error scores for the Control condition and Conditions 2 and 4 were approximately 50 percent higher than those of Conditions 3, 8 and 9 for the last 24 trials -- and that such differences appear to have stabilized. The implication here is that use of certain predictor instrument configurations during training can effect a more rapid and, very importantly, permanent increase in performance on a simulated approach to landing task than can be accomplished without it. Such an implication is probably only partially correct, as will be discussed in Section IV of this report.

In general, with the exception of Condition 2, all experimental conditions appeared to be superior to the Control condition. Moreover, most of the experimental conditions showed sharp declines in error scores during the first 24 trials. Condition 9 demonstrated by far the highest level of performance at the start.

2. Transfer Effects

Two one-way analyses of variance were performed on the test trial data (altitude and airspeed error) to derive error terms for use in Duncan's multiple comparison test (Edwards, 1960). The Duncan test was subsequently used to determine the significance of differences between all combinations of the ten conditions.

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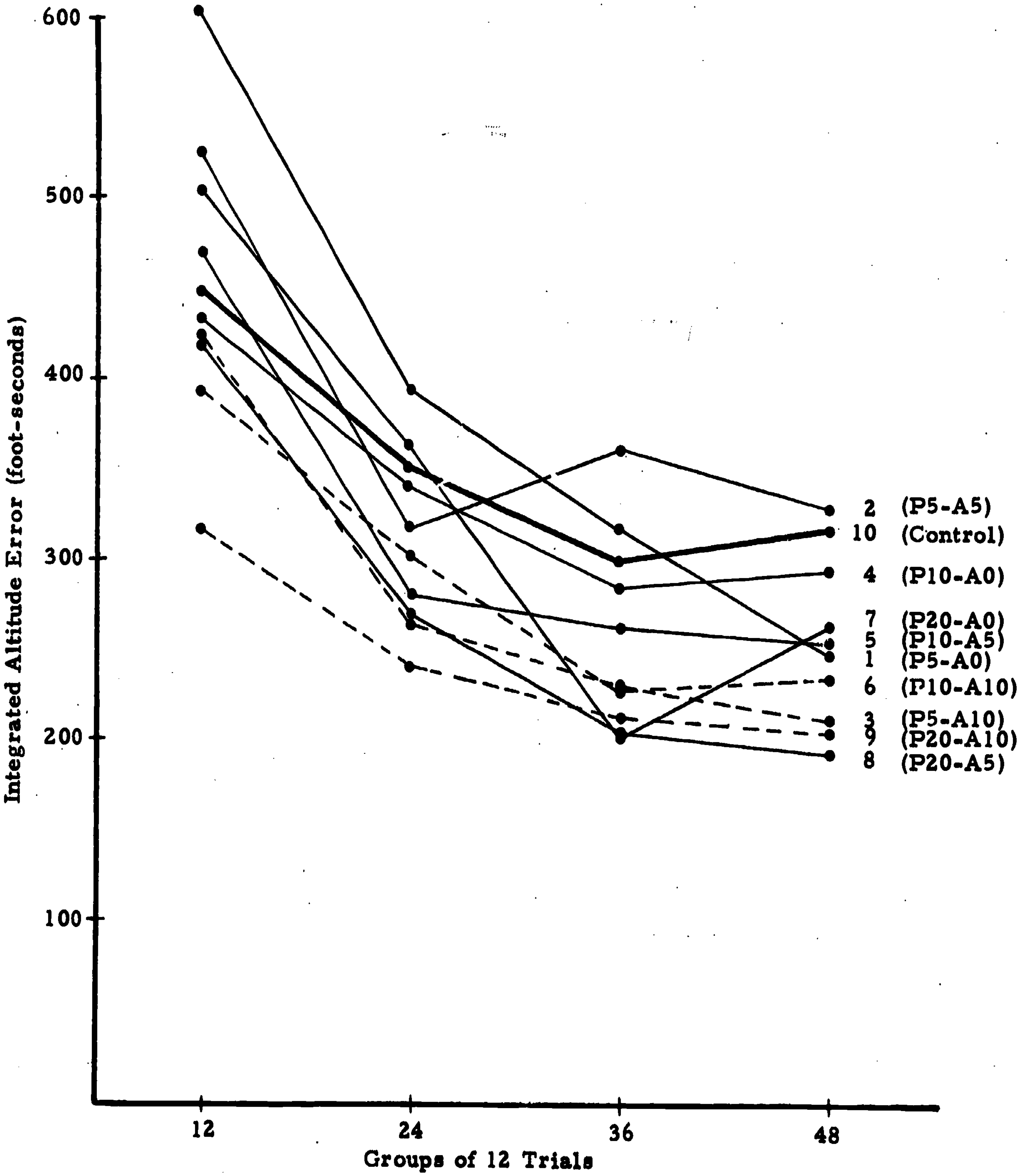

Figure 5. Mean altitude error as a function of experimental condition: test trials. Symbols within the parentheses refer to the level of prediction span (P) and adaptive mode (A).

a. Altitude Error

Figure 6 shows the mean integrated altitude error (in foot-seconds) for each of the 10 conditions on the last 24 trials. A summary of the ANOVA for altitude error is presented in Table 1. As can be seen, the main effects (conditions) was significant beyond the .01 level.

Results of the Duncan's range test are shown in Table 2. All experimental conditions except Conditions 1, 2 and 4 were significantly superior to the Control condition. Moreover, Conditions 3, 6, 7, 8 and 9 were significantly better than Conditions 1, 2, 4 and 10, with Conditions 8 and 9 also superior to Condition 5.

In considering the independent effects on performance of prediction span and adaptive mode, Figure 7 shows each variable when averaged over the other variable. For the variable of prediction span, an ANOVA yielded an F ratio of 20.71, significant beyond the .01 level. A Duncan's range test revealed that performance on each of the three prediction spans was significantly different ($p < .05$) from the others. Thus, performance improved significantly on test (transfer) trials as prediction span increased from 5 seconds to 10 seconds to 20 seconds on training trials.

With regard to adaptive mode (Figure 7b), an ANOVA yielded an F ratio of 11.56 which was again significant beyond the .01 level. A Duncan's range test indicated that the 10 second adaptive mode was significantly better than the 0 and 5 second modes ($p < .01$), but that modes 0 and 5 seconds were not significantly different from each other, as is clearly implied in the figure. These results indicate, therefore, that the sooner the predictor instrument appeared on the operator's display during training trials -- predicting an out-of-tolerance condition -- the better the performance on test trials.

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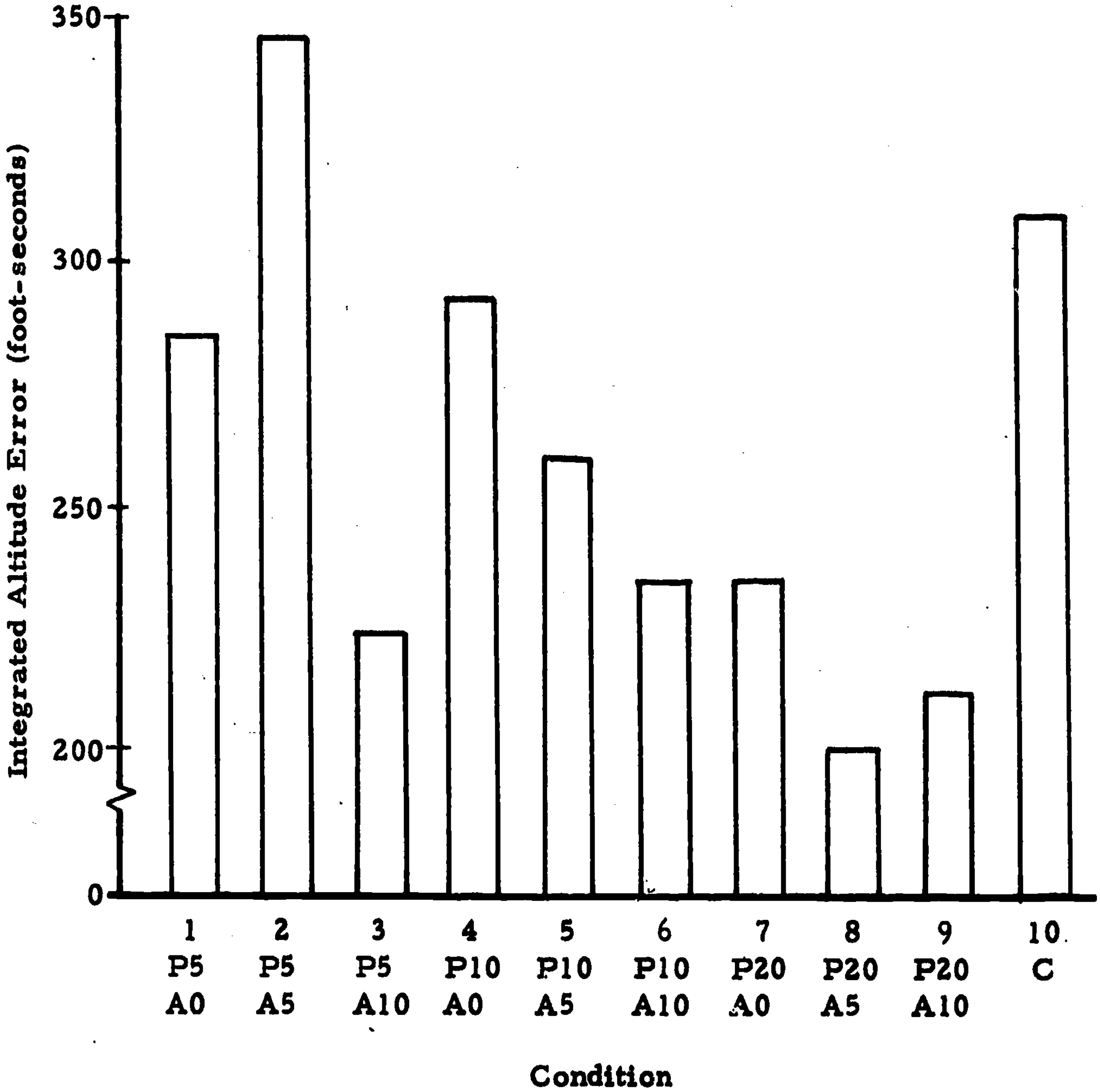

Figure 6. Mean integrated altitude error as a function of experimental condition (test trials).

Table 1

Analysis of Variance of Altitude Error Scores

Source	df	SS	MS	F	P
Between Conditions	9	2,401,038.69	266,782.07	11.96	.01
Within	1190	26,535,850.60	22,299.03		
Total	1199	28,936,889.29			

An analysis of variability revealed that standard deviations of the means of all conditions were almost identically proportional to the means (Figure 8). Figure 8 is essentially the same as Figure 6 except that the standard deviations are much smaller than the means. In fact, they are surprisingly small for the relatively complex task employed in this study (note the percent size figures within the bar graph). For the most outstanding conditions, 3, 8 and 9, standard deviations were only slightly greater than one-third the size of their respective means.

As prediction span increased from 5 to 10 to 20 seconds, standard deviations decreased from 149.72 to 146.60 to 111.18, respectively. Similarly, standard deviations were smaller, the longer the adaptive mode, i.e., 162.58, 151.93 and 92.99 for modes 0, 5 and 10 seconds, respectively.

b. Airspeed Error

Figure 9 presents the mean integrated airspeed error (in Knot seconds) for each of the 10 conditions on the last 24 trials. A summary of the ANOVA for airspeed error is given in Table 3. Significance of the main effects was again beyond the .01 level.

Table 2

Results of Duncan's Range Test
(Altitude Error)

	Condition	1	2	3	4	5	6	7	8	9	10
1	P5-A0		*								
2	P5-A5										
3	P5-A10	*	*		*						*
4	P10-A0		*								
5	P10-A5		*								*
6	P10-A10	*	*		*						*
7	P20-A0	*	*		*						*
8	P20-A5	*	*		*	*					*
9	P20-A10	*	*		*	*					*
10	Control										

NOTE: Conditions in rows at left demonstrated a significantly lower altitude error ($p < .05$) than conditions in columns at top if an asterisk appears at the junction of row and column. For example, Condition 3 was significantly superior to Conditions 1, 2, 4 and 10.

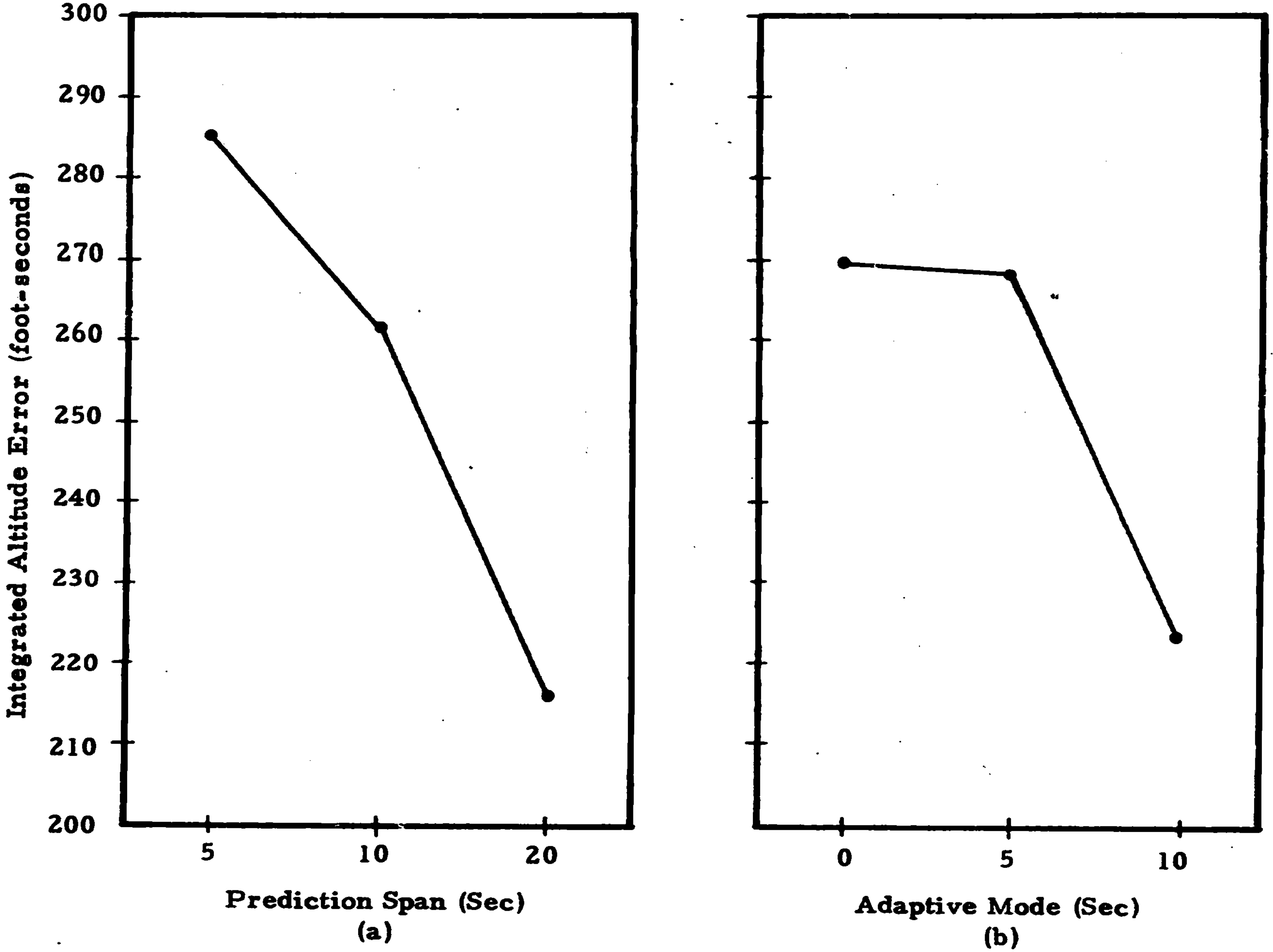

Figure 7. Mean altitude error as a function of (a) prediction span and (b) adaptive mode (test trials).

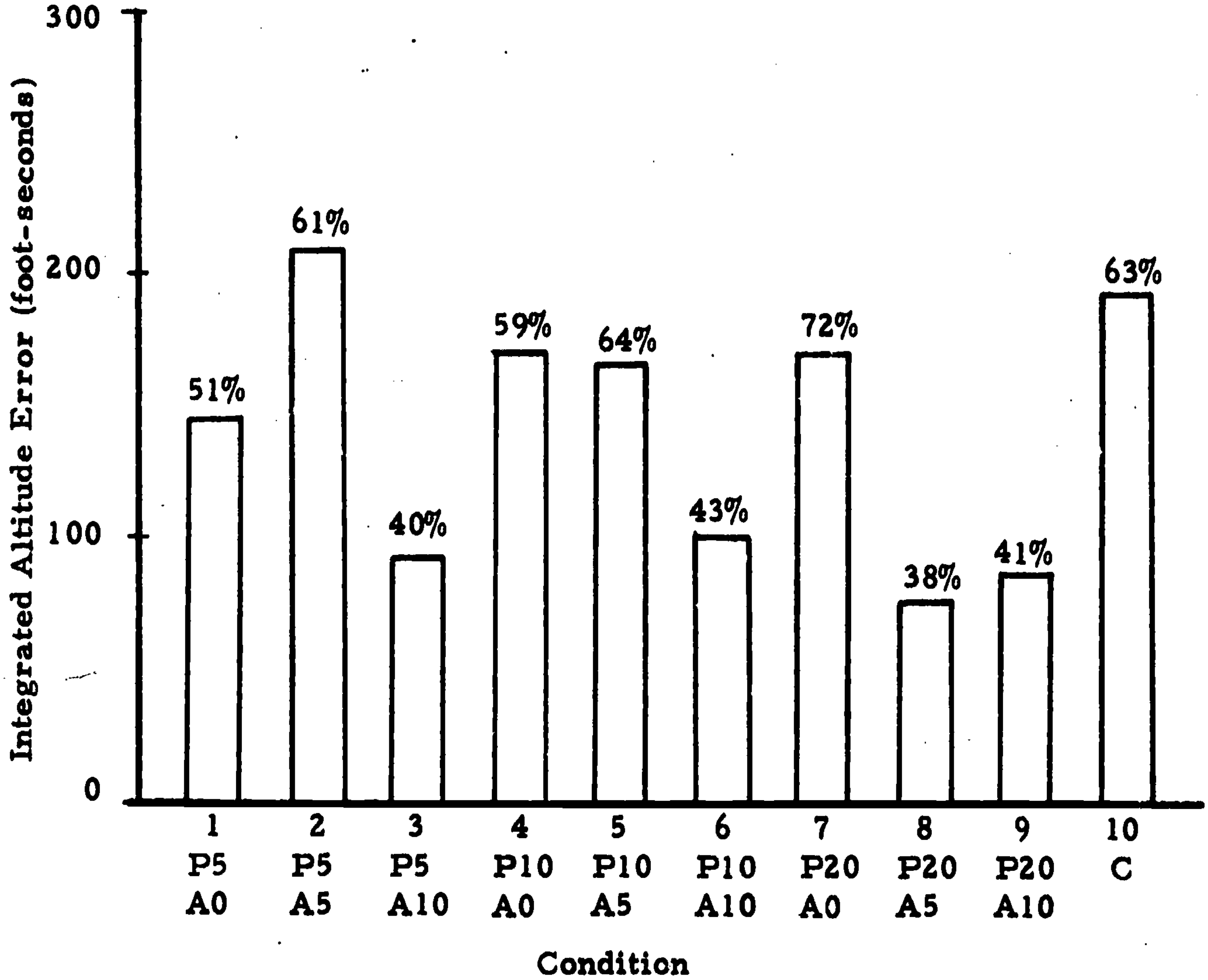

Figure 8. Standard deviations of the mean altitude error scores of Figure 6. The percent figures above the conditions indicate the size of the standard deviations relative to the associated means.

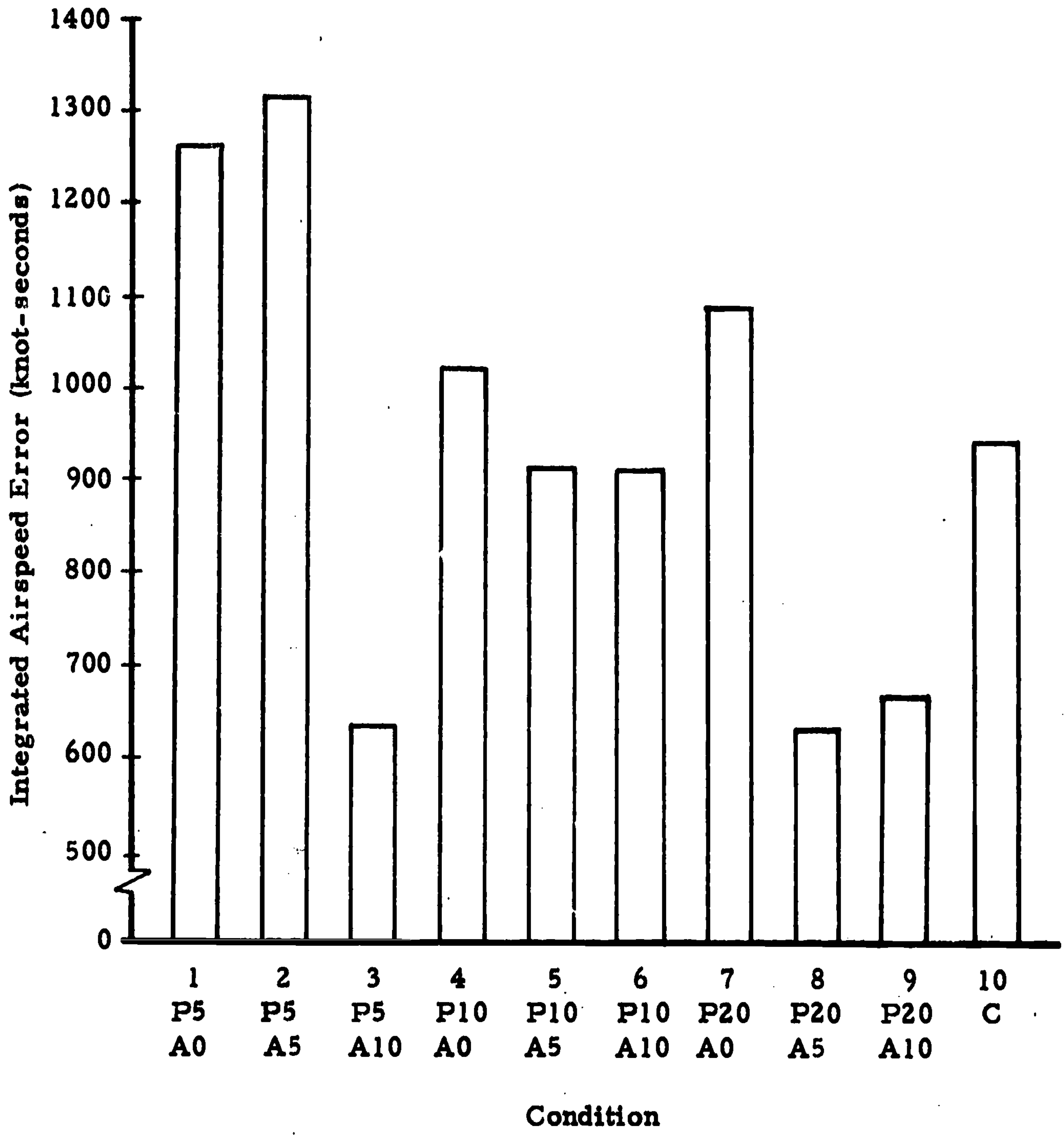

Figure 9. Mean integrated airspeed error as a function of experimental condition (test trials).

Table 3

Analysis of Variance of Airspeed Error Scores

Source	df	SS	MS	F	P
Between Conditions	9	65,661,626.83	7,295,736.31	18.48	.01
Within	1190	469,729,264.21	394,730.47		
Total	1199	535,390,891.04			

Results of the Duncan's range test are given in Table 4. Conditions 3, 8 and 9 demonstrated the lowest airspeed errors, being significantly lower than all other conditions, but not significantly different from each other. Conditions 1, 2, 4 and 10 (control) generated the highest airspeed errors, with the control condition being significantly superior to Conditions 1 and 2.

Figure 10 shows the effects of prediction span and adaptive mode independently. For the variable of prediction span, an ANOVA yielded an F ratio of 11.61, which was significant beyond the .01 level. A Duncan's range test indicated that performance on each of the three prediction spans was significantly different ($p < .05$) from the others.

Statistical tests showed essentially the same results for adaptive mode as they did for prediction span. The ANOVA yielded an F ratio of 13.47 ($p < .01$), while a Duncan's test showed that each of the adaptive modes was significantly different ($p < .05$) from the others.

Variability of the distributions of airspeed scores is shown in Figure 11. As with altitude error scores, the correspondence between Figures 9 and 11, in terms of the relative differences between conditions, is quite high. Again, standard deviations were smaller than their respective means, although not as small proportionally as was the case for

Table 4

. Results of Duncan's Range Test
(Airspeed Error)

Condition		1	2	3	4	5	6	7	8	9	10
1	P5-A0										
2	P5-A5										
3	P5-A10	*	*		*	*	*	*			*
4	P10-A0	*	*								
5	P10-A5	*	*					*			
6	P10-A10	*	*					*			
7	P20-A0	*	*								
8	P20-A5	*	*		*	*	*	*			*
9	P20-A10	*	*		*	*	*	*			*
10	Control	*	*								

NOTE: Conditions in rows at left demonstrated a significantly smaller airspeed error ($p < .05$) than conditions in columns at top if an asterisk appears at the junction of row and column.

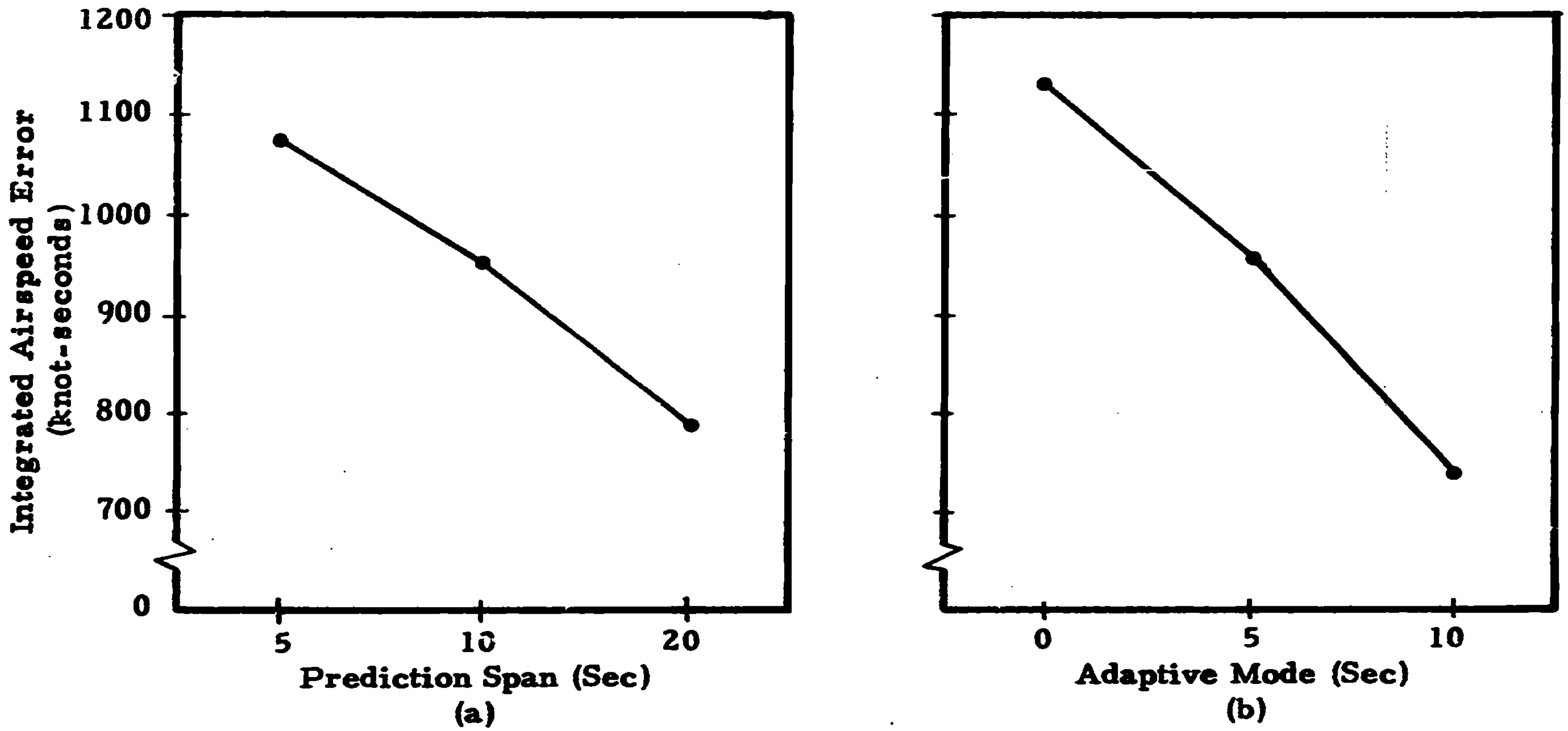

Figure 10. Mean airspeed error as a function (a) prediction span and (b) adaptive mode (test trials).

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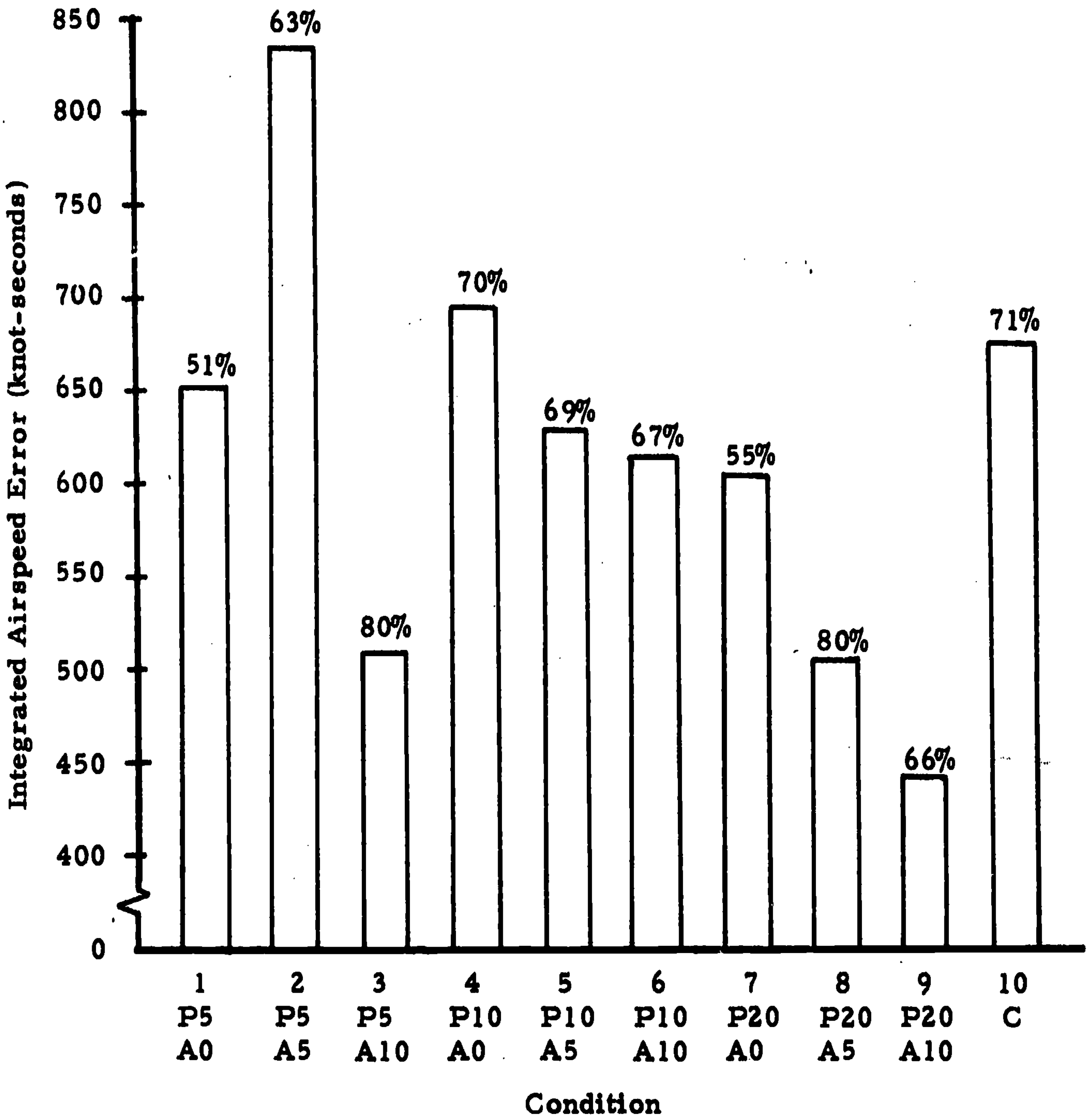

Figure 11. **Standard deviations of the mean airspeed error scores of Figure 9. The percent figures above the conditions indicate the size of the standard deviations relative to the associated means.**

altitude error scores. Also, the standard deviations decreased in size as prediction span and adaptive mode increased, i.e., 665.65, 654.37 and 517.57 for spans 5, 10 and 20 seconds, respectively, and 658.88, 656.69 and 522.02 for adaptive modes 0, 5 and 10 seconds, respectively.

Thus, the results of airspeed error are similar to those of altitude error, i.e., as prediction span increased and as the predictor instrument appeared sooner during training trials, the better the performance *on test* trials.

c. Comparing Altitude and Airspeed Error Results

Conditions 1 through 10 were ranked from best to worst on both altitude and airspeed error and a rank-correlation coefficient (Dixon & Massey, 1957) was computed to determine consistency of the two performance measures. A coefficient of .794 was obtained, indicating a relatively high degree of correspondence between altitude and airspeed error. Contributing most (47 percent) to the failure of achieving a perfect correlation was Condition 7 which was ranked fourth on altitude error and eighth on airspeed error.

If we compute the average rank for each condition (which assumes altitude and airspeed error to be of equal importance), the best to worst condition is as follows:

Conditions 8-9, 3-6-5-7-4, 10-1-2

where two numbers separated by a comma indicate rank ties. However, this analysis is presented for descriptive purposes only and should not be construed as a valid measure of overall performance. Rank order merely indicates relative order and not the absolute error generated on each measure. Moreover, altitude error is probably much more important than airspeed error for most landing circumstances.

B. TRAINING TRIALS

Analysis of performance on training trials was limited to the last 24 trials. Descriptive, rather than statistical analyses were performed because the latter would not appear to have particular meaning within the context of this study.

1. Altitude Error

Figure 12 shows the mean integrated altitude *error scores* for each of the 10 conditions on training trials. Test trial means are shown as dotted lines for comparison. With the exceptions of Conditions 4 and 5, training performance on the conditions was much the same as observed for test trials. Such an outcome was more or less expected in view of the fact that asymptotes had been reached by the end of the 24th trial and the fact that the predictor display was, during the last 24 trials, off more than on.

With regard to the exceptional Conditions, 4 and 5, no readily available explanation would appear to account for the finding that one of these conditions generated superior scores during training while the other revealed better performance during test trials. Similar reversals can be seen in Figure 12 for the other conditions, but the magnitude of the differences suggests no more than common random error. In general, then, performance scores on the training trails for most of the conditions were, as expected, similar to those observed for test trials.

Figure 13 shows mean performance scores for each of the variables, averaged over the other. Again, little difference can be observed between training and test trials for the three levels of prediction span. Larger discrepancies occurred for the 0 and 5 second adaptive modes. However, these differences are directly due to Conditions 4 and 5, noted above, and easily seen in Figure 12.

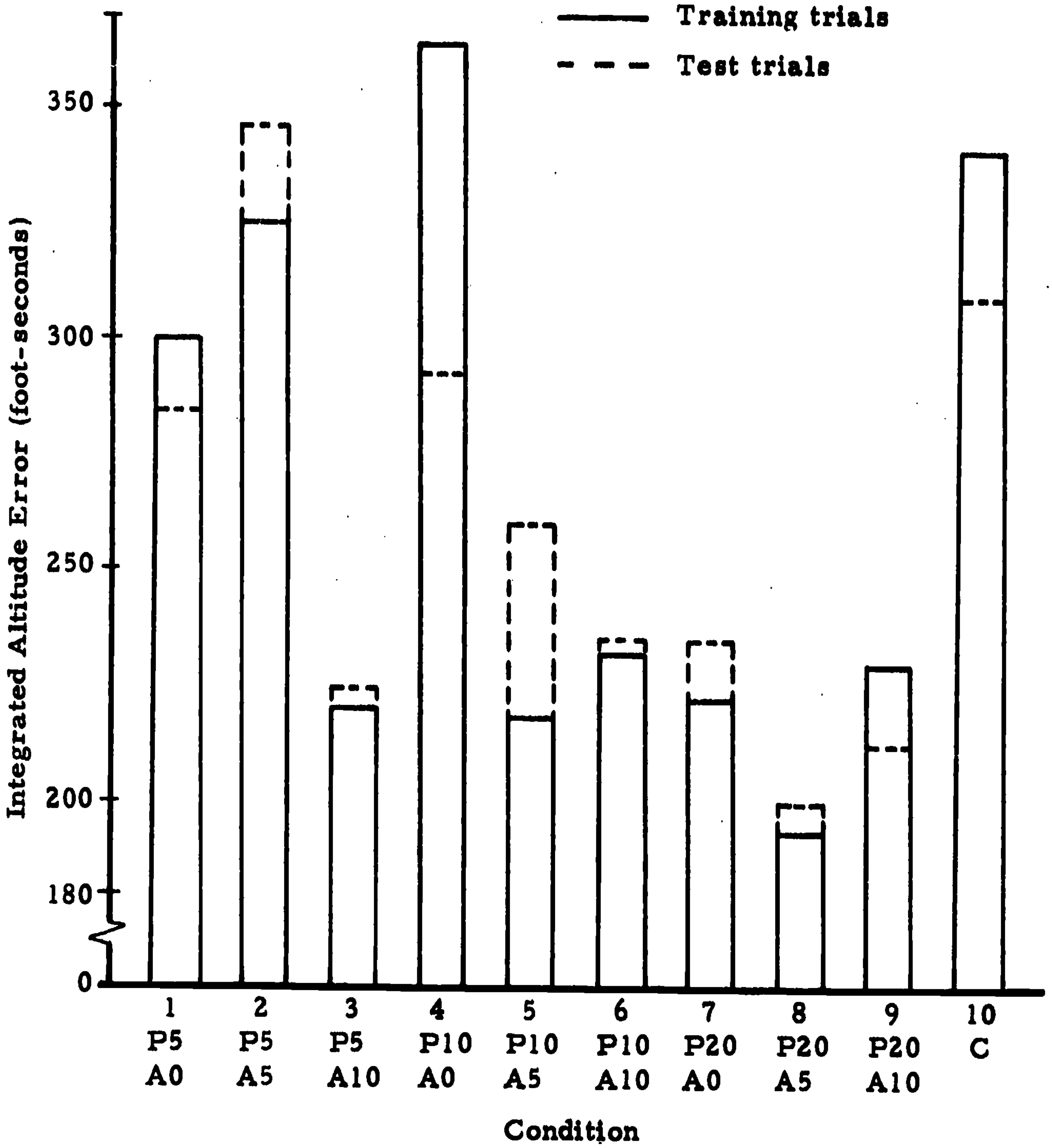

Figure 12. Mean integrated altitude error as a function of experimental condition (training trials).

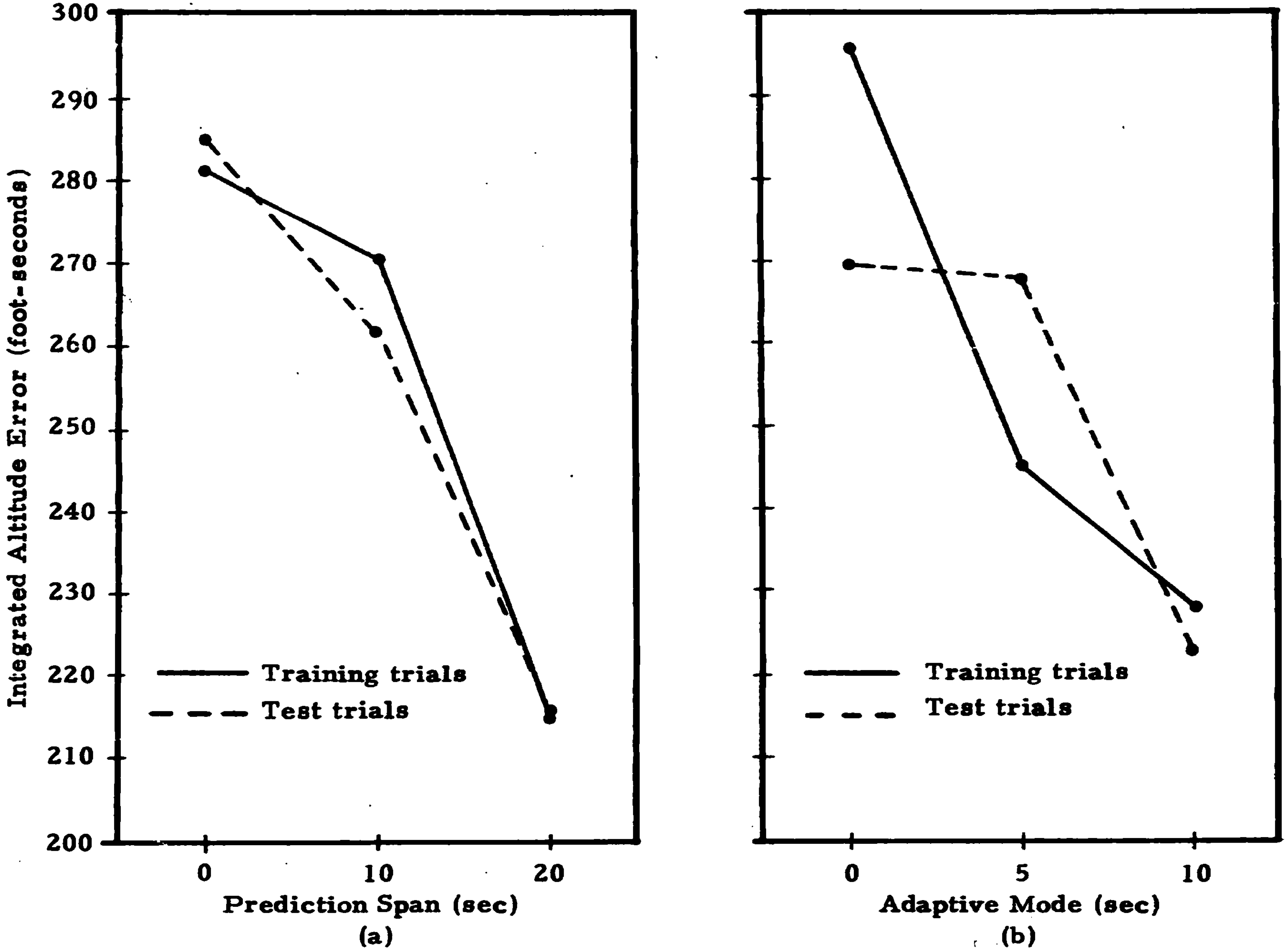

Figure 13. Mean altitude error as a function of (a) prediction span and (b) adaptive mode (training trials).

A further examination of the data related to individual differences on training and test trials. While mean altitude scores were, for all practical purposes, similar for both training and test trials, standard deviations were not. Figure 14 shows that standard deviations for Conditions 1, 2, 4 and 10 (recall that these conditions demonstrated the poorest performance, e.g., see Figure 6) were extremely large, relative to those for the test trials. On the other hand, differences between training and test trials for the most outstanding conditions (3, 8 and 9) were relatively negligible.

A cursory examination of Figure 12 suggests that the magnitude of standard deviations was strongly related to adaptive mode. Computing the standard deviations for each mode, averaged over all prediction spans, yielded mean standard deviations of 335.8, 180.9 and 90.8 for adaptive modes 0, 5 and 10 seconds, respectively. Thus, the deviation essentially doubled in size from 10 to 5 and again from 5 to 0 seconds.

Differences between prediction spans were, by contrast, much smaller. Mean standard deviations for the 5, 10 and 20 second spans were 270.1, 228.9, and 108.7, respectively.

Analysis of standard deviations thus suggests that the earlier the appearance of the predictor and the longer the prediction span, the smaller the individual differences.

2. Airspeed Error

Figure 15 shows the mean integrated airspeed error scores for each of the 10 conditions on the last 24 training trials. Test trial means are also shown as dotted lines for comparison. Differences between training and test trials were even smaller than was the case for altitude error scores. For practical purposes, in fact, differences were negligible and due to random sampling fluctuations.

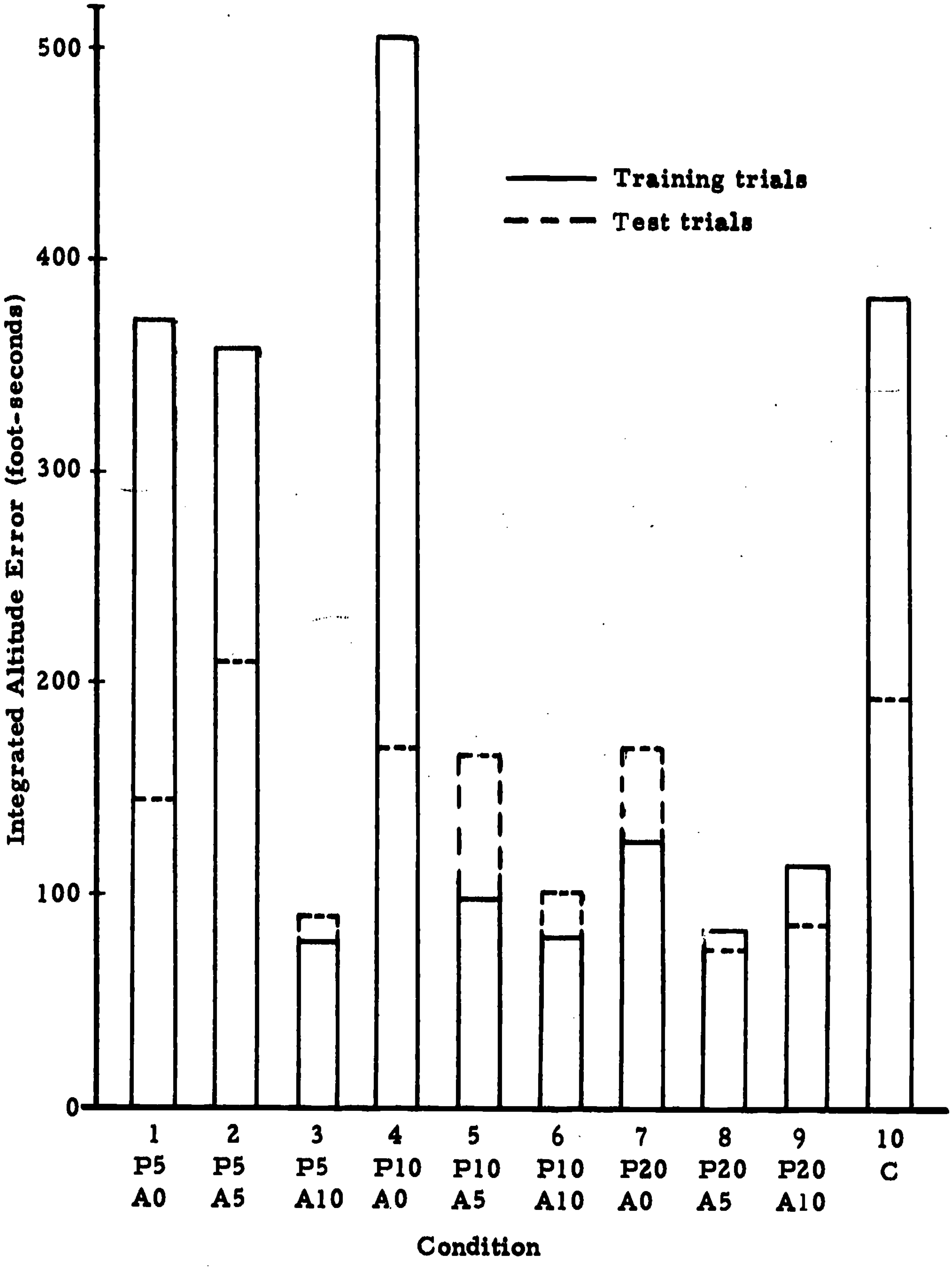

Figure 14. Standard deviations of the mean altitude error scores of Figure 10.

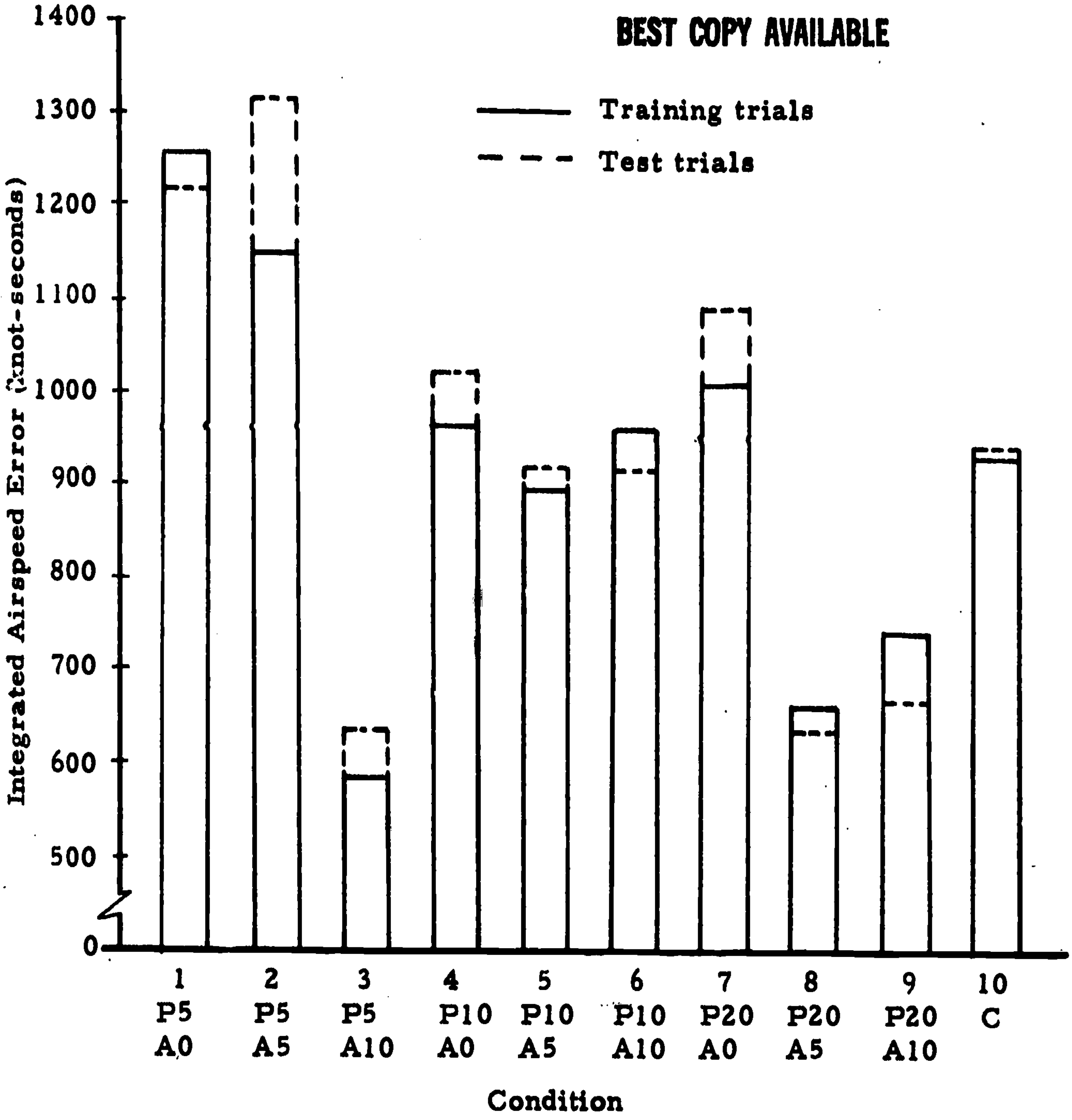

Figure 15. Mean integrated airspeed error as a function of experimental condition (training trials).

Figure 16 presents mean error scores for each of the variables, averaged over the other. As can be seen, curves for training and test trials were essentially identical.

Examination of individual differences revealed that Conditions 2, 5, 6 and 7 exhibited somewhat larger standard deviations on test trials than on training trials (Figure 17). All other conditions showed similar standard deviations. In general, the tendency for test trials to have larger *standard deviations* than training trials is the reverse of that observed for altitude error. However, such tendencies were not representative of the majority of conditions, nor were they systematically associated with the same conditions.

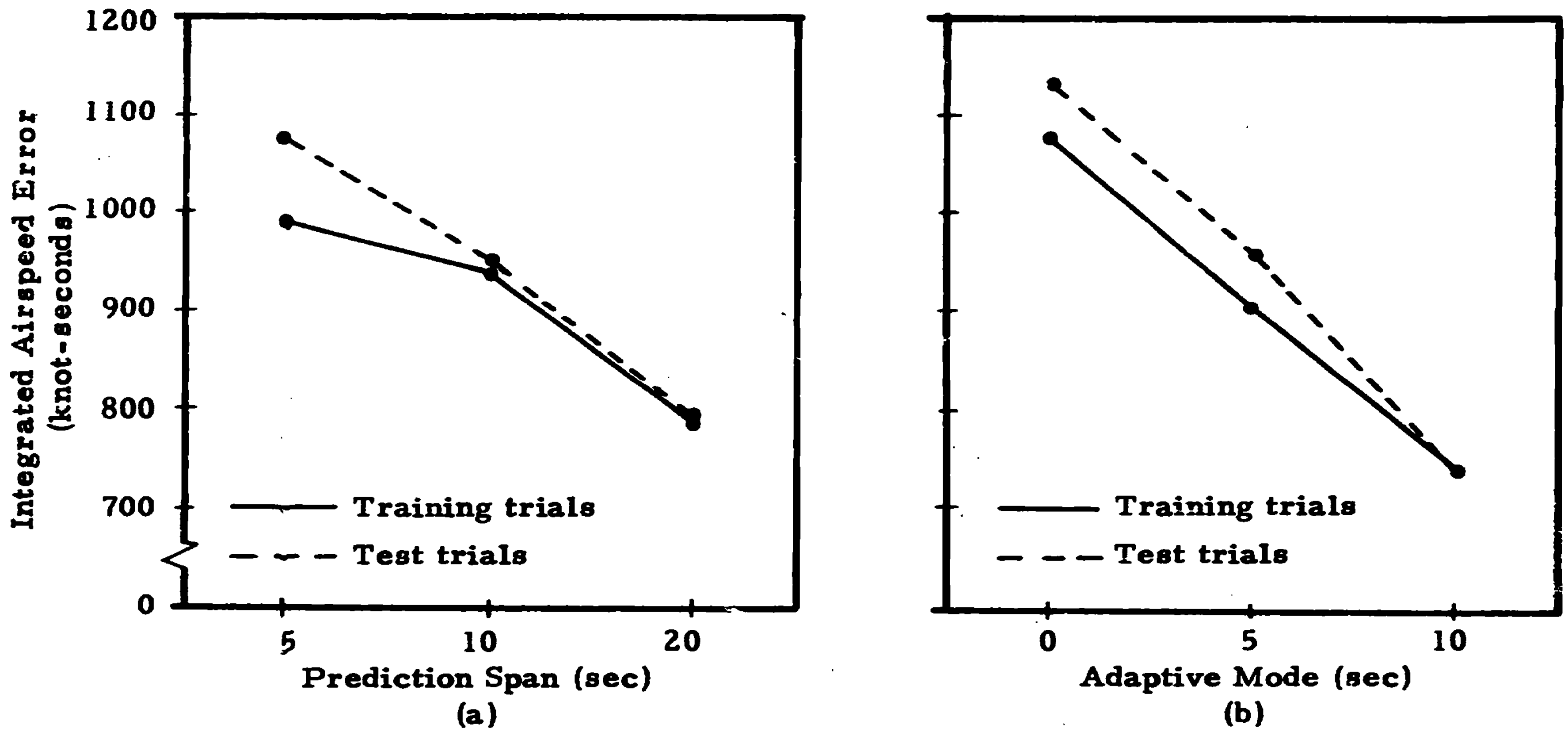

Figure 16. Mean integrated airspeed error as a function of (a) prediction span and (b) adaptive mode (training trials).

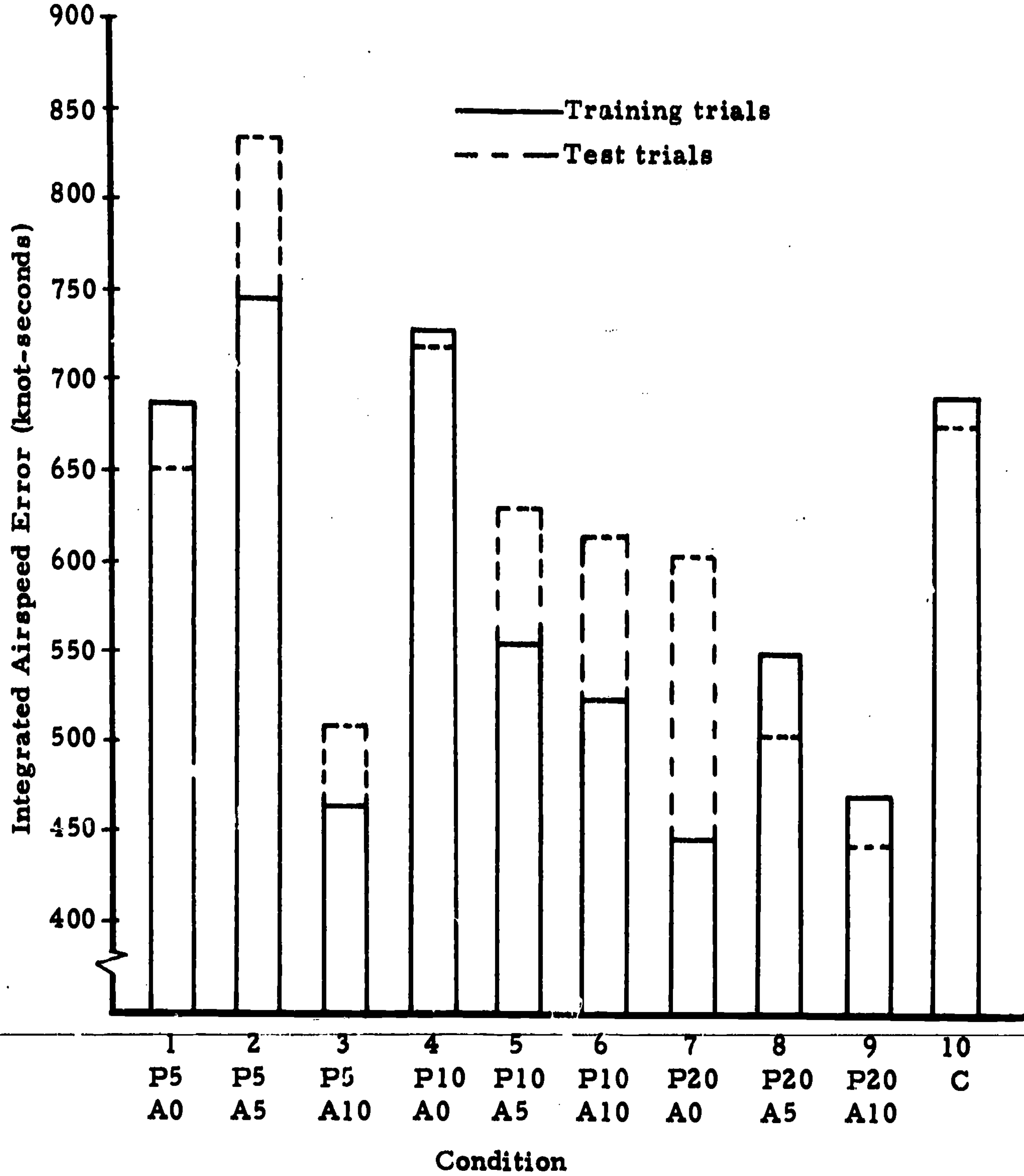

Figure 17. Standard deviations of the mean airspeed error scores of Figure 13.

IV. DISCUSSION AND RECOMMENDATIONS

A. GENERAL

The primary objective of the present study was to explore the predictor instrument's utility as a training aid in a relatively complex, manual control task. Various predictor display configurations were systematically evaluated for purposes of determining optimum designs for a specific training application. The results of the study were quite promising, although more research is needed, especially in view of the fact that the present study appears to be the first of its kind.

While previous experimentation has demonstrated unequivocally the utility of the predictor instrument as a manual control aid, the instrument has not been systematically evaluated with respect to training applications or specific design variables in training applications. Thus, this study initiated the first steps toward such an evaluation by employing nine configurations, representing three levels each of two variables, prediction span and adaptive mode.

Conservative attitudes usually prevail in drawing conclusions from experimental results, often to protect against the possibility of contradictory future research. However, conventional conservativism is sometimes set aside in light of somewhat dramatic and far-reaching findings. At the forefront of our results was the finding that certain predictor display configurations facilitated learning to such an extent that mean performance on transfer (test) trials was considerably higher than that of a control condition in which the predictor display was never used. And, it can be seen in Figure 5 that the performance curves of the control and several predictor display conditions appear to have reached asymptotes, implying that the effect of the predictor on transfer is a permanent one.

Of course, the apparent stability of the differences shown in Figure 5 may not be permanent and, in fact, would not be expected to be permanent, given increased training. Certainly, operators would continue to improve over prolonged periods, as is the case with pilots, for example. But such an expectation and likelihood is clearly consistent with our hypothesis that the predictor instrument would accelerate learning. Thus, whether the asymptotes in Figure 5 are real or apparent, the conclusion is the same, namely, that the predictor display accelerated training substantially. Only the absolute magnitude of the facilitation gain remains undetermined, but it appears that perhaps two to three times the number of trials employed in this study might be necessary before all conditions would approach one another.

The use of ground training simulators for pilots has become widespread because of the almost prohibitive costs involved in extensive airborne training. This fact notwithstanding, the costs of purchasing, operating and maintaining costly, complex ground simulators are by no means insignificant. On the contrary, they are substantial. The results of the present study suggest that training time, along with operational and maintenance costs, might be reduced by as much as 25 to 50 percent through use of an optimally configured predictor instrument. Moreover, this suggestion is not limited to pilot-aircraft systems, for a variety of systems contain similar complex and interrelated manual tasks that require lengthy periods of human operator training.

B. SPECIFIC FINDINGS

1. Experimental Predictor Displays

As implied in the paragraphs above, not all predictor displays led to higher performance than the control condition. In general, conditions having the shortest prediction spans and adaptive modes exhibited somewhat poorer performance than the control condition, while the opposite configurations showed superior performance. This finding was not expected, nor does it lend itself to easy explanation, for it was believed that even a small amount of prediction information would have a positive effect on performance.

Perhaps a meaningful explanation for the differential results at this time is related to the concept of "facilitation-interference." Almost any secondary task that is imposed on an operator simultaneously with a primary task may have some degree of interference with the latter. In the present case, periodically observing the predictor trace at the expense of continuously monitoring the aircraft symbol clearly might have been a conflicting and somewhat incompatible secondary task during training trials. In view of the fact that the shortest prediction spans and adaptive modes provided very little prediction information, it is quite possible that whatever utility they may have provided an operator may have been completely transcended by their interference with the primary task. Hence, learning was slower than the control condition which was not confronted with the predictor's interference.

By similar reasoning, it can be held that the longer prediction spans and adaptive modes provided operators with so much valuable information that their interference with the primary task was insignificant by contrast.

2. Prediction Span

Prediction spans of 5, 10 and 20 seconds were used in this study. For both altitude and airspeed error measures, when averaged over adaptive modes, performance was significantly better the longer the spans used during training trials. In the present investigation, therefore, the further into the future the display predicts the projected position of the aircraft, the more information an operator has available to help him determine and understand the specific response characteristics of his vehicle.

Slopes of the performance curves (Figures 7 and 10) indicate that the optimum prediction span for the task and display used in this study was not achieved, i.e., neither asymptotes nor U-shaped functions were evident. Thus, it must be presumed that spans longer than 20 seconds would have revealed even higher performance than that observed which, together with the general findings discussed earlier and described in Figure 5, has led us to conclude that the predictor instrument has something more than a simple "facilitating" effect as a training aid.

These results obviously elicit speculations as to what the optimum prediction span might be. Such a span should be closely related to the temporal aspects of the display used. For example, the display used in the present study required approximately 60 seconds of "flying" time from beginning to end of task. Thus, a 20 second span consumed one-third of the display flight path and progressively less of the predictor trace was visible after two-thirds of the display was traversed. In considering a longer span, say 30 seconds, visibility reduction would commence after only 50 percent of the display was traversed. We suspect, therefore, that the optimum configuration for our display lies between 20 and 30 seconds but, in view of the lack of related research and theory in this area, we would not be surprised to find the optimum span to exceed our expectation.

3. Adaptive Mode

Much the same discussion can be advanced for adaptive mode as was given for prediction span. For both altitude and airspeed error measures, performance increased with longer adaptive modes during training trials (0, 5 and 10 seconds). This conclusion is only slightly tainted by the fact that the slope of the performance curve for altitude error between 0 and 5 second modes was quite insignificant (Figure 7). However, because performance increased substantially on the 10 second mode, and because the airspeed error curve was consistently sloped downward (Figure 10), we suspect the negligible difference found between 0 and 5 second modes to be apparent, rather than real. Examination of Figure 6 reveals that Condition 2 (P5-A5) was primarily responsible for the failure of the 5 second adaptive mode to be significantly better than the 0 second mode, when averaged over prediction spans. That condition exhibited an unusually high altitude error rate.

Figure 5 may provide some insight into the performance of Condition 2. It can be noted that its performance on the second 12 trials was superior to both the Control and three experimental conditions. Subsequently, Condition 2's performance decreased rather substantially (14 percent) on the third 12 trials and then improved again on the last 12 trials. Unless one accepts the notion of "unlearning" as a result of training, this performance decrease must be considered to be due to extraneous factors, such as failing motivation or conscientiousness on the part of one or more Subjects within Condition 2 and/or to equipment problems. In any event, the negative trend cannot be taken seriously, although it also cannot be discarded, unfortunately, in the overall statistical and graphic analyses.

The reader will note in Figure 5 that a similar performance reversal was demonstrated by Condition 7 on the last 12 trials. Since this condition showed the highest performance on the third 12 trials, it is likely that it is at least comparable to Conditions 3, 8 and 9.

4. Performance Variability

It is usually the case that the simpler the task, whatever it might be, the smaller the individual *differences* in performing it. All "normal" Subjects would be expected to perform almost equally well on an extremely easy task, while a highly complex task would yield rather wide individual differences -- as a function primarily of inherent capability and task experience. Although the task used in this study was a simplified version of that confronting a pilot during an approach to landing and must be considered a much easier task than the pilot's, it was, nevertheless, relatively complex in contrast to most tracking tasks employed in most laboratory studies. Since individual differences found in the latter research tend to be relatively broad, perhaps even wider differences might have been anticipated in the present study. Such was not the case, however.

Standard deviations of the mean altitude and airspeed errors were substantially smaller than the means (Figures 8 and 11). In some conditions, they were only slightly larger than one-third of their respective means. Even the control group showed relatively small standard deviations for altitude and airspeed errors (63 percent and 71 percent of the means, respectively).

Probably the major factor contributing to relatively small standard deviations was the homogeneous group of Subjects employed, i.e., ROTC students having physical and intellectual qualifications for flight training. However, it is apparent that specific experimental conditions employing the predictor instrument also had much to do with depressing individual differences (see Conditions 3, 6, 8 and 9 in Figure 8).

Variability is often ill-discussed in favor of mean performance. This is unfortunately because it may often be more important in specific situations. In their study on the effects of the predictor instrument on aircraft landing performance, for example, Wulfeck, Prosin and Burger (1973) found similar means for control and experimental conditions but a much smaller standard deviation for the predictor instrument group. The implication is that use of the predictor would lead to far fewer accidents and wave-offs than would be the case without it. In the present study, not only were mean performances of several predictor groups substantially superior to the control condition, standard deviations were also highly depressed, indicating very narrow distributions about high mean performance levels. In general, then, nearly all Subjects in these predictor conditions performed with accuracy and precision on transfer trials.

5. Training Trials

Performance on the last 24 training trials was almost exactly as expected, in view of the fact that performance on test trials had asymptoted, for the most part, at that point. Few differences could be observed between training and test trials for most of the conditions (Figures 12 and 15) and for the specific levels of prediction span and adaptive mode (Figures 13 and 16).

Similarities between training and test trials are easily explained, particularly for the high performing conditions. The more accurate an operator performs the task, the less frequent is the appearance of the predictor instrument. In the extreme case, the predictor would not appear at all during a trial. Thus, conditions were almost identical for training and test trials during the last half of the experiment for several of the predictor instrument groups. Performance would therefore be expected to be identical as well.

With regard to airspeed error measures (Figure 15), it can be concluded that differences between training and test trials were negligible for all conditions. Some discrepancies existed, however, for altitude error scores (Figure 12). Here, Conditions 4 and 5 showed rather large differences, but in opposite directions. No explanation is readily apparent for either the magnitude of the differences or, in particular, the observed reversals. In both conditions, the predictor span was *10 seconds* but it was ON more frequently in Condition 4, due to the larger error accrual in that condition than in Condition 5 on training trials. On the other hand, the trace should theoretically have been ON more frequently during the first 24 trials because of the longer adaptive mode (5 seconds vs. 0 seconds), thus leading to higher performance on the last 24 trials. However, none of this dialog lends much to a useful explanation. Suffice it to say that, in general, performance on training and test trials was very much alike, as expected.

C. IMPLICATIONS

Heretofore, research on predictor instruments for potential use in manual control tasks has been limited, although the first relevant study was conducted well over a decade ago and yielded most promising results (Kelley, 1962). Literally thousands of experiments have demonstrated that the human operator has limited capacity to control complex vehicles and systems with precision. Since there are few such vehicles and systems which do not at least require manual control as back-up to automated devices, there is a clear need for devices, methods and/or procedures to improve the human operator's performance. Results of the present study add to those of previous research which point to the use of a predictor instrument as a significant step towards increasing the manual control operator's capability to learn and control complex systems at a level of precision not previously believed possible.

1. Operational and Training Applications of the Predictor Instrument

Results of this study suggest strongly that the predictor instrument may have considerable utility as a training aid in a wide variety of complex, manual control tasks. Transfer effects appear to have achieved practical, as well as statistical significance. Very importantly, design configurations used appear not to have been optimum for the specific task/display employed (see Figures 7 and 10) and, therefore, the ultimate utility of the predictor instrument for our task is apparently yet to be determined. That is, our data suggest that a more appropriately designed predictor display (e. g., a predictor span of 30 seconds and an adaptive mode of 15 seconds) would have led to even greater transfer effects than that observed in this study.

2. Optimizing the Predictor Instrument

Although our current results do not directly imply it, it seems quite apparent that optimum configurations of the predictor display are likely to be different for every major category of vehicle. For example, the faster the vehicle, the more likely will be the need for longer prediction spans. In the training situation, different adaptive modes may also prove optimum for different vehicles. Other design variables which were not included in this experiment would similarly require treatment during the optimization process.

The present study was limited to a one-dimensional tracking task, although the power control provided elements of a two-dimensional task and the display, of course, was two-dimensional. Ultimately, evaluation of the predictor instrument for purposes of deriving optimum designs should involve three-dimensional displays and models of vehicles which account for four to six degrees of freedom.

D. RECOMMENDATIONS

In a sense, this study represents a milestone in the investigation of predictor applications to manual control tasks. Evidence now is available which indicates that the predictor instrument has significant utility in both operational and training environments. It facilitates operator performance and it enables operators to learn a control system more rapidly than they would without it. In either case, however, we have only begun to investigate the parameters which affect the design of predictor instruments and which undoubtedly affect the operator's performance as well. Recommendations for further research are listed below:

- With the results of the present study in hand it would now be possible to evaluate transfer of training from the predictor/side-looking CRT display task to one in which the Subject engages in an approach to landing by using only conventional instruments, such as the pitch indicator, glideslope indicator, altimeter, vertical speed indicator, airspeed indicator and percent power tachometer.

- The present study showed rather wide performance differences between control Subjects and those in certain predictor configuration conditions. Such differences appeared to have stabilized midway through the experiment. It would be useful to conduct a longer study to determine the absolute extent to which the predictor reduces training time. Results from this study suggest that a training time savings of from 25 to 50 percent might be achievable on the particular task employed.

- Typically, training on simulators requires close observation by one or more instructors. This "one on one" relation is an expensive training mode. It would be of considerable interest to determine whether a single instructor, equipped with several predictor displays, could monitor adequately the performances of several trainees simultaneously. In addition to the savings in cost that might accrue, a major advantage might be the diagnostic attribute of the predictor displays in determining the weaknesses of trainees, i.e., the predictor provides forecasts of trainees' immediate responses which indicate correct or incorrect control actions.

- Variables important to the design of predictor instruments need to be investigated for determining optimum configurations for general classes of vehicles. Light, intermediate and heavy aircraft and seagoing vessels constitute a wide array of dynamics that would likely require different configurations. However, differences are likely to be solely in quantitative, rather than qualitative terms. Ideally, a large parametric investigation should be conducted which evaluates the variables across vehicle systems. Results from such a study would enable the development of "handbook" data for the design of specific predictor displays for specific vehicles or classes of vehicles.

Recent advances in computer technology, primarily developments in micro-miniature circuitry, indicate that computers required to generate complex predictor instruments can be of relatively small size and cost. The feasibility of installing such instruments on board small vehicles as helicopters and fighter aircraft appears to be all but established. It is of no little importance, therefore, that predictors be thoroughly researched so that ultimate utility and cost-effectiveness can be established with some degree of precision.

The predictor concept has been empirically shown to be a significant advancement in the area of manual control. We believe that it is now time to investigate the limits of its worth and applications.

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APPENDIX A

PHASE I EXPLORATORY RESEARCH

Exploratory research was performed which examined the feasibility of simulating a T-37 instrument landing. In the later stages of the investigation, a number of Subjects participated as operators for purposes of evaluating the instrumentation, procedures, and one adaptive predictor concept. Brief descriptions of the elements of this research are presented in the following subsections.

A. CONVENTIONAL INSTRUMENTATION

The relatively large number of primary displays and controls used by the pilot in executing the final approach are listed in Table A-1. His general strategy is to control airspeed and heading with the stick while controlling sink rate with the throttle. The interactions among these variables in actual landings result in a task that is much more complicated than one might expect. To keep the training and instrumentation problems within manageable bounds, we simplified and reduced the simulated task to that of longitudinal control, i. e., glideslope tracking in a T-37 dirtied-up in the landing configuration. The instruments used and their locations in the trainer/simulator which was modelled after the T-37 ASUPT are shown in Figure A-1. Note that the compass and radio, listed in Table A-1 are excluded.

Controls for the simulation consisted of a pedestal mounted joystick and a throttle mounted at elbow height. The joystick, adapted from an autopilot controller, was spring loaded, moderately self-centering, and traveled through an angular excursion of $\pm 20^{\circ}$. The oil-damped throttle traveled through a total arc of 60°; full back position represented engine idle (50 percent rpm), while full forward position constituted maximum power (100 percent). Normal trim power setting of 82 percent was achieved by a throttle position 8 to 10 degrees forward of vertical.

Table A-1. Displays and Controls Used in IFR Final Approach

Instruments	Controls
Tachometer	Throttle
Airspeed indicator	Stick
Altimeter	Trim switch*
Vertical velocity indicator	Pedals*
Attitude indicator	
Compass*	
ILS indicator	
Radio*	

*Not required for altitude and airspeed control

(Air Training Command, 1972)

B. ADAPTIVE PREDICTOR INSTRUMENTATION

A fast-time, repetitively cycled analog model, based on a real-time T-37 aircraft model, was used to generate a prediction of future aircraft trajectory. This model operated with a time scale 1000 times faster than the real-time model and was reset and operated 15 times per second. During each reset cycle, each integrator in the fast-time model sampled the output value of the corresponding integrator in the real-time model. The fast-time model operated under the assumption that the pilot would maintain whatever control stick position he held at the start of any single prediction cycle for the duration of a 10-second prediction. Such an assumption is necessary for the generation of a usable prediction, but the selected value of 10 seconds was somewhat arbitrarily, rather than empirically, based.

The model also operated under an identical assumption relating to the throttle control.

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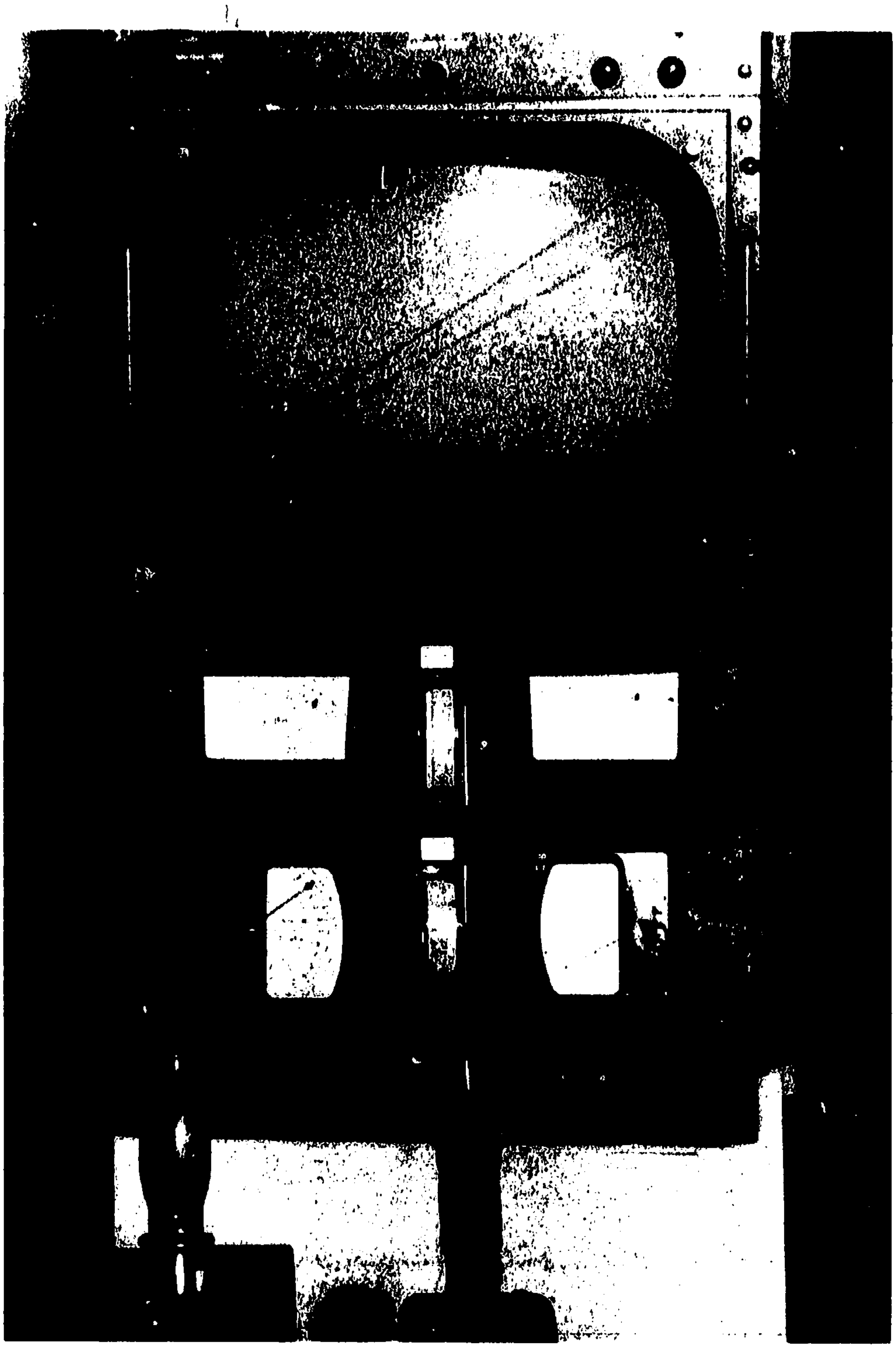

Figure A-1. Photograph of simulated instrument panel and predictor display with throttle (left) and control stick (center).

If either of the controls were moved during a prediction cycle, the next cycle (occurring in .067 seconds) would display the effect of the control input changes. For all practical purposes, prediction changes were continuous in nature.

An annular symbol showing present aircraft position with aircraft trajectory prediction from it was presented as an outside in, side looking display on a 16-inch diagonal CRT mounted immediately above the conventional instrument array (see Figure 1 on Page 6). The display was scaled to show a 6,666 ft or roughly 1-1/4 mile ground range with an initial altitude of 500 feet at the upper right corner. The glideslope of 4.3° and a plus and minus 0.5° envelope about it were drawn on the face of the CRT. A 10-second predictor trace indicating predicted trajectory extended approximately two inches from the left side of the aircraft symbol and varied slightly in length as airspeed varied.

The adaptive feature of the predictor instrument was represented by the appearance of the predictor display when the aircraft symbol departed from the ±0.5° envelope or when the predictor indicated that the aircraft would depart within five seconds and its subsequent disappearance after a preselected period. Specifically, a program of five seconds on and 10 seconds off was selected for the display while the aircraft was out or about to go out of tolerance. The display did not appear during periods in which the aircraft remained within the envelope.

C. PERFORMANCE MEASURES AND CRITERION

Two measures of performance on each attempted approach were recorded: percent of time within the ±0.5° glideslope envelope; and percent of time within ±6 knots airspeed tolerance about the 98 knot nominal airspeed. Both measures were cumulated and printed-out by an analog-digital system. A secondary performance measure was number of airspeed failures, i.e., any time the speed of the aircraft fell 18 knots below the nominal 98 knots, the "flight" was considered a failure since the aircraft would stall at such an airspeed.

The criterion for successful training performance on the glideslope task was three successive landings of 95 percent "within tolerance time" in terms of both glideslope and airspeed control.

D. EXPERIMENTAL DESIGN

The purpose of the experiment was to determine whether or not the predictor instrument used in an adaptive mode would reduce the number of training trials required to achieve criterion on the approach task. Two experimental conditions constituted the exploratory experimental design. A Control Group learned to perform the task without benefit of the predictor instrument. The predictor display was available, "as needed," to a Predictor Group during training trials but not during test trials in which both groups were tested on the conventional instruments.

E. SUBJECTS

Twelve Subjects, six in the Control Group and six in the Predictor Group, completed the experiment. Several Subjects dropped out because of frustration with the task. All Subjects were students at local colleges who volunteered from a pool comprised of candidates who had scored above the norms for college students on the Guilford-Zimmerman Aptitude Survey, Parts IV and V, and on the Witkin Group Embedded Figures Test. None had had previous flight training.

F. PROCEDURES

Written instructions were presented to the Subjects describing the instrumentation, their task, scoring procedures and the training goal or criterion. The Predictor Group's instructions differed from the Control Group's only in that information describing the predictor instrument and its use was also included.

Subjects were administered an average of 48 trials per day for four days (sessions). Within a session, trials were sequenced such that one test trial immediately followed five training trials. Short interpolated rest periods occurred at the end of each set of 12 trials except for those Subjects who "passed" a test trial. In those cases, additional test trials were administered until the Subjects reached criterion or failed a test.

Each trial began with the aircraft positioned at the same range. However, three different initial altitudes were used: 0.49° above, 0.49° below and on the desired glideslope. Altitudes were sequenced such that all three were administered when criterion was achieved. Performance scores were available following each trial and Subjects were given immediate knowledge of their performance.

A payment of $25.00 was made to each Subject who completed the study and an additional $10.00 bonus was offered and given to the Subject in each group who reached criterion within the least number of trials.

G. RESULTS

The results of the exploratory study were apparently confounded by a number of factors. First, Subjects who completed the study exhibited unmanageable variations in performance and the variability in criterion performance among them was unusually large. For example, the standard deviation for Control Subjects was more than 300 percent larger than it was for the Predictor Group. Moreover, the criterion score distributions for both the Control and Predictor Groups were strongly bimodal. It was considered inappropriate to evaluate the data statistically, even though they tended to support the use of the predictor instrument as a training aid.

A second factor that appeared to influence results of the study was associated with the analog computer and the simulated conventional glide-slope control instrumentation. Although relatively accurate for most purposes and properly calibrated before the experiment, the computer was found after the experiment to have become differentially stable in driving the simulated conventional display instruments in relation to the predictor display. Such instability may have varied over the course of the study and it can not be assumed that its effects were distributed equally across Control and Predictor Subjects.

The adaptive logic employed in the predictor condition may have been a third factor that influenced results. No empirical basis or developed rationale exists for selecting an appropriate ON-OFF program. The 5 second ON - 10 second OFF sequencing of the predictor trace was chosen arbitrarily so that the predictor would only prompt the student without allowing him to become dependent on it. Since the OFF mode tended to dominate a trial with respect to time, the program probably reduced considerably the expected differences in conditions between Control and Predictor Groups.

In summary, data from the exploratory study seemed clearly affected by factors unrelated to the specific conditions which were intended to differentiate between Predictor and Control Groups. Such factors apparently overwhelmed differences that may have occurred and could not be extracted by statistical process. Even so, most of the Predictor Subjects out-performed Control Subjects in terms of criterion scores, and airspeed failures, and their variability was substantially lower. Thus, while conducting and reporting statistical analyses would be inconsistent with rigorous scientific procedure, the predictor instrument nevertheless demonstrated utility in transfer of training despite the confounding variables.

APPENDIX B

COMPUTER SIMULATION EQUATIONS

Glideslope Parameters

Air Speed $= 98$ knots

$= 165.4 \text{ fps} = V_0$

$\therefore V_0^2 = 2.736 \times 10^4 \text{ ft}^2/\text{sec}^2$

Altitude at 0.75 mi. = 300 ft.

$\therefore$ Glideslope angle $= \tan^{-1} \dfrac{300}{3960} = 4.3^\circ$

Nominal pitch angle $\theta_0 = 5^\circ$

$\therefore$ nominal angle of attack $\alpha_0 = 9.3^\circ$ or $\alpha_0 = 0.162$ rad.

$V_{X_B} = 165.4 \cos 5^\circ = 164.8$ fps

$V_{Z_B} = V_{X_B} \tan \alpha_0 = 164.8 \tan 9.3^\circ = 26.98$ fps

Sink Rate (two methods)

1. $SR = V_{Z_B} \cos\theta - V_{X_B} \sin\theta = 12.51$ fps

or

2. $SR = \dfrac{h}{d_{TD}/V_0} = 12.53$ fps

Scale Factors (ref = 50 volts)

$V_{X_{B_{max}}}$	= 200 fps	$\Rightarrow$ $[0.25\ V_{X_B}]$
$V_{Z_{B_{max}}}$	= 50 fps	$\Rightarrow$ $[V_{Z_B}]$
Q_{max}	= 0.2 rad/sec	$\Rightarrow$ $[250\,Q]$
θ_{max}	= 0.333 rad	$\Rightarrow$ $[150\theta]$
$V_{X_{I_{max}}}$	= 200 fps	$\Rightarrow$ $[0.25\ V_{X_I}]$
$V_{Z_{I_{max}}}$	= 50 fps	$\Rightarrow$ $[V_{Z_I}]$
$X_{I_{max}}$	= 6666.667 ft	$\Rightarrow$ $[7.5 \times 10^{-3} X_I]$
$Z_{I_{max}}$	= 501.3 ft	$\Rightarrow$ $[0.1\ Z_{I_{max}}]$
α_{max}	= 0.25 rad (14.3°)	$\Rightarrow$ $[200\alpha]$

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$$V_{X_I} = V_{X_B} \cos 5^\circ + V_{Z_B}\theta \qquad (V_{X_{I_0}} = 165.4 \text{ fps})$$

$$V_{Z_I} = V_{Z_B} \cos 5^\circ - V_{X_B}\theta \qquad (V_{Z_{I_0}} = 12.5 \text{ fps})$$

$$X_I = \int V_{X_I}\, dt \qquad X_{I_0} = 6666.667 \text{ ft}$$

$$Z_I = \int V_{Z_I}\, dt \qquad Z_{I_0} = 501.3 \text{ ft}$$

$\therefore$

$$[7.5 \times 10^{-3} X_I] = \int \left\{ \frac{7.5 \times 10^{-3}[0.25\, V_{X_B}] \times .9962}{.25} + \frac{7.5 \times 10^{-3}[V_{Z_B}][150\theta]\, 50}{150\ \boxed{50}} \right\} dt$$

$$[7.5 \times 10^{-3} X_I] = \int \left\{ 0.0299[0.25\, V_{X_B}] + 0.0024 \frac{[V_{Z_B}][150\theta]}{\boxed{50}} \right\} dt$$

$$[0.1\, Z_I] = \int \left\{ 0.1[V_{Z_B}] \times .9962 - \frac{0.1[0.25\, V_{X_B}][150\theta]\, 50}{0.25 \times 150\ \boxed{50}} \right\} dt$$

$$[0.1\, Z_I] = \int \left\{ 0.09962[V_{Z_B}] - 0.133 \frac{[0.25\, V_{X_B}][150\theta]}{\boxed{50}} \right\} dt$$

Pitch Equation

$$Q = \int \frac{\rho S\bar{c}}{2I_{yy}} V^2 C_M \, dt = 9.33 \int C_M \, dt$$

$$C_M = C_{M_0} + \alpha C_{M_\alpha} + \delta_e C_{M_{\delta_e}} + \Delta C_{M_Q}$$

$$C_{M_0} = \underset{(13)}{0.057} - \underset{(14)}{0.027}$$

$$C_{M_\alpha} = \underset{(14)}{-1.003/\text{rad}}$$

$$C_{M_{\delta_e}} = 0.0171/\text{deg}$$

$$\Delta C_{M_Q} = -\frac{45}{V_0} Q\,(57.3) = -15.59Q$$

$$[250Q] = 250 \times 9.33 \int \left\{ 0.03 - \frac{1.003\,[200\alpha]}{200} + \frac{0.0171\,[2\delta_e]}{2} - \frac{15.59[25Q]}{250} \right\} dt$$

$$[250Q] = \int \left\{ 69.98 - 11.7\,[200\alpha] + 19.94\,[2\delta_e] - 154.8\,[250\,Q] \right\} dt$$

Z-Body Axis Velocity

$$V_{Z_B} = \int \left\{ Q\, V_{X_B} = 32.2 \cos 5^{o} + \frac{\rho S}{2M}\, V^2\, C_L \right\} dt$$

$$= \int \left\{ Q\, V_{X_B} + 32.08 + 37.9\, C_L \right\} dt$$

$$C_L = C_{L_0} + \alpha\, C_{L_\alpha} + \delta_e\, C_{L_{\delta_e}}$$

$$C_L = -\underset{(17)}{(0.256 + .3856)} - \underset{(17)}{4.503}\,\alpha + \underset{(9)}{0.00572}\,\delta_e$$

$$[V_{Z_B}] = \int \left\{ \frac{[250\,Q][0.25\, V_{X_B}]\, 50}{250 \times .25\ \boxed{50}} + 32.08 - 37.9 \times .6416 \right.$$

$$\left. - \frac{37.9 \times 4.503\, [200\alpha]}{200} + \frac{37.9 \times .00572\, [2\delta_e]}{2} \right\} dt$$

$$[V_{Z_B}] = \int \left\{ \frac{0.8\, [250\,Q][0.25\, V_{X_B}]}{\boxed{50}} + 7.76 - 0.8533\, [200\alpha] \right.$$

$$\left. + 0.108\, [2\delta_e] \right\} dt$$

$\rho = 2.35 \times 10^{-3}$ (slugs/ft^3 air density sea level)

$S = 183.9 \text{ ft}^2$

$\bar{c} = 5.58$ ft.

$b = 33.80$ ft

$W = 5000$ lbs

$\frac{\rho S}{2} = .21608$

$\frac{\rho S}{2} V^2 = 5912.02$

$\therefore \; M = 156.25$ or 155.28

$$Iyy = Iyy_{owe} + Iyy_{fuse}$$

$$= 3484.46 + 0.09415 \times W_F$$

$$= 3484.46 + 0.09415 \times 547 = 3535.96$$

$$= 3536$$

APPENDIX C

SUBJECT INSTRUCTIONS

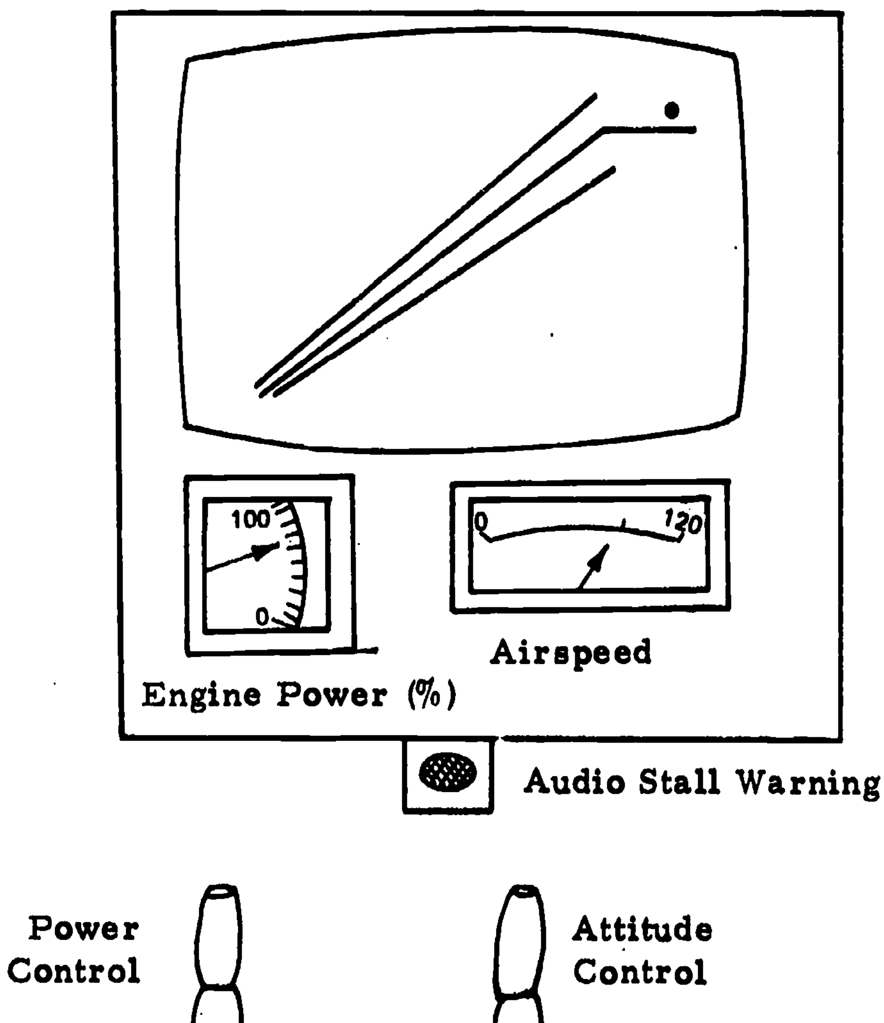
General instructions were administered to all Subjects. Subsequently, supplementary instructions were given to the nine experimental groups, describing the predictor instrument and how to use it.

A. GENERAL INSTRUCTIONS

The following instructions were read by all Subjects:

This experiment is concerned with various ways flight information can be presented to a pilot during a particular aircraft maneuver -- that is, an approach to a landing. The aircraft is represented as a simplified computer simulation of a twin-engine jet trainer, the T-37.

To operate the aircraft, you will have four displays and two controls, as shown in the figure below.



The primary display is the large television screen. Imprinted on to the screen is a black line, indicating the ideal path for the aircraft to follow, and two red lines, outside of which the aircraft is dangerously high or low. Your main task will be to try and keep the aircraft, represented by a small circle, as close to the black line as you can.

Below the television screen is an airspeed display, having a scale of 0 to 120 knots. Your secondary task will be to keep the aircraft's speed between 90 and 110 knots. If the airspeed drops below 80 knots, the landing will be considered a failure because a real aircraft would stall out at that speed and crash. However, while we will automatically record stalls, you will continue to guide the aircraft to the bottom of the black line.

The simulator is equipped with an audio warning device which activates at airspeeds at and below 80 knots. This warning indicates that the airspeed is dangerously close to stall speed. Airspeed can be increased by applying forward pressure on the attitude control, increasing power, or both.

On the left of the display panel is an engine power indicator. On normal approaches, when the aircraft is on speed and the aircraft symbol has been tracking fairly close to the desired flight path, you will find that about 88 percent power will maintain the airspeed desired.

The attitude control will be located between your legs when seated at the "cockpit" console. This control allows you to bring the aircraft nose upward and downward. Slight movement of this stick backwards (towards you) will cause the aircraft symbol on the display to climb. Similarly, slight forward movement of the stick (away from you) will cause the aircraft symbol to descend.

As with an automobile starting up a steep grade, the aircraft's speed will decrease when climbing unless some power is added. Increased power can be obtained by moving the power control forward (away from you). Similarly, when the aircraft stops climbing and begins to descend, some power should be removed or the aircraft will begin to accelerate.

The task which you are about to perform can be described very simply. You will be asked to land the aircraft many times. Each landing is called a "run." Prior to each run, the displays will indicate that the aircraft is in level flight at constant speed.

The attitude and power controls will already be adjusted to maintain level flight and constant speed, and were you not to touch either of the controls, the aircraft would remain in this stable state and fly straight ahead. When the display indicates that it is time for descent, you will manipulate the two controls such that the aircraft symbol follows the desired flight path (black line) and the airspeed display shows that your airspeed is within a safe range.

You will be given two unmeasured runs on the simulator so that you can become familiar with the displays and controls. If you have any questions, this is the time to get clarification.

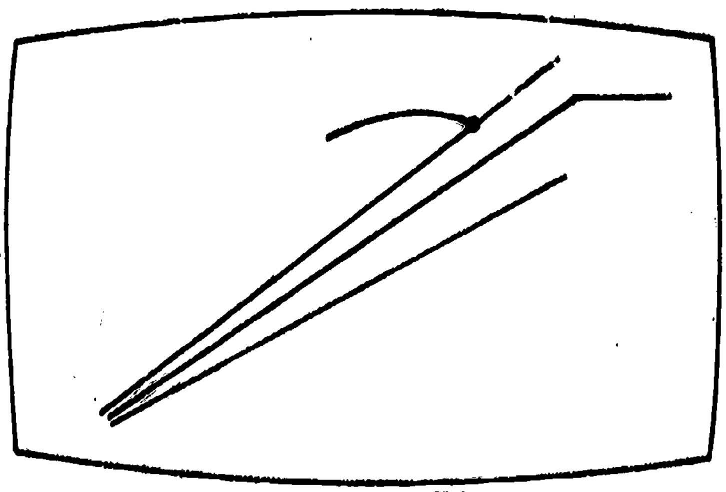
We fully realize that you have not had experience on this type of task. That's why we chose you. All that we ask is that you do the best you can.

The overall task will consist of sets of landings, with short rest periods between sets.

B. SUPPLEMENTARY INSTRUCTIONS

Supplementary instructions given to the experimental groups were slightly different from each other, reflecting the different predictor instrument configurations. Therefore, instructions given to Condition 4 are presented below as a typical example of that used for all experimental groups.

An important part of this experiment is the evaluation of a television display feature which tells you <u>in advance</u> where your aircraft will be if you make no changes in your attitude and power controls. This prediction feature is represented by a line projected from the aircraft symbol, as shown below:



The predictor line shown indicates that, with no further control movements, the aircraft will continue to climb slightly and then start to descend. The end of the line is where the aircraft will be 10 seconds from now. To control the aircraft more effectively, you should manipulate the attitude control such that the end of the predictor line touches the center black line.

The predictor line will appear only when the aircraft symbol is touching or is outside the red lines. When the aircraft returns within the red lines, the predictor line will disappear.

In the course of this experiment, you will be given one run with the predictor line, one run without it, one run with the predictor, and so on.

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18. SUPPLEMENTARY NOTES

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19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Manual Control
Predictor Instrument
Tracking
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Previous research in this laboratory has demonstrated that use of a predictor instrument, i.e., a graphic display of the future position and trajectory of a controlled vehicle, greatly simplifies a manual control operator's task and increases control performance substantially. This study investigated the potential utility of the predictor instrument for an entirely different

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application, namely, the training of manual control operators in aircraft simulators. Various predictor display design configurations were presented to Subjects during training trials on an aircraft approach to landing task. Subsequently, Subjects were tested on trials devoid of the predictor instrument to determine transfer effects. Each of the predictor display configurations was contrasted with a control or baseline display which did not include the predictor. Results of the study indicated that transfer from a predictor to a non-predictor display was dramatic; learning was greatly accelerated and the difference between predictor trained and non-predictor trained Subjects appeared permanent, in view of rather stable asymptotes observed during the last 24 test trials. It was concluded that the predictor display accelerated learning through its ability to provide immediate feedback to operators regarding the unique response of the system to control actions. In effect, such feedback enabled operators to learn the complex dynamics of the vehicle much more rapidly than was possible without it. Implications for use of the predictor instrument in a wide variety of operational and training applications are disc d.

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