SIMULATOR COCKPIT MOTION AND THE TRANSFER OF INITIAL FLIGHT TRAINING

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Transfer of flight training from a Singer-Link GAT-2 training simulator, modified to approximate a counterpart Piper Cherokee Arrow airplane, was measured for independent groups of nine flight-naive subjects, each trained in one of three simulator cockpit motion conditions: normal washout motion in bank with sustained pitch angles, washout banking motion in which the direction of motion relative to that of the simulated airplane was randomly reversed 50% of the time as the cab passed through a wings-level attitude, and a fixed-base condition. Subjects received predetermined fixed amounts of practice in the simulator on each of 11 flight maneuvers drawn from the Private Pilot flight curriculum. Transfer performance measures, including flight time and trials to FAA performance criteria and total errors made in the process, showed reliable transfer for all groups with differential transfer effects and cost-effectiveness implications depending upon the type of simulator motion.

BACKGROUND

The acquisition of complex flying skills through practice in a simulated, as opposed to actual, operating environment is hardly a new concept. During the First World War, Grahame-White and Harper (1916) suggested that student aviators practice positioning flight controls as appropriate to various flight conditions in a parked aircraft prior to flight. However, ground-based flight trainers were not used widely until the Second World War when the need to train pilots quickly with few training aircraft led to rapid advancements in simulation technology and more efficient training.

Smode, Hall, and Meyer (1966) note that by the end of the war, an appreciation had been gained for the flight simulator, not only as a primary aid but also for such specialized flight training activities as transition training and training for specific missions. It was realized, as Adams (1957) points out, that economic factors favored the use of the relatively inexpensive-to-operate simulator rather than the parent aircraft, that the simulator was useful in teaching skills too complex, expensive, or risky to practice in the air, and that the simulator provided the ability to isolate and practice particular segments of the overall task. Further, simulator operation is independent of weather conditions, and single-place aircraft simulators allow supervised practice impossible in the aircraft itself.

Transfer of Training

The value of a flight training simulator in a particular training curriculum is expressed quantitatively by its transfer and cost effectiveness. Whether a training system should include a training simulator depends upon whether time spent in the simulator reduces the need for training in the aircraft sufficiently to be cost effective. If the simulator operating cost is less than that of the aircraft by a ratio greater than the inverse of the transfer effectiveness ratio, a saving of overall training cost may be achieved. The transfer effectiveness ratio is quantitatively expressed by:

$$TER = \frac{Y_o - Y_x}{X}, \text{ where}$$

Y_o = time to criterion in the transfer task for the control group,

Y_x = time to criterion in the transfer task for the experimental group,

X = time spent on the practice task in the simulator by the experimental group.

These variables may also be defined in terms of trials or errors totaled prior to criterion performance; however, the cost of operation is determined by time of use.

Simulator Training Effectiveness

More than a dozen reported investigations have demonstrated positive transfer of training from flight simulators to airplanes. For example, Williams and Flexman (1949) found that non-pilots could be trained to perform a series of maneuvers using a Link trainer and an aircraft in an alternating practice sequence with 28% fewer trials and 22% fewer errors than a group trained entirely in a North American SNJ/T-6 airplane. Flexman, Matheny, and Brown (1950) reported similar findings in terms of a reduction in time required to reach private pilot proficiency. Povenmire and Roscoe (1971; 1973) investigated the transfer benefits of a Singer-Link GAT-1 trainer used in the University of Illinois's primary flight training program, confirming not only that transfer was positive to a Cherokee 140B airplane, but disclosing diminishing returns associated with successive increments of practice in the simulator.

It can be stipulated, in view of this evidence, that the simulator does constitute a viable basic training aid and that this is widely recognized is evidenced by the wide use of such devices in basic flight training. The demonstrated transfer effects apparently are sufficient to justify the outlay of funds for procurement of training simulators by both small and large schools in the highly competitive flight training industry. Transfer effects are not, however, uniform across the entire spectrum of skill categories required for pilot certification.

Ornstein, Nichols and Flexman (1954) found that the simulator is most effective for procedure loaded flight exercises, presumably because such tasks are readily simulated. Simulators are least effective for tasks that are difficult to reproduce faithfully. They discuss the relationship between the transfer effectiveness of the device and the fidelity, or verisimilitude, of reproduction of the aircraft procedural and environmental cue structure. Ornstein, et al. suggested that by extending the range and fidelity of the simulation transfer is maximized. This would logically follow by analogy from the Osgood (1949) transfer-surface concept in which both stimulus and response fidelity facilitate positive transfer and negative transfer can occur only when similar stimuli require opposite or antagonistic responses in the transfer situation.

Motion Cue Fidelity

Advancements in simulation technology during the present decade, particularly in the simulation of visual scenes and cockpit motion dynamics, make extremely high stimulus and response fidelity possible but at very high procurement and operating costs. Motion systems have been refined to provide a cue structure that is highly realistic in all dimensions with the exception of sustained linear acceleration cues accompanying turns. The discrepancy arises here because of the physical impossibility of artificially creating centripetal acceleration experienced by a turning aircraft and its occupants. The resultant forces of gravitational and centripetal accelerations are perceptually combined by the aircraft pilot's vestibular system, so that in a properly coordinated turn, the sensation is one of increased weight in addition to the rotational accelerations associated with roll into and out of the bank. There is no side force because the resultant force summation of gravitation and centripetal accelerations is kept perpendicular to the pilot's seat and the cabin floor.

In the simulator, any cabin tilt for the purpose of generation of rotational acceleration cues tends to displace gravitational force from the cabin vertical axis. Thus an unrealistic tendency to slide across the seat is perceived. This cue to the change in aircraft bank angle is unavailable in actual flight. Dependency by the simulator pilot on this cue for attitude information is unrealistic, and less positive transfer to the aircraft may result.

The most realistic simulation of airplane motion cues resulting from turns is provided by "washout" roll motion. By introducing roll acceleration cues via simulator cab tilt, the sensations accompanying initiation of turns are provided. As the simulated airplane assumes a steady state of bank, the cab is returned gently to horizontal with subthreshold acceleration. In this way, the side forces are avoided during sustained banked attitudes. However, because linear accelerations of the magnitude experienced in flight can only be generated by translation through great distances, and even by this means, such accelerations can be sustained only briefly, washout motion systems, at best, provide imperfect representations of the flight environment.

Simulator Cockpit Motion, Performance, and the Transfer of Training

Adams (1957) identified three primary application areas for flight simulators: research, evaluation of performance, and training. Recent research had demonstrated that simulator motion cue structure is a determining factor of pilot performance in simulators in each of these applications. Ince, Williges, and Roscoe (1975) compared flight attitude displays in a simulator under three motion conditions. Overall performances in the simulator under washout banking and sustained pitching motion were reliably better and more representative of actual flight performance than performance without motion cues. The order of merit of the experimental displays, in terms of disturbed attitude tracking performances, also corresponded most closely to their order of merit in flight when the simulator was operated with washout motion, thereby clarifying earlier findings by Jacobs, Williges, and Roscoe (1973).

However, recoveries from unknown attitudes incurred fewest control reversals when subjects had the benefit of the gravitational cues of absolute attitude afforded by the sustained banking and pitching mode. An intermediate frequency of reversals occurred with no motion, and the highest frequency with washout motion, which corresponded most closely with the acceleration cue structure encountered in flight. Furthermore, the high reversal frequency associated with washout motion corresponded most closely with the frequency of reversals in flight.

The first experiment bearing directly upon the transfer of training from a simulator to an airplane as a function of the kind of simulator cockpit motion was recently conducted for an entirely different purpose; the apparent finding of differential transfer was incidental but nonetheless historic. Major Jefferson Koonce (1974), USAF, was concerned with the reliability of instrument flight checks given in a modified Link GAT-2 simulator and their predictive validity to performance in a Piper Aztec airplane.

Independent groups of 30 instrument pilots were tested on Day 1 and Day 2 in the simulator and then on Day 3 in the airplane, as shown in Figure 1.

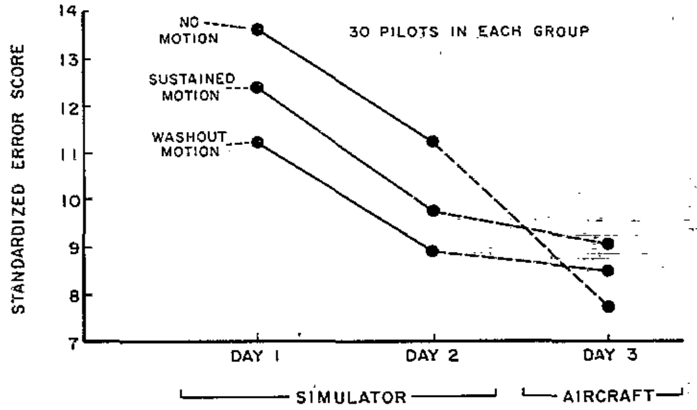

Figure 1. Transfer of refreshment of instrument skills in a Singer-Link GAT-2 to flight check performances in a Piper Aztec airplane.

The three groups of pilots were treated identically except that one group was tested in the simulator with the cockpit motion system turned off; for the second group, the motion system of the GAT-2 was operated with its normal sustained banking and pitching; for the third group, the motion system was modified to provide subliminal washout of banked attitudes during turns. An experimenter in the right seat and a second observer in the rear seat (both in the simulator and in the airplane) scored each subject's performances independently to allow calculation of reliability and validity coefficients, all of which were quite high.

Group performances revealed the usual finding that either type of cockpit motion makes a simulator easier to fly as indicated by the successively better flight check scores by the sustained motion group and the washout motion group. Clearly, pilots make use of whatever cockpit motion cues are provided in a simulator. Furthermore, the two closely spaced flight checks of approximately 1.5 hours each resulted in statistically reliable improvement by all groups from Day 1 to Day 2, indicating that the flight check performances of all were refreshed by practice in the simulator ($p < .001$).

But on the way to the airplane, a funny thing happened. There was a statistically reliable interaction between group performances in the simulator and in the airplane as a function of the presence and type of cockpit motion in the simulator ($p < .001$). All groups showed further improvement on Day 3 in the air, indicating either that it is easier to fly the airplane or that there *was transfer from the three hours of refreshment* in the simulator during Days 1 and 2. However, the reliably disproportionate improvement by the group tested with no cockpit motion in the simulator strongly indicates differential transfer.

PROBLEM

Any of three possible explanations, or some combination thereof, may account for Koonce's unprecedented finding. Because the differences among group performances observed in flight fell short of statistical reliability ($p < .10$ but $> .05$), they may have occurred by chance, and the reliable interaction between performances in the simulator and in flight could reflect only the differential difficulty of flying the simulator with and without motion. Alternatively, differential transfer may indeed have occured, in which case the apparently greater transfer from fixed-base simulator training might be uniquely associated with the refreshment of instrument flight skills, or it might reflect a general training benefit.

In each example, performance differences between groups of subjects operating the simulator with washout motion and those operating the simulator without motion suggest that motion-aided subjects achieve better performance in the simulator. Holding (1965) distinguishes between "learning feedback" and "action feedback" in the learning process. He concludes that the "intrinsic, concurrent, and immediate" nature of such cues as motion feedback of control inputs facilitates performance more than it facilitates learning. Certainly cockpit motion provides acceleration cues useful to the student in his performance of practice tasks, but do these cues improve transfer?

Koonce's experiment dealt with the refreshment of instrument flight skills of experienced pilots in various states of currency and non-currency. It has been speculated by many that the effects of simulator cockpit motion interact with pilot experience level. More specifically, some believe that faithful cockpit motion is more important for experienced pilots (Briggs and Weiner, 1957; Flexman, 1966), while others have suggested that motion combined with contact cues is more important during the initial stages of learning (Muckler, Nygaard, O'Kelly, and Williams, 1959).

Koonce found motion cue structure to be an important performance determinant for pilots of considerable experience in flight and in simulators having cockpit motion characteristics other than those in which they were tested by Koonce. Such experience may have caused differ*ential habit interference among his subjects*. To provide comparative data at the lower extreme of flight experience, and thereby avoid markedly differential habit interference, original learning by flight-naive students was investigated as a function of simulator cockpit motion conditions.

The present experiment addressed two issues:

1. Whether *simulator cockpit motion facili*tates transfer of basic flight skills during initial pilot training.

2. Whether cockpit motion cues play a

directing or merely an alerting role in training student pilots to cope with the visual and vestibular cue conflicts encountered in flight.

To resolve the first issue, one group of student pilots received simulator training with normal washout cockpit banking motion and a second group with no cockpit motion. To resolve the second issue, a hybrid, directionally random, washout banking motion mode was included. In each case, pitch attitudes were sustained. A control group received all training in flight.

Although suprathreshold angular accelerations provide both alerting and directing cues, it has been speculated by many that it is the alerting function that makes moving-cockpit simulators easier to fly than their fixed-base counterparts. By retaining alerting cues from the onset of motion but making the direction of roll acceleration an undependable cue, the ab initio pilot may be taught to depend more completely on flight instruments as he must learn to do in the air.

METHOD

One difficulty to be dealt with in the investigation of any learning process is the effect of individual differences in aptitude among subjects. Large aptitude differences can mask important treatment effects. A technique that helps to reveal main effects against the background of aptitude differences is the independent estimation of aptitude followed by removal of variation from this source through analysis of covariance (Tatsuoka, 1971).

Gopher and North (1974) previously had found a predictive relationship between attention-sharing performance and success in primary flight training. Four of their standardized measures, added to produce a composite prediction score, were administered to each of the 36 flight-naive subjects in the present experiment. The ratio of acceleration to rate determinants in adaptive tracking control dynamics, digit processing latency, and percent of performance retained in terms of RMS tracking accuracy and correct digit-response interval during simultaneous tracking and digit processing were the four measures making up the composite scores. These scores were used both for group matching and for later removal of aptitude dependence from performance scores.

Four groups of nine subjects each were formed and balanced using the prediction scores. A discriminant analysis failed to show reliable differences among the groups as constituted (Bartlett's $\chi^2 = 16.925$, df = 21). One group, serving as a control, underwent a highly standardized instructional sequence on a series of instrument-referenced flight maneuvers in a Piper PA-28R-200 Cherokee Arrow airplane. The sequence included 11 criterion maneuvers representing the basic elements of initial pilot training excluding takeoffs and landings. Each maneuver had to be mastered to a standard of two performances within stated error limits before progressing to the next. In addition, a series of review maneuvers was included in the sequence to test retention of skills. Error limits were comparable to standards used in the FAA private pilot flight test.

Three transfer groups were given instruction on all maneuvers in a Singer-Link GAT-2 training simulator prior to aircraft exposure. While the simulator is designed to represent a light twin-engine airplane, modifications were made to represent a single-engine airplane and to make the dynamics more nearly represent those of the transfer vehicle. One transfer group was trained in the simulator in a fixed-base condition, while a second was trained using normal washout motion. A third transfer group received similar practice in the simulator under a washout-motion condition in which the onset and amplitude of accelerations were normal but the direction of motion was randomly reversed 50% of the time, as the cab passed through a wings-level attitude, to provide alerting cues without reliable direction cues.

To minimize the effect of such external influences as instructor differences, all instructional material was either video-taped and presented to subjects prior to flight or audio-taped for presentation during flight in either the simulator or the aircraft. A safety-pilot/observer and a second observer, both licensed flight instructors, independently assessed student performance. For each maneuver, a number of flight control measures, such as altitude, heading, and turn rate errors, were scored relative to standards for the private pilot flight test. Exceeding tolerances caused an error to be scored.

Transfer subjects received a fixed number of trials on each exercise during simulator practice regardless of performance. During aircraft instruction, they were required to repeat each maneuver until criterion performance was observed, as were the control subjects. Equal numbers of subjects from each treatment group were scheduled in the training sequence at any one time to distribute the prejudicial influences of weather and equipment breakdown delays.

RESULTS

Almost incredibly, not one of the subjects who flew the simulator with randomly reversed banking direction commented on this characteristic during training, and when questioned specifically at the conclusion of simulator training, none could recall any instance in which the cockpit motion had seemed strange. No subject was told about the hybrid motion, or any other condition, either before simulator training or before proceeding from the simulator to the airplane, and care was taken to conceal the fact that the simulator was capable of motion from the fixed-base group. There was no indication at any time during the experiment that any subject realized that cockpit motion was an experimental variable.

Errors during Simulator Training

Because each transfer subject received a fixed number of trials on each maneuver in the simulator, time was nearly invariant, and the only measure reflecting differences in performance among transfer groups was error count. Regression lines for error counts plotted against aptitude predictor scores are shown in Figure 2.

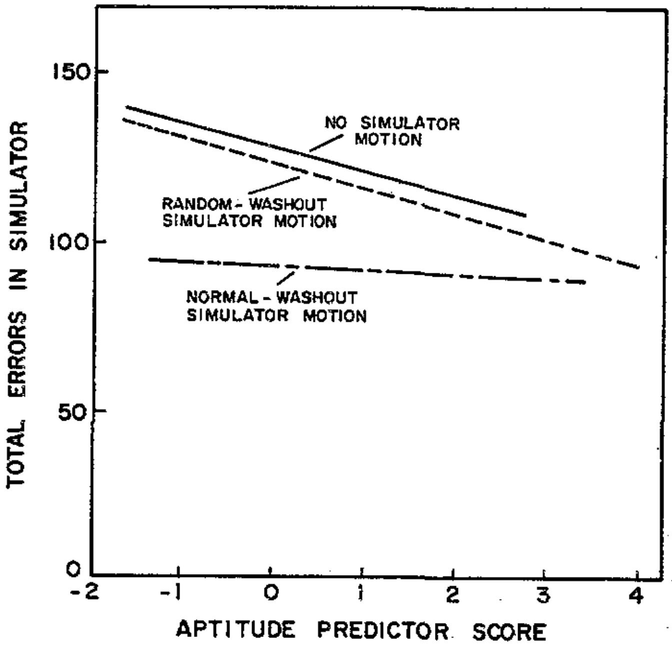

Figure 2. Regression lines showing best-fitting linear relationships between error counts during simulator practice and aptitude predictor scores for independent groups of nine subjects in each of three experimental conditions.

An analysis of covariance revealed group intercept differences approaching reliability (p_{int} = .07). The relatively flat slope of the regression line for the normal washout motion group suggests that, regardless of aptitude, these subjects tended to make small and equal numbers of errors during simulator practice compared with counterpart subjects in the other groups whose error frequencies depended on aptitude.

These slope differences can be interpreted as indicating that all subjects trained with normal washout motion advanced in skill to the practical limit in the simulator prior to performance in the airplane, whereas students of decreasing aptitude in the random washout and fixed-base groups may have gained additional benefit from additional practice in the simulator. If subjects in the normal washout motion condition were to receive somewhat less practice in the simulator, their performances likewise would be expected to depend on aptitude. Furthermore, the more apt would still be expected to gain maximum transfer benefit, and the less apt would not.

Transfer to the Airplane

Group means for practice time and trials prior to criterion performances and total error counts are presented in Table 1. By any definition of the measure, it is clear that large positive transfer occurred.

TABLE 1

Mean Times, Trials, and Errors to Reach Performance Criteria in the Airplane, Adjusted to Eliminate Individual Aptitude Effects, for a Control Group and Three Transfer Groups of Nine Subjects Each

	Control Group	*Cockpit-Motion Transfer Group*		
	Airplane Only	*Normal Washout*	*Fixed Base*	*Random Washout*
Time in min	182.4	69.8	80.0	111.2
Errors	90.0	46.5	56.4	59.9
Trials	38.5	16.1	17.1	22.2

Time-to-criterion scores. Analyses of covariance were performed to remove individual aptitude effects and to test for reliable differences in flight training required for the 11 maneuvers. A summary of the covariant relationships between practice time to achieve performance criteria and aptitude predictor scores is represented graphically in Figure 3 by the four group regression lines. Covariance analysis revealed highly reliable differences among intercepts for groups (p_{int} = .0013). Pairwise comparisons revealed reliable transfer to the airplane for normal washout motion and fixed-base groups (p < .01 and .05, respectively), while the random washout motion group approached a reliable level of transfer (p < .10 but > .09). Transfer groups were not found to differ reliably from one another in time scores in the air, although the normal-washout/random-washout motion comparison approached reliability (p < .08 but > .07), an interesting finding in view of the failure of any subject in the random washout group to notice reversed banking motion at any time during training in the simulator.

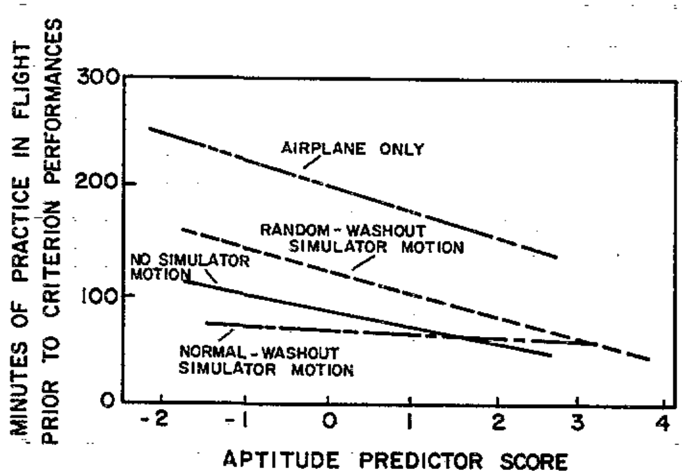

Figure 3. Best-fitting linear relationships between flight time and aptitude scores by groups.

Errors in the airplane. The covariance between errors made in flight, including those made during review and criterion trials in addition to those made during practice on maneuvers prior to criterion performances, and the aptitude predictor scores for subjects in each group are graphed in Figure 4. Analysis of the covariance between total error count and aptitude predictor scores again showed reliable overall transfer (p_{int} = .003). Both normal washout and fixed-base groups individually exhibited reliable transfer (p < .005 and .05, respectively), and the reduction in errors by the random washout motion group relative to the control group approached reliability (p < .06 but > .05). Among transfer groups, only the normal-washout-motion/fixed-base comparison approached reliability (p < .09 but > .08).

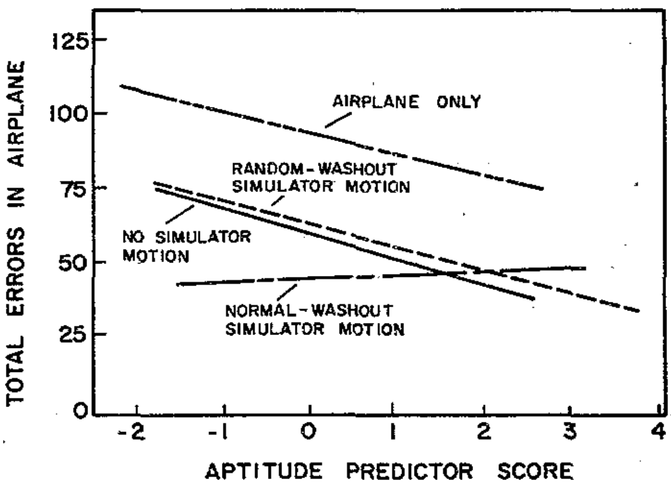

Figure 4. Regression lines showing best-fitting linear relationships between total error counts, including errors made during review and criterion trials, and aptitude predictor scores for a control group and three transfer groups of nine subjects each.

Trials to criterion. There were similar overall differences among groups in the number of trials prior to criterion performance in flight (p_{int} = .002) and reliable transfer for each simulator group individually (p < .01, .05, and .05 for normal washout, fixed-base, and random washout groups, respectively). Furthermore, there was a reliable difference in the slopes of the regression lines between trials and predictor scores for the normal washout and fixed-base groups (p < .05).

The relative flatness of the regression line for the normal washout motion group on this measure, as on time and errors as well, indicates that all subjects, regardless of aptitude, gained all benefit possible from the simulator prior to performance of each maneuver in the air. In clear contrast, the times, errors, and trials prior to criterion performances for the random washout and fixed-base groups indicated that, while the more apt students gained full benefit from practice in the simulator, the less apt did not.

Perceptual Equivalence

Two regression lines from Figure 3, relating time-to-criterion in flight and pilot aptitude for the groups that flew the simulator with normal washout motion and with random washout motion, are reproduced with an expanded ordinate scale in Figure 5. In view of the fact that no subject in the random washout group at any time detected the half-time diametric conflict between roll accelerations and instrument indications of bank attitudes, there is no reason to question the subjective perceptual equivalence of the two simulator motion conditions for these beginning flight students, although the randomly reversed direction of cockpit motion was painfully evident to the experimenters and performance observers in the simulator.

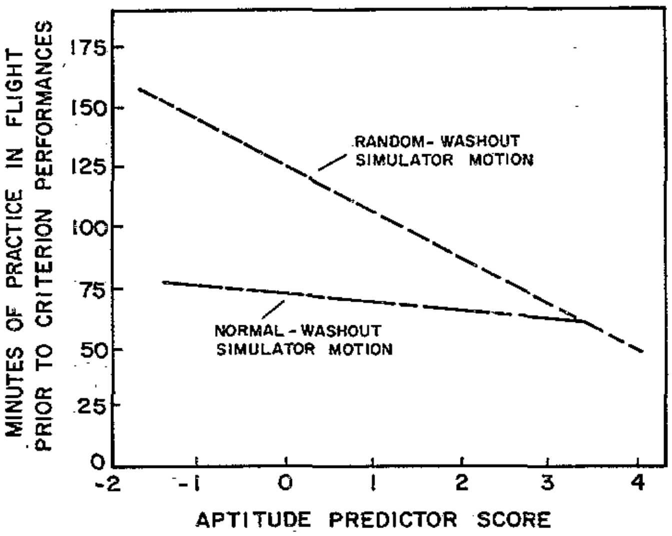

Figure 5. Regression lines showing best-fitting linear relationships between times to reach performance criteria in flight and aptitude predictor scores for the normal washout and random washout simulator motion groups.

Although these two widely different simulator motion conditions may be "perceptually equivalent", they are equivalent in no other respect. Group performances in the simulator, illustrated in Figure 2, showed a close performance equivalence between the random washout group and the fixed-base group, both of which appeared to differ from the normal washout group. Clearly the fixed-base condition is not perceptually equivalent to either type of cockpit motion, even for beginning flight students.

In terms of transfer, performances of the normal washout and fixed-base groups were similar, and the interaction between transfer and pilot aptitude associated with random washout motion, relative to normal washout motion, approached statistical reliability ($p < .08$ but $> .07$). These findings in conjunction with those of Koonce serve as a warning against predicting group performances in flight from group performances in training simulators, despite the fact that predictions of individual performances in flight relative to group means may be highly reliable (Koonce, 1974).

DISCUSSION

Once again training in a ground-based flight simulator has been shown to yield positive transfer to performance in flight, but more importantly, the amount of such transfer has been shown experimentally to vary with the type of simulator cockpit motion. Normal washout banking motion of the simulator cockpit yielded consistently greater transfer, of borderline reliability, than the hybrid, randomly reversed banking motion and slightly, though not reliably, greater transfer than fixed-base simulator operation. Performance in a training simulator also depends upon the type of cockpit motion, but such performance and its transfer effectiveness do not bear a simple, direct relationship.

Overall Savings and Transfer Effectiveness

Flight time measures used in the statistical comparisons of group performances included only the time spent practicing the 11 criterion maneuvers. Additional flight time, in amounts approximately equal for each transfer group and slightly greater for the control group, was required for presenting taped instructions, for review and criterion trials, and for flight activities by the safety pilot/instructor unrelated to student training, such as takeoffs, flying to and from the practice area, approach delays, and landings.

While the scientific aim of providing a uniform and sensitive quantitative basis for evaluating experimental treatments was enhanced by basing comparisons on practice time only, the practical meaning of the associated findings requires an additional analysis more representative of actual instructional economics. For meaningful cost effectiveness comparisons, total flight time, excluding only that required for demonstration of criterion performance, is presented for each group in Table 2, which also includes flight time saved, time spent in the simulator, and the resulting transfer effectiveness ratios (Roscoe, 1971).

TABLE 2

Summary of Overall Flight Time Savings in Minutes and Transfer Effectiveness as a Function of Simulator Cockpit Motion Conditions

Experimental Group	*Flight Time*	*Time Saved*	*GAT-2 Time*	*Transfer Ratio*
Airplane Only	387			
Normal Washout	248	139	442	0.314
Fixed-Base	255	132	442	0.299
Random Washout	280	107	429	0.250

Cost Effectiveness

The transfer effectiveness ratio is a measure of the efficiency of training in the simulator relative to the airplane. Here, for example, each hour of simulator time under the normal washout motion condition replaced, or "saved", 0.314 hr of practice in flight prior to criterion performances. The inverse of the transfer effectiveness ratio sets a threshold of airplane to simulator operating costs above which simulator use is cost effective. The inverse values of the transfer effectiveness ratios given in Table 2 are 3.18, 3.35, and 4.00 for normal washout, fixed-base, and random washout modes of simulator operation respectively. Typical costs of owning and operating primary training airplanes at a modest profit are on the order of $28/hr, including instruction. Corresponding costs for two ground-based flight trainers representative of moving-base and fixed-base operation, respectively, are summarized in Table 3.

TABLE 3

Typical Direct Costs of Owning and Operating Representative Moving-Base and Fixed-Base General Aviation Flight Trainers

Costs	*TYPE OF SIMULATOR*	
	Sustained Pitch, Bank, and Yaw Motion	*Fixed-Base*
Yearly Amortization @ 1%/mo	$2625	$1560
Yearly Maintenance	$2850	$ 375
Yearly Total	$5475	$1935
Hourly Cost @ 750 hr/yr	$ 7.30	$ 2.60
Hourly Instruction	$ 8.00	$ 8.00
Hourly Total	$15.30	$10.60

Although the type of moving-base trainer cited in Table 3 was not represented in this experiment, the normal washout motion of the modified GAT-2 included pitching and banking cues most nearly corresponding to those in question. Multiplying the inverse transfer effectiveness ratios obtained for normal washout motion and fixed-base operation by the respective costs given in Table 3 yields minimum airplane operating costs of $48.65 and $35.44 for economical use of moving-base and fixed-base trainers in the 6.5-hr flight curriculum taught in this experiment. If there were no other considerations, use of either type of trainer should be rejected as uneconomical. However, such a conclusion is unwarranted and would be misleading.

Factors Affecting Transfer

Factors other than simulator cockpit motion influenced transfer effectiveness in predictable directions but by unknown amounts in this experiment. The maneuvers taught, the amount of training given in the simulator, the highly standardized instructional procedures, and limited performance feedback were all decided upon in the interest of precision of experimental control and sensitivity of discrimination among experimental conditions; each served also to limit transfer in all groups, presumably to a uniform extent.

Certain maneuvers that can be taught effectively in simulators were not included to reduce the likelihood of disrupting the experiment by damaging the specially equipped airplane. Individualization of instruction in response to student difficulties and other techniques of training for maximum transfer were not employed by the instructors in the interest of uniform experimental treatment. The fixed amount of simulator training, independent of student aptitude or demonstrated performance, was essential to the meaningful comparison of motion conditions in terms of transfer effectiveness but does not represent the optimum simulator use strategy.

Optimization of Simulator Use

Optimization of simulator use involves consideration of the diminishing nature of the incremental transfer effectiveness function (Roscoe, 1971) and the fact that this function varies both among students and with changes in simulator characteristics, curriculum content, instructional practices, and interpolation of practice in the simulator and airplane, to name but a few of many factors. The amount of simulator training given was determined during extensive pretesting to assure students at the lower aptitude levels sufficient transfer to reach criterion performance in the airplane in a reasonable time, regardless of the simulator motion condition. This inevitably gave the more apt students, particularly those in the normal washout motion group, simulator training well beyond their individual cost-effective crossunder points (Roscoe, 1975). This effect is clearly evident from the varying slopes of the regression lines for different groups shown in Figures 2-5.

Simulator Selection and Use

Despite the experimental constraints that served to limit total transfer for some and transfer effectiveness for others, a further cost analysis of the unduly pessimistic results provides, through example, a rational basis for simulator selection and use. Figure 6 depicts hypothetical relationships among incremental and cumulative transfer effectiveness and associated profit or loss as functions of the amount of training time in representative fixed-base and moving-base general aviation flight trainers. The scales of transfer, time and cost have been set to be consistent with the amount of training and findings of this study, but the relationships shown are of a generalizable nature, subject to scale adjustments to accommodate longer periods of training and higher levels of transfer effectiveness associated with better conditions for learning.

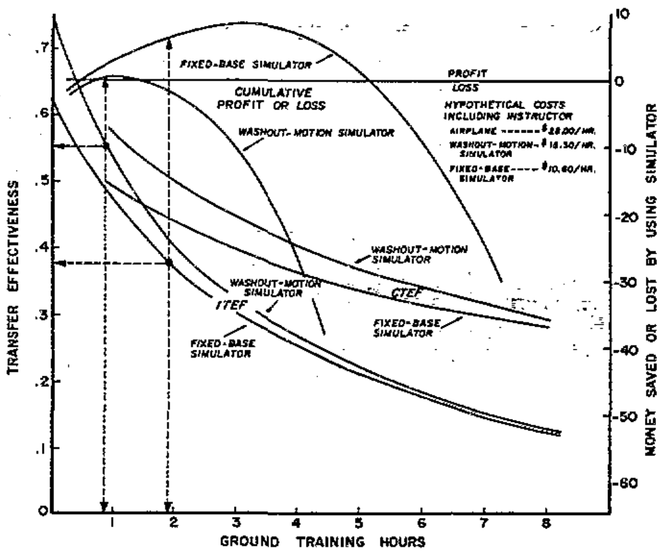

Figure 6. Hypothetical incremental and cumulative transfer effectiveness, in a 6.5-hr initial flight training curriculum, as functions (ITEF and CTEF) of the amount of training time in representative fixed-base and moving-base general aviation flight trainers and the associated profit or loss.

For a particular simulator, a cost effectiveness crossunder point is reached when its incremental transfer effectiveness ratio equals the ratio of its hourly cost to that of the counterpart airplane. With cost ratios of 0.546 and 0.379 between the two simulators and the airplane represented in Figure 6, corresponding incremental transfer effectiveness ratios are reached at slightly less than 1 hr and 2 hr, respectively, for this brief, 6.5 hr flight curriculum. Thus, in each cockpit motion condition, use of the simulator beyond these respective points would waste the time of the student, the instructor, and the simulator, all of which may be expressed in terms of money.

There is compelling evidence from the results obtained that the amount of simulator training given students in this experiment was uneconomical under the particular circumstances that prevailed. For a training simulator to be cost effective, its cost must be low, its transfer effectiveness high, and its use limited to the point at which its incremental transfer ratio crosses under its cost ratio relative to the airplane.

Experimental Methodology

The stability of the results from this experiment demonstrates that discrimination among treatment groups as small as nine subjects each is possible when subjects are effectively matched among groups by analyzing the covariance between their performances and their independently predicted aptitudes. Neither aptitude prediction nor analysis of covariance has been used previously to cope with the large individual differences among subjects typically encountered in flight training and transfer research.

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