Professional Paper 1-76

HumRRO-PP-1-76

HumRRO

[redacted]

Some Factors Influencing Transfer of Simulator Training

Paul W. Caro

Presented at Third Flight Simulation Symposium of the Royal Aeronautical Society
London, England April 1976

HUMAN RESOURCES RESEARCH ORGANIZATION
300 North Washington Street • Alexandria, Virginia 22314

August 1976

Approved for public release;
distribution unlimited

Prefatory Note

This paper is based on an invited address given by Dr. Paul W. Caro of HumRRO Eastern Division (Pensacola, Fla., Office) at the Third Flight Simulation Symposium of the Royal Aeronautical Society in London, England, on April 8, 1976.

Dr. Caro is Manager of HumRRO's flight training research and development activities, and was one of only two Americans to present papers at this symposium on "Theory and Practice in Flight Simulation."

SOME FACTORS INFLUENCING TRANSFER OF SIMULATOR TRAINING

Paul W. Caro
Human Resources Research Organization

INTRODUCTION

The use of simulators and other training devices is increasing rapidly. One assumes that this phenomenon is intended to enhance the effectiveness and/or the efficiency of the training programs in which such devices are used, but the seriousness with which simulator makers and users pursue this intent might well be questioned from both the practical and scientific points of view. Following a study of the use of aircraft simulators in selected U.S. military and civilian pilot training programs, the Comptroller General of the United States recently issued a report to the Congress which was critical of the extent to which simulators are being used in the military training programs studied (1). The report suggested that present knowledge of simulator design and employment is sufficient to support much more extensive use of simulators than was typically found to be the case. The report cites certain pilot training agencies which seem to employ that knowledge more effectively than do others, even though the knowledge is available to all.

The Comptroller General report was not intended as a scientific study of psychological factors and their influences on simulator training effectiveness. Instead, it identified factors related to the management of simulator training and attitudes toward such training which tend to impede more extensive use of simulators. Factors identified include regulations emphasizing aircraft rather than simulator training, inadequate instructor training, failure to use simulator capabilities fully, and poor simulator maintenance. The influence of such management factors upon trainer use has been documented in the research literature (e.g., 2,3). Other factors which have been identified as impediments to effective simulator use include the design of the simulators themselves and of the training programs in which the simulators are employed (e.g., 4,5). Still other factors have been reported which influence the acceptance of simulators by those who must use them and thereby indirectly impede their more extensive use (e.g., 6).

Clearly, the intent of simulator users is to achieve effective training rather than merely to use training equipment extensively. It is possible, however, to use simulators extensively, while at the same time to use them ineffectively. In one study (7), for example, it was found that the extensive use of a particular device added cost, but no training value to an already expensive pilot training program. Another study demonstrated that the training value of a device could be increased substantially without increasing the amount of device training time involved when the manner in which it was used was changed (8).

While there is a great deal of scientific and training literature in existence dealing with simulator training, some of the more significant factors influencing transfer of simulator training have not received the systematic attention they warrant. The purpose of this paper is to call attention to certain of the factors observed over the last decade to be of significance in our simulator research and that of our professional colleagues elsewhere. The emphasis will be upon increasing the effectiveness of simulator training as opposed merely to increasing simulator use. While simulator effectiveness and use obviously are not independent (a simulator cannot be used effectively when it is used little or not at all), they are not always coincident. Some simulator designers and users appear unaware of factors which, if properly treated or managed, would markedly enhance the value and efficiency of simulator training programs. The unfortunate consequence of their lack of awareness is that simulator training effectiveness suffers: skills which may be critical to safe operation of an aircraft may not be developed; aircraft may be required unnecessarily for training when they are needed for other purposes; training costs become excessive; or simulator training, although effective, is conducted in an inefficient manner.

MEASURING SIMULATOR TRAINING EFFECTIVENESS

In order to identify factors which influence simulator[a] training effectiveness, it is necessary to measure those influences. Since simulator training effectiveness[b] is not independent of the extent to which the device is used, one indication of whether a factor can be influential is to determine how much a simulator training program embodying that factor is used, e.g., the elapsed time that the device is in use, or the number of tasks practiced in it. While simulator training cannot be effective if these values equal zero, high indices of use do not indicate effective simulator training. Even improved pilot performance in the simulator resulting from its use does not assure improved performance in the aircraft. Therefore, measures must be used which reflect improvements in pilot performance in the aircraft, not how proficient the pilot became at flying the simulator or how much training he received in it.

The Transfer Model

The transfer of training model can be employed to determine whether simulator training has improved subsequent pilot performance in an aircraft. Transfer of training is a phenomenon which occurs whenever the existence of a previously learned behavior or skill has an influence upon the acquisition, performance, or relearning of a second behavior or skill. Thus, if a behavior learned in a device has an influence upon the subsequent acquisition, performance or relearning of behavior in an airplane, transfer is said to have occurred.

A simple experimental design based upon the transfer of training model involves two groups of trainees: an experimental group which receives simulator training prior to further training or performance testing in the aircraft; and a control group which receives all its training in the aircraft. This design permits measured differences in performance in the aircraft between the experimental and control groups to be attributed to the influence of training received in the simulator by the experimental group. The groups must be equated, of course, in terms of relevant prior training and experiences, and a means for measuring in-flight performance must be available.

[a]Many writers distinguish between simulators (e.g., ". . . a high degree of relevance to operational equipment. . .") and training devices (e.g., ". . . any piece of apparatus which is used for training. . ."). The present writer will treat these examples of training equipment as members of a single class. To quote Gagne (9, p. 96), the source also of the above quotations, "What distinguishes a training device (from other training equipment) is not its appearance or construction, but rather *how* and *for what purposes* it is used." The term simulator is used here to identify ground based training equipment used for the purpose of training pilots to fly aircraft. The question of *how* it is used will be addressed in the paper.

[b]. . . or, as more properly stated by Jeantheau (10), the effectiveness of training with the simulator. . .

Other Approaches to Determining Simulator Training Effectiveness

Determining the effectiveness of simulator training can be a costly, time-consuming task if an in-flight performance measurement system is not readily available. Some analysts have attempted to conduct simulator evaluations by asking pilots, instructors, training specialists and even students their opinions concerning simulator effectiveness, i.e., the probable impact upon student performance of training in the simulator. I have observed instances in which surveys of pilots' and instructors' opinions yielded results (both pro and con) unrelated to data subsequently obtained in transfer studies involving the devices in question. Meister, Sullivan, Thompson & Finley (11) found that such an approach yielded different estimates of the effectiveness of a particular device where different instructors made the judgments involved. Instructor evaluations of simulator effectiveness are unreliable, probably due to attitude factors such as those discussed by Mackie, et. al. (6), as well as because of the inherent unreliability of judgments, and should not be used where much is at stake. Simulator effectiveness is a matter of trainee in-flight performance, not of instructor, pilot, or trainee opinions about the device and its probable usefulness.

Another simulator evaluation technique, backward or inverse transfer of training, has been described by Adams and McAbee (12). In a backward transfer study, a pilot who has already demonstrated mastery of in flight training objectives is "transferred" to the simulator where he is required to perform tasks corresponding to those he has mastered in the aircraft. If he can perform such tasks at criterion levels in the simulator without practice there, backward transfer is said to have occurred, and this fact is taken as evidence that transfer in the simulator-to-device sequence, although of unknown quantity, will be positive. The backward transfer design should be used with caution for at least three reasons: (a) the results assume (often incorrectly) that a suitable training program exists for the simulator; (b) experienced pilots already proficient at operational tasks often have generalized skills not possessed by recent graduates and may be able to transfer to the device because of such general skills rather than skills needed to pilot a particular aircraft or perform a particular mission; and (c) the simulator may be suitably designed for the performance and evaluation of a particular set of behaviors but may lack the cues essential to the development of those behaviors. While backward transfer data should not be the sole justification for simulator procurement, one would be hesitant to use a simulator which could not be operated by competent pilots.

Jeantheau (10) has described four approaches to simulator evaluation: (a) conduct of a transfer experiment as is described above; (b) analytic study of the device and its program of instruction; (c) use of the device without experimental controls which would permit measurement of its effectiveness; and (d) comparison of various ways of using the device. These latter three approaches are appropriate to assuring that a simulator is used correctly, but they do not yield data which demonstrate that pilots who are trained in the simulator are more competent than pilots who are not so trained. Sometimes such approaches must be relied upon for administrative reasons or because experimental controls involve unacceptable risks (e.g., the effectiveness of lunar landing simulators could not be determined in a study involving a no-simulator-training control group).

The fact that simulator training research cannot always involve transfer to an aircraft is not necessarily all bad. Many research issues, including issues related to efficient methods of simulator training, can be investigated in simulators and laboratories to considerable advantage. A higher degree of control can be exercised over independent variables in such studies, and the cost of aircraft operations can be avoided. The chief disadvantage lies in the resulting uncertainty concerning the effectiveness of that training in the operational situation. Recent efforts of Matheny (13) on perceptual equivalence may offer a means of testing simulator effectiveness without costly transfer studies.

A number of analytic models have been suggested for predicting simulator effectiveness (14, 15, 16, 17), but none of them takes into account all of the factors believed relevant. They are useful in designing simulators and training programs, but they do not measure simulator effectiveness and estimates based upon them are subject to unknown error.

Indices of Simulator Effectiveness

Various formulae have been suggested to express simulator effectiveness as a single value. Gagne, Foster & Crowley (18) proposed nine such formulae, corresponding to different operations involved in deriving the raw data, e.g., counting trials, measuring time, or counting errors. Six formulae have been suggested by Murdock (19) and five by Hammerton (20), each of which deals with specific experimental design and data problems. An index which takes into account the amount of effort involved in device training as well as subsequent in-flight performance, the Transfer Effectiveness Ratio (TER), has been proposed by Povenmire & Roscoe (21). A variation of the TER takes into account the relative cost of simulator vs. aircraft training (22). While all such indices provide a means for comparing simulator effectiveness, they contribute little to our understanding of the training value of simulators. The raw data themselves, a description of circumstances under which the measures were made, and identification of the dependent variables are more useful in understanding factors influencing simulator training. If a single index is necessary, it might better be one which reflects the cost savings resulting from the use of the device in a specified way in a particular training program.

FACTORS INFLUENCING SIMULATOR TRAINING EFFECTIVENESS

A recent summary of simulator training studies (3) indicated that simulator training effectiveness has increased markedly since World War II. Some of the increase can be attributed to advances in engineering and instructional design technologies. Simulation engineers now have the technology available to build simulators which more nearly satisfy Thorndike's common elements design hypothesis, and instructional system designers have learned how to zero in on tasks to be trained. But much of the increase has come about as a result of research and experience with simulators in operational training settings.

In spite of the large number of simulator effectiveness studies which have been completed, there remains much to be learned about training with these devices. Factors have been nominated as influences upon simulator training effectiveness, but many of those nominations have been based on inference rather than experimental evidence. In their review of simulator research, Muckler, Nygaard, O'Kelley, and Williams (23) noted that many studies compound the influence of several potential influences such as training program content, instructional technique, and instructor qualification, into a single independent variable so that the transfer effects can be attributed only to the unique combination of those influences. Even in the few experimental investigations which isolate assumed influences, the results must be interpreted cautiously because they address unique training requirements and have not been replicated.

The methodological problems involved in identifying factors which influence simulator training effectiveness cannot easily be overcome. Suspected factors can seldom be examined in isolation. It is difficult, for example, to determine experimentally the relative value of a remote instructor station vs. an on-board or in-the-cockpit station even if a suitably designed simulator were available for the research, because to use each station to its best advantage would necessitate having two methods of training: one optimized for remote instruction; the other optimized for on-board instruction. The experiment would thus compare instructor station-training program combinations, not a simulator design feature in isolation from other factors. The training program factor cannot be held constant. It would be inappropriate to compare two simulator designs using a program optimized for only one, or for neither.

The problem of generalizable results is not limited to studies involving operational simulators. Even using equipment designed and dedicated to research, problems arise. For example, to pursue the illustration of instructor station location described above, simulator hardware inflexibility makes it difficult to conduct the necessary research leading to the design of the optimum remote instructor station for experimental comparison with the optimally designed on-board station. Additionally, the on-board station design which is optimum for a single seat, high performance attack aircraft simulator with a visual display may bear little resemblance to the optimized on-board station for undergraduate instrument training in a side-by-side seating helicopter simulator.

Definitive data do not exist which will permit the quantification of the influence of all factors believed to influence simulator training effectiveness. In fact, the mere identification of most such factors rests upon inference, conjecture, and untested hypotheses. The absence of hard data obviously cannot justify suspected factors being ignored, however. Where inferences can be made and supported by consensus, factors believed to influence simulator training must be taken into account by those responsible for simulator design and use unless evidence can be assembled to refute those inferences. It is the responsibility of the research community to undertake the systematic investigation of such factors.

The following discussion is intended to call attention to selected factors which influence simulator training effectiveness. It would not be fruitful to attempt to cite all the researchers who have contributed to the identification of such factors—those who have contributed to the literature on physical vs. psychological variables in simulator design, for example, are legion, as are those who have remarked upon the importance of how the simulator is used. Review articles touching on the subject include references no. 2, 3, 23, 24 and 25. Except where specific reference is made to a particular report, the present writer will acknowledge responsibility for the inferences set forth herein, as well as for the selection of factors to be discussed.

Simulator Design

There are two areas of interest with respect to the influences of simulator design upon transfer of training: fidelity of simulation and design for training. Fidelity refers to whether features of the aircraft and its environment are included in the simulator's design, and the extent to which features which are included represent or duplicate their real world counterparts. Design for training refers to the inclusion in simulator design of features or configurations which facilitate training but which may bear no particular resemblance to features of the aircraft and environment being simulated.

Fidelity of simulation is often equated with physical correspondence between the device and its real world counterpart. In their discussion of simulator design considerations, however, Smode and Hall (26) emphasize instructional strategies and capabilities and suggest that fidelity has meaning in terms of the process and the realism necessary to promote learning. Design characteristics, they assert, should be defined in terms of assuring transfer of training. In other words, fidelity of simulation is a matter of the relevance of the simulation to the training objectives, not solely a matter of physical correspondence. This concept of fidelity accounts for the effectiveness of so-called low fidelity devices as well as simulators that faithfully reproduce much of the aircraft.

Design for Training. The Smode and Hall concept of fidelity is of particular interest with respect to simulator features not modeled after the aircraft. These features, which are concerned primarily with application of principles of learning to the training process, include freeze, adaptive training, prompting and cueing, performance recording and playback, performance measurement, and various instructor station displays and controls. It is generally held that such features improve the conditions under which learning takes place and thereby facilitate the attainment of training objectives. Therefore, they are factors to be considered in judging the fidelity of a device so far as training is concerned.

It is general practice to adopt innovative simulator design features such as those mentioned above on the basis of their apparent utility without subjecting them to experimental scrutiny. For example, the widely used simulator freeze feature was implemented because it was seen as an aid to attaining training objectives and to implementing learning concepts during the instructional process. Similarly, other design decisions are made because the training objectives and planned concepts of simulator employment lead to the conclusion that a particular design is appropriate in preference to others. For example, in the design of U.S. Army simulators for the Vertol CH-47 and the Bell AH-1 helicopters, the instructor stations were located virtually inside the cockpits of these devices, and certain instructor displays were positioned so that they could be viewed by both the instructor and the trainees in order to facilitate instructor-trainee interactions during key training activities. The training effectiveness of these features probably will never be determined in a transfer experiment for the methodology reasons discussed above. Analytically, they are believed to represent effective simulator designs with respect to the Army's training program and the training objectives to be addressed.

Visual Fidelity. Generally, tasks which cannot be duplicated or even approximated in a device cannot be learned there for subsequent transfer to the aircraft. Therefore, a simulator in which more tasks characterizing flying can be performed has greater potential training effectiveness than one in which fewer such tasks can be performed. For example, a simulator which does not include an extra-cockpit visual display would seem to have less effectiveness potential with respect to training tasks requiring visual references than a simulator with such a display.

There have been a number of studies in which transfer from a simulator with a visual display has been demonstrated. The scenes presented by some of these displays are much simpler than scenes viewed from an aircraft. For example, savings in aircraft time required to perform visual reference maneuvers were demonstrated in a study by Flexman, Matheny & Brown (27) using a simulator with a visual display consisting of a line drawing on a blackboard placed in front of the cockpit and tilted by an instructor to change perspective as the device was maneuvered with respect to simulated ground references. The effectiveness of other simple displays consisting of stylized grids and lines has been demonstrated in backward transfer situations during studies of contact analog displays developed for helicopters (28). Displacement of scene elements consisting only of dots and lines was found by Thielges and Matheny (29) to provide sufficient information for the performance of aircraft control tasks, although their study was not based on a transfer model.

These studies indicated that tasks involving aircraft control in relation to extra-cockpit visual information can be practiced effectively in simulators with very simple visual scene displays. The displays consisted of no more than points, lines and geometric patterns arranged in accord with a set of mathematical relationships described by Gibson (30). Several manufacturers currently are taking advantage of the utility of these simple scene content design requirements by marketing displays which represent night scenes as patterned points of light on a black field, and their displays are being used with apparent success in commercial airlines' simulator training programs.

While the effectiveness of such simple visual displays has been demonstrated to the extent described above, it is also noted that simulators without a visual display can be effective in the training of visual reference flight tasks. In a study involving a helicopter simulator without a display or any other representation of outside visual cues except the aircraft's navigation and attitude instruments, and without any attention during simulator training to extra-cockpit visual cues per se, students trained to fly instrument flight missions in the device qualified in the aircraft under visual conditions more rapidly than did students not receiving the prior device training (31). In a similar study using a fixed wing simulator without a visual display, a saving in visual flight time required to complete a transition course of approximately 50% of the scheduled course length was obtained (8). An unreported study by the U.S. Air Force involving cognitive training in a simulator with no visual display demonstrated transfer to visual flying maneuvers such as traffic patterns (32).

While it is not indicated by these studies' results that visual displays have no training value, it appears that many behaviors required as responses to extra-cockpit visual stimuli in the aircraft can be practiced—or at least approximated—in response to stimuli in a simulator without an outside display. Further, cockpit instruments provide information about and an analog display of the visual world outside the cockpit, so a pilot flying instruments is responding to stimuli analogous to those available to the pilot flying visually. At least some of the simulator effectiveness attributed to the simpler visual displays probably would occur without the presence of such a display at all.

During the current review, no studies were found which unequivocably established the effectiveness of any extra-cockpit visual display. While transfer studies involving visual displays were found, only one, an exploratory study judged inconclusive by its authors (33), included a control group in which students were trained in the simulator without using its display. Commerical airlines have reduced aircraft training time following the addition of a visual display to an existing simulator, but some if not all of the reduction resulted from a priori judgments by government agencies and the airlines themselves concerning increased simulator training effectiveness. In no cases have there been reports of efforts to design training programs which would seek the same flight training savings using simulators without visual displays that presumably have been achieved using simulators with such displays.

The lack of evidence of visual display training effectiveness cannot be taken as evidence of their lack of effectiveness. There is a consensus that they are effective, and data to contest that consensus do not exist. Logically, it would appear that an extra-cockpit visual display is an effective way to present visual information used in some operational tasks—such as landing on a carrier, taxiing, refueling, delivering certain kinds of weapons, and air-to-air combat. In some instances, it may be the only effective way. In others, it may be effective, but inefficient, particularly when cost is taken into consideration.

Motion Fidelity. Not much more is known about the influence of motion upon simulator training effectiveness than about visual displays. Although motion simulation has represented a significant portion of the cost of simulator procurement and operation for a number of years, the investigation of the influence of motion upon simulator training effectiveness has been largely ignored. The first significant study involving simulator motion in the transfer of pilot training was reported in 1975 by Jacobs and Roscoe (34).

The results of the Jacobs and Roscoe study provide evidence that transfer may not benefit from the presence of normal washout cockpit motion. In that study, training received in a two-axis normal washout motion condition, compared with training in the same device without motion, resulted in non-significant differences in amount of transfer to the aircraft for these two conditions. There was however, significant positive transfer for both motion and no-motion conditions. Similar results have been obtained in an unpublished U.S. Air Force undergraduate pilot training study involving a more sophisticated six-axis motion system (32).

The Jacobs and Roscoe finding that, at least with beginning trainees, the presence of motion may not increase simulator training effectiveness must be treated with caution until investigated further, since there are other studies suggesting that, at least under some circumstances, motion may be desirable even if not essential. For example, Fedderson (35) reported a slight advantage in favor of a motion-simulator trained group over a no-motion group during brief transfer trials hovering a helicopter. More importantly, perhaps, the motion group in his study reached asymptotic performance in the simulator more rapidly, suggesting that simulators with motion may provide more efficient training, even if not more effective training. NASA researchers (36) have found that the correlation between pilot performance in an aircraft and in a simulator increases with the addition of simulator motion cues where such cues help the pilot in coping with a highly damped or unstable vehicle or a sluggish control system, or under some circumstances, where the control system is too sensitive. Where the aircraft is easy to fly, however, as is the case with the aircraft used in the Jacobs and Roscoe study (Piper Cherokee) and in the Air Force study (T-37), motion has no effect. In another NASA study (37) of the effects of simulator motion on pilots' performance of a tracking task, the results from a moving flight simulator resembled the results from flight much more than did those from a motionless simulator. Huddleston and Rolfe (38) reported that, using simulators without motion, experienced pilots are often able to achieve acceptable levels of performance, but their patterns of control response show that their performance is achieved using a strategy different from that used in a dynamic training environment. Since control strategies may be important during in-flight emergency maneuvers where transfer of training research is not feasible, it would appear inadvisable to eliminate motion from all simulators until further investigation shows the generality of the Jacobs and Roscoe findings. At the present time, we cannot be certain of the role of motion in simulator training effectiveness and efficiency.

Handling Characteristics. Simulators built with the technology available two decades ago tended to have handling characteristics which were sometimes quite unlike those of an aircraft, and their effectiveness was limited largely by the fact that pilots resisted training in them or would use them only as procedures trainers (5). There were—and still are—strong pilot opinions that a simulator had to "feel" like an aircraft if it were to be effective. Transfer studies of individual aircraft control parameters, such as a study of the correspondence in stick pressures between a device and a training aircraft (39) failed to lend support to the pilots' opinions. Where the correspondence between the device and the aircraft is gross, however, as was found in one device in which forward pressure on the wheel resulted in a climb configuration (40), simulator effectiveness undoubtedly will suffer. Thus, although in the extreme case simulator response characteristics unlike those of the aircraft can produce negative transfer of training, there is little evidence that the simulator must precisely duplicate the feel of the aircraft in order to be effective. It is possible, however, that even minor dissimilarities in feel or response could lead to the same kinds of potential problems found in simulators without motion, i.e., lower correlation between simulator and flight performance, particularly where the more difficult to fly aircraft are concerned.

Our understanding of simulator design features in relation to simulator training effectiveness is quite limited. It is clear that designing a simulator is not entirely a matter of duplicating an aircraft. The physical correspondence between the simulator and the aircraft is probably more related to cost, as Miller (41) indicated almost two decades ago, than to training effectiveness. If the degree of correspondence between the device and the aircraft is relevant to the objectives of the intended training, training in the simulator can be made effective—whether it is or not is a matter related to other factors.

Training Programs

Frequent note has been taken of the influence upon training effectiveness of the manner in which a simulator is used. Yet, the literature is full of reports of situations in which the importance of training program design and execution seemed to be ignored (e.g., 5). Although there is an increasing emphasis upon effective use of devices, current instances can be cited of training programs in which simulators are misused or are used inefficiently. Even in simulator effectiveness research, participating instructors often are permitted to conduct training in various non-standardized ways.

To list all training program design and execution variables which potentially influence simulator training effectiveness, would be an almost interminable task. Any of the numerous textbooks on human learning will provide a source for identification of variables which influence learning and performance, e.g., schedules of reinforcement, meaningfulness and difficulty of material to be learned, size of learning blocks and knowledge of results. Flexman, et al., (27) have shown how such variables can be employed to increase simulator and flight training effectiveness.

The sequencing of simulator and aircraft training has been suggested as a factor which could influence the effectiveness of simulator training. Smode, et al. (2) concluded that the evidence concerning whether sequencing is influential was inconclusive. Meister, et al., (11) presented data which suggest that switching from the aircraft to the simulator reduces performance in the simulator on the following sessions, resulting in a training inefficiency. While there may be some interactive effects between the sequence, the manner in which the device is used, and the design of the device which could influence effectiveness, it would appear quite likely that training in the aircraft before the full benefit of the simulator has been realized with respect to a particular task would tend to reduce the overall efficiency of the simulator-device training program. In an unpublished instance which illustrates this view, a fifty training hour program in which the simulator was used prior to training in the aircraft became a sixty training hour program when the sequence was changed to mix simulator and aircraft training, although other changes were introduced concurrently which could have contributed to the resulting inefficiency.

Training program content is an obvious influence upon simulator training effectiveness. A dynamic flight simulator used only as a procedures trainer, for example, is not being used effectively. It is also believed that simulator training presented in the context of simulated mission activities, as opposed to abstract training exercises, tends to be more effective, and the literature on learning and forgetting suggests that behavior learned within such a meaningful context will be less quickly forgotten (42).

There are a number of other training program factors which influence simulator training efficiency and thus would lead to a higher TER value, although not to increased effectiveness per se. These include the amount of simulator training, the sequence in which instruction is conducted in the simulator, the use of individual (as opposed to group) pacing, training to specified criterion levels (as opposed to training for fixed time periods), and the extent to which simulator training includes tasks which can be learned more efficiently in the aircraft. Smode, et al., (2) pointed out a decade ago that little was known about how to manipulate such factors to best advantage. That observation is still valid.

Personnel

Simulator training involves trainees and instructors. Both categories of personnel represent potential influences upon effectiveness. The most obviously relevant considerations with respect to both are their qualifications and prior experience, but occasionally other variables are suggested. For example, Meister, et al. (11), found a difference in the effectiveness of one simulator training program for student and operational pilots vs.

reservists. The difference could also be attributed to considerations such as fatigue and stress, factors which probably account for many unexpected findings in transfer studies. The present paper will discuss only the more obvious personnel factors.

Trainees. All investigations of human learning are subject to the influences of task-related aptitudes of the learners. Aptitudes are defined in terms of learning efficiency, and high aptitude students learn a given task more rapidly or to a greater degree than do low aptitude students. Where the training program involves fixed amounts of simulator training time, high aptitude students learn more tasks to transfer to the aircraft; where training is to fixed performance levels and training time varies, high and low aptitude students achieve about equally, but high aptitude students require less training time in the simulator. A measure of simulator training efficiency such as the TER will yield a higher value for high aptitude students, but this does not indicate that the simulator training program is more effective with such students. It is probably equally effective with both groups of students, but training time in the device will be shorter for one than for the other. Thus, while high aptitude students learn more efficiently, aptitude per se is not believed to be an influence upon simulator training effectiveness.

The influence upon simulator training effectiveness of level of trainee skill or amount of prior flight experience is frequently questioned. Many military pilots and managers acknowledge that simulators provide appropriate training for the airlines, where the trainees are highly experienced, but insist that the deivces cannot be relied upon as extensively to train less experienced military pilots. The skills possessed by these two groups of trainees do differ, qualitatively as well as quantitatively, and the tasks for which they undergo training are not identical. Therefore, the training they receive should not be identical if it is optimally designed to meet their respective training needs, and the characteristics of the simulators involved in their training should vary as well. It does not follow, however, that simulator training can be appropriately designed and conducted for one experience level trainee but not for another. In fact, the experimental evidence does not support the contention that simulator training effectiveness is influenced by level of trainee experience in isolation from other factors. After reviewing a large number of transfer of training studies, Micheli (3) concluded that flight training devices are effective for both neophyte pilot trainees and airline pilots.

Instructors. After reviewing the literature on the flight instructor, Smode, et al. (2), concluded that experienced pilots do not make better in-flight instructors than inexperienced pilots. The same conclusion can be extrapolated to simulator instructors. While the evidence is skimpy, it appears that even personnel with no flight experience can be trained to be effective simulator instructors. For example, in a simulator training study comparing an instructor with several thousand hours military instructor-pilot experience, a recent flight training program graduate, and a non-rated individual with a few hours dual instruction but no other aeronautical experience, no significant differences were found in the in-flight performance of their students (13).

There is some evidence that not all simulator instructors are equally prepared for their job. Hall, et al. (5) surveyed a number of military training programs and found that non-rated enlisted instructors were ill prepared as compared with pilots, particularly with respect to relevant knowledge of the aircraft. They also noted that pilots were similarly ill prepared with respect to knowledge of the capabilities and limitations of the simulators. Since no transfer data were reported, it cannot be determined whether this factor had an influence upon subsequent in-flight performance in favor of either type of instructor.

Muckler, et al. (23) observed that in some cases a simulator instructor must provide supplementary information about the in-flight task which might not be available to a non-rated instructor, thus presumably tipping the scale in favor of pilots as simulator instructors. Muckler, et al., also noted that instructor ability and fidelity of simulation are related in such fashion that as fidelity increases, the necessary level of instructor ability may decrease, and, conversely, as fidelity decreases, instructor ability must increase. This relationship would tend to place the more able instructor in the lower fidelity simulator where a greater amount of supplementary information might be required. It has been my observation that just the opposite situation often obtains. The more experienced pilots instruct in high fidelity simulators, while less experienced and non-rated personnel instruct in older, lower fidelity devices.

Another consideration is whether there should be one instructor or two in a simulator training program. That is, is simulator training effectiveness influenced by whether the simulator instructor is also the in-flight instructor? While this variable has not been isolated for study, there appears to be an increase in effectiveness when a single instructor is responsible for both simulator and aircraft training, and it has become a standard feature of the simulator training programs developed by my organization.[a] One apparent benefit is that the instruction given in the simulator is more compatible with that given in the aircraft when only one instructor is involved, thus reducing any potential negative transfer attributable to instructor-peculiar performance requirements.

It often has been assumed that the instructor is an important factor influencing training effectiveness, and such may well be the case. If so, the influence must be attributable to the manner in which the instructor functions, i.e., to non-standardization in his administration of the training program. There is insufficient evidence available at this time to attribute the assumed influence to instructor experience or qualification per se—assuming he has undergone an instructor training program appropriate to the instructional task at hand.

Attitudes

While the influence of simulator design upon simulator training effectiveness may not always be clear, simulator design has an impact upon instructors and trainees, reflected in their attitudes, which in turn has a large influence upon simulator training effectiveness. Flexman described this impact as follows (quoted in 23, p. 69): "Fidelity of simulation can operate as a motivational variable. If the simulator looks, acts, feels and sounds like the airplane, then the trainee is more likely to be convinced that practice in the device will be beneficial to him." In circular fashion, attitudes also influence simulator design. Williges, et al. (25) noted this phenomenon when they stated that decisions to include complex and expensive motion systems in simulators are invariably determined by pilots' attitudes. It has been my observation that fidelity of simulation has a greater impact upon the attitude of the simulator instructor, particularly if he is a pilot, than it has upon the trainee, and, in turn, instructor attitudes concerning simulator training can determine trainee attitudes.

The most direct effect of trainee and instructor attitude upon simulator training effectiveness is probably upon their willingness to engage in simulator training in the first place. That is, devices which are viewed favorably seem to be used more than those which are viewed less favorably. If the addition of a motion system or visual display to a simulator will result in favorable trainee and instructor attitudes toward simulator training and hence greater utilization of the device, it is possible that more effective simulator training will result from the greater utilization, even though the motion and visual per se may contribute nothing directly to transfer.

[a]The single instructor concept has been used elsewhere at least as early as the late 1940s (44).

It would be a mistake to attribute all favorable attitudes toward simulator training to high fidelity. There are relatively low fidelity devices which are viewed favorably by many trainees and instructors, and some quite sophisticated devices have been maligned unbearably by some of the same people. One device used extensively by the U.S. Army as an instrument trainer for a number of years was extolled by the device instructors, maligned by flight instructors, and described variously as a beast and an aid by trainees. A study of the effectiveness of training conducted in the device was less ambiguous: it was useless (7).

Except to the extent that favorable attitudes increase device use, the effects of attitude upon simulator training appear to be practically nil. In a study reported by Muckler, et al. (23), negative attitudes toward a trainer were induced in an experimental group by stressing the device's low fidelity, while positive attitudes were induced in another group by stressing the same device's training effectiveness. During transfer trials in the aircraft, both groups were found to have benefited, about equally, from the device training, thus indicating that the induced negative attitude did not affect device training effectiveness. An interesting aspect of that study was that the negative attitude group required more training in the device to reach criterion, so that the TER value, had that measure of effectiveness been used, would have been greater for the positive attitude group.

No transfer study was found during the current review which indicated that attitude *per se* was a factor influencing simulator effectiveness. On the basis of my own experience, it appears that just the reverse may be the case: simulator training effectiveness influences attitudes toward simulator training. I have observed abrupt shifts in attitudes, particularly among instructors and training program managers, following demonstrations of simulator effectiveness. In one instance, instructors' very negative attitudes toward reduced scale paper mockups of a cockpit became favorable when they discovered that, unknown to them, their better students were using these "devices" on their own. In a study reported by Meyer, et al. (1), pilots' opinions concerning simulator training were found to be more favorable following their participation in an effective simulator training program than were the opinions of non participating pilots.

In spite of a lack of supporting research evidence, there is a consensus among trainees, instructors and administrators that favorable attitudes toward simulator training increase training effectiveness. This probably is correct in the sense that more extensive use will be made of simulators if they are viewed favorably. It may be, however, that attitudes are influenced more by simulator training effectiveness, than the other way around. A well conducted "test" of the training effectiveness of a simulator may be a very influential factor in assuring that its training value will be realized.

Expectations

Many aviators accept the proposition that training in a simulator might be helpful but view it as less effective than training in an aircraft. It has been my observation that simulator training administered under the control of such individuals never exceeds their expectations. If simulators are viewed as useful only as procedures trainers or as instrument trainers, they tend to be used only as procedures or instrument trainers, even though the same devices might be used more effectively by others who view them as offering a greater range of training opportunities. If simulators are viewed as useful only for the initial stages of the development of a particular skill, to be followed by further development of that skill in the aircraft, simulator training is less effective than if they are viewed as substitutes for the aircraft to be used for the development of a particular skill to criterion before transferring to the aircraft. While simulator training may not always prove as effective as some might expect, expectations appear to place a limit upon realized effectiveness by limiting the manner and extent of simulator training.

Expectations can influence simulator training effectiveness in more subtle ways as well. The expectation that a simulator training program will prove ineffective can influence its evaluation in the expected direction. Research by Rosenthal (45) has shown that, even with no intention to do so, an experimenter influences the outcome of his research in the direction of his expectations. Since many "tests" of the effectiveness of simulator training are conducted by pilots who hold strong views concerning the value of simulator vs. aircraft training, we must assume that their expectations can and sometimes do influence the test data. In those instances in which there is real or perceived pressure from a higher authority to reach a particular finding concerning the utility of a particular simulator, the effect might be even greater.

There is an almost infinite number of factors which might shape expectations concerning simulator training effectiveness. An obvious factor is prior experience with simulator training. The more favorable opinions of pilots toward simulators following participation in an effective simulator training program were noted above. Another factor may be their age. Smode, et al. (2), noted that older pilots tend to make poorer flight instructors, possibly because of a hesitancy to adopt new teaching methods such as the use of simulation. Total flight time is probably also a factor, since the older, more experienced pilots are more likely to have had unsatisfactory experiences with old simulators and typically put greater confidence in in-flight training.

INCREASING SIMULATOR TRAINING EFFECTIVENESS

It is unlikely that the effectiveness of any simulator training program can be attributed to a single influence. Instead, all the factors discussed above, and probably many more subtle ones, act in combination to produce effective simulator training. Even factors which may not be thought influential in isolation may serve as catalysts. Effective simulator training depends upon a proper combination of hardware, program, personnel, and other factors.

Although progress has been made over the four decades since Edwin Link introduced his first instrument flight trainer, there is still an element of uncertainty involved in the design and use of simulators in meeting training objectives. Wheaton and Mirabella (46) noted that simulator designers have often been more artisans than technicians, and because of the informal nature of the methods they use, it is difficult to reproduce their results or to train others to produce effective devices. The same comment can be applied to training program developers, perhaps to an even greater degree. There are artisans who devise effective ways of using simulators, even apparently poorly designed simulators, but these artisans have not been notably successful in training others to produce effective simulator training programs. Conversely, it can be noted that others have produced precious little in the way of effectiveness, even though working with costly simulators of apparently excellent design.

While simulator training artisans can sometimes produce spectacular results, there are too few such individuals to develop and continously update all of the simulator training programs required by military and civilian pilot training establishments and operational units. The present paper was conceived as an attempt to highlight some considerations which, if attended to, might lead to increases in simulator training effectiveness. It may have that effect in some instances, but I am not convinced that our present data base is sufficient to that objective.

Clearly, more research is needed to increase our understanding of factors influencing simulator training effectiveness. But a conceptual framework which could make the conduct of that research more efficient and relevant to generalizable problem solutions is lacking. Because of this lack, training specialists have no theoretically acceptable design models to follow and no effectiveness goals to seek. I do not see much in the recent research literature which will provide the conceptual underpinning for required simulator training designs.

One problem is that insufficient information is being disseminated about the design of simulators and training programs—both effective and ineffective ones. Most published simulator training research reports state the identity of the simulator, the experimental design model, and the results. Often information is not included in the report or otherwise available about the simulator's design, the way it was used, the attitudes and expectations of the personnel involved, and other factors which should be of interest to someone trying to apply the study's results to meet operational training requirements. There needs to be much more emphasis upon *how* the reported results were achieved.

Attempts to apply research results in the design of simulators and training programs are important, but greater benefit can be derived from study of existing devices and programs to locate features which can be adopted in new simulator training programs under development. The most useful model to follow in the development of effective simulator training is that provided by an existing application, modified to incorporate features from other such models as seems appropriate.

The simulator training practitioners and researchers alike need more case study reports of simulator training applications. Such case studies would serve two purposes: they would provide models to be followed in other applications; and they would present design data which could then be assembled and studied in efforts to develop conceptual models for future applications and to guide research.

While I do not mean to relegate research to a lesser position of importance in our efforts to increase simulator training effectiveness, I feel that there needs to be more emphasis at the present time upon gathering data about existing simulators and training programs so that a better conceptual framework can be developed for such research. Our theories need to rest upon a broader data base—data which is derivable from present applications. At the present time, there needs to be more use of the scientific method called naturalistic observation so that a broader data base can be developed. Perhaps the first step is to recognize a need for better communication among practitioners and researchers about the nature of effective simulator training. Such a step could lead to increased simulator training effectiveness through greater familiarity with the processes involved in simulator training.

REFERENCES

1. COMPTROLLER GENERAL OF THE UNITED STATES. Department of Defense Use of Flight Simulators—Accomplishments, Problems, and Possible Savings. Government Printing Office GAO Code 952050, Washington, D.C., 1975.

2. SMODE, A.F., HALL, E.R. and MEYER, D.E. An Assessment of Research Relevant to Pilot Training. Aerospace Medical Research Laboratories Technical Report AMRL-TR-66-196, Wright-Patterson Air Force Base, OH, 1967.

3. MICHELI, G. Analysis of the Transfer of Training, Substitution and Fidelity of Simulation of Training Equipment. Naval Training Equipment Center TAEG Report 2, Orlando, FL, 1972.

4. MEYER, D.E., FLEXMAN, R.E., VAN GUNDY, E.A., KILLIAN, D.C. and LANAHAN, C.J. A Study of Simulator Capabilities in an Operational Training Program. Aerospace Medical Research Laboratories Technical Report AMRL-TR-67-14, Wright-Patterson Air Force Base, OH, 1967.

5. HALL, E.R., PARKER, J.F. Jr. and MEYER, D.E. A Study of Air Force Flight Simulator Programs. Aerospace Medical Research Laboratories Technical Report AMRL-TR-67-111, Wright-Patterson Air Force Base, OH, 1967.

6. MACKIE, R.R., KELLEY, G.R., MOE, G.L. and MECHERIKOFF, J. Factors Leading to the Acceptance or Rejection of Training Devices. Naval Training Equipment Center Technical Report NAVTRAEQUIPCEN 70-C-0276-1, Orlando, FL, 1972.

7. ISLEY, R.N., CARO, P.W. and JOLLEY, O.B. Evaluation of Synthetic Instrument Flight Training in the Officer-Warrant Officer Rotary Wing Aviator Course. Human Resources Research Organization Technical Report 68-14, Alexandria, VA, 1968.

8. CARO, P.W., ISLEY, R.N. and JOLLEY, O.B. Research on Synthetic Training: Device Evaluation and Training Program Development. Human Resources Research Organization Technical Report 73-20, Alexandria, VA, 1973.

9. GAGNE, R.M. Training Devices and Simulators: Some Research Issues. American Psychologist. Vol. 9, No. 3, p. 159, March 1954.

10. JEANTHEAU, G.G. Handbook for Training Systems Evaluation. Naval Training Device Center Technical Report NAVTRADEVCEN 66-C-0113-2, Orlando, FL, 1971.

11. MEISTER, D., SULLIVAN, D.J., THOMPSON, E.A. and FINLEY, D.L. Training Effectiveness Evaluation of Naval Training Devices Part II. A Study of Device 2F66A (S-2E Trainer) Effectiveness. Naval Training Device Center Technical Report NAVTRADEVCEN 69-C-0332-2, Orlando, FL, 1971.

12. ADAMS, J.A. and McABEE, W.H. A Program for a Functional Evaluation of the GAM-83 Melpar Trainer. Air Proving Ground Center Report APGC-TN-61-41, Eglin Air Force Base, FL, 1961.

13. MATHENY, W.G. Training Simulator Characteristics: Research Problems, Methods and Performance Measurement. In Aircrew Performance in Army Aviation. U.S. Army Office of the Chief of Research, Development and Acquisition, Washington, D.C., 1974.

14. CARO, P.W. Equipment-Device Task Commonality Analysis and Transfer of Training. Human Resources Research Organization Technical Report 70-7, Alexandria, VA, 1970.

15. GAGNE, R.M., BAKER, K.E. and FOSTER, H. On the Relation Between Similarity and Transfer of Training in the Learning of Discriminative Motor Tasks. Special Devices Center Technical Report SDC 3.6-1-5, U.S. Navy Office of Naval Research, Washington, D.C., 1949.

16. OSGOOD, C.E. Method and Theory in Experimental Psychology. Oxford University Press, New York, 1953.

17. MIRABELLA, A. and WHEATON, G. Prediction of Training Device Effectiveness from Quantitative Task Indices. In Proceedings of the Sixth Naval Training Equipment Center and Industry Conference. Naval Training Equipment Center Report NAVTRAEQUIPCEN IH-226, Orlando, FL, 1973.

18. GAGNE, R.M., FOSTER, H. and CROWLEY, M.E. The Measurement of Transfer of Training. U.S. Naval Medical Research Laboratory Report No. 3388, New London, CT, 1947.

19. MURDOCK, B.B. Jr. Transfer Designs and Formulas. Psychological Bulletin. Vol. 54, p. 313, 1957.

20. HAMMERTON, M. Measures for the Efficiency of Simulators as Training Devices. Ergonomics. Vol. 10, p. 63, 1967.

21. POVENMIRE, H.K. and ROSCOE, S.N. An Evaluation of Ground-based Flight Trainers in Routine Primary Flight Training. Human Factors. Vol. 13, p. 109, 1971.

22. ROSCOE, S.N. A Little More on Incremental Transfer Effectiveness. Human Factors. Vol. 14, p. 363, 1973.

23. MUCKLER, F.A., NYGAARD, J.E., O'KELLY, L.I. and WILLIAMS, A.C. Jr. Psychological Variables in the Design of Flight Simulators for Training. Aerospace Medical Laboratory Technical Report WADC 56-369, Wright-Patterson Air Force Base, OH, 1959.

24. VALVERDE, H.H. Flight Simulators: A Review of the Research and Development. Aerospace Medical Research Laboratory Technical Report AMRL-TR-68-97, Wright-Patterson Air Force Base, OH, July 1968.

25. WILLIGES, B.H., ROSCOE, S.N. and WILLIGES, R.C. Synthetic Flight Training Revisited. Human Factors. Vol. 15, p. 543, 1973.

26. SMODE, A.F. and HALL, E.R. Translating Information Requirements into Training Device Fidelity Requirements. In Proceedings Human Factors Society 19th Annual Meeting. Human Factors Society, Santa Monica, CA, 1975.

27. FLEXMAN, R.E., MATHENY, W.G. and BROWN, E.G. Evaluation of the School Link and Special Methods of Instruction in a Ten-hour Private Pilot Flight-Training Program. University of Illinois Aeronautics Bulletin No. 8, Urbana, IL, 1950.

28. DOUGHERTY, D.J. Final Technical Report, JANAIR Contract 4429(00). Bell Helicopter Company, Joint Army and Navy Aircraft Instrumentation Research (JANAIR) Technical Report No. D288-100-001, Fort Worth, TX, 1966.

29. THIELGES, J.R. and MATHENY, E.G. Analysis of Visual Discriminations in Helicopter Control. Human Resources Research Organization Technical Report 71-13, Alexandria, VA, 1971.

30. GIBSON, J.J. The Perception of the Visual World. Houghton Mifflin Co., New York, 1950.

31. CARO, P.W., ISLEY, R.N. and JOLLEY, O.B. Mission Suitability Testing of an Aircraft Simulator. Human Resources Research Organization Technical Report 75-12, Alexandria, VA, June 1975.

32. Personal Communication, Technical Director, U.S. Air Force Human Resources Laboratory—Flying Training, January 26, 1976.

33. YOUNG, L.L., Jensen, R.S. and TREICHEL, C.W. Uses of a Visual Landing System in Primary Flight Training, University of Illinois Aviation Research Laboratory Technical Report ARL-73-26/AFOSR 73-17, Savoy, IL, 1973.

34. JACOBS, R.S. and ROSCOE, S.N. Simulator Cockpit Motion and the Transfer of Initial Flight Training. In Proceedings Human Factors Society 19th Annual Meeting. Human Factors Society, Santa Monica, CA, 1975.

35. FEDDERSON, W.E. The Role of Motion Information and its Contribution to Simulation Validity. Bell Helicopter Company Technical Data Report No. D228-429-001, Fort Worth, TX, 1962.

36. RATHERT, G.A. Jr., CREER, B.Y. and SADOFF, M. The Use of Piloted Flight Simulators in General Research. Advisory Group for Aeronautical Research and Development, North Atlantic Treaty Organization Report 365, Paris, France, 1961.

37. DOUVILLIER, J.G. Jr., TURNER, H.L., McLEAN, J.D. and HEINLE, D.R. Effects of Flight Simulator Motion on Pilots' Performance of Tracking Tasks. National Aeronautics and Space Administration Technical Note NASA-TN-D-143, Washington, D.C., 1960.

38. HUDDLESTON, H.F. and ROLFE, J.S. Behavioral Factors Influencing the Use of Flight Simulator for Training. Applied Ergonomics, Vol. 2.3, p. 141, 1971.

39. MATHENY, W.G., WILLIAMS, A.C. Jr., DOUGHERTY, D.J. and HASLER, S.G. The Effect of Varying Control Forces in the P-1 Trainer upon Transfer of Training to the T-6 Aircraft. Human Resources Research Center Technical Report HRRC-TR-53-31, Goodfellow Air Force Base, TX, 1953.

40. U.S. ARMY AVIATION TEST BOARD. Military Potential Test of Fixed Wing Basic Instrument Trainer 2-B-12A. U.S. Army Aviation Test Board Report of Test USATECOM Project No. 4-3-5150-01-9, Ft. Rucker, AL, 1963.

41. MILLER, R.B. Psychological Considerations in the Design of Training Equipment. Wright Air Development Center Technical Report WADC TR-54-563, Wright-Patterson Air Force Base, OH, December 1954.

42. JENKINS, J.J. Remember that Old Theory of Memory? Well Forget It! American Psychologist. Vol. 29, p. 785, 1974.

43. CARO, P.W., ISLEY, R.N. and JOLLEY, O.B. The Captive Helicopter as a Training Device: Experimental Evaluation of a Concept. Human Resources Research Organization Technical Report 68-9, Alexandria, VA, 1968.

44. WILLIAMS, A.C. Jr. and FLEXMAN, R.E. Evaluation of the School Link As an Aid in Primary Flight Instruction. University of Illinois Institute of Aviation Aeronautical Bulletin No. 5, Savoy, IL, 1949.

45. ROSENTHAL, R. Unintended Communication of Interpersonal Expectations. American Behavioral Scientist. Vol. 10, p. 24, 1967.

46. WHEATON, G.R. and MIRABELLA, A. Quantitative Task Analysis and the Prediction of Training Device Effectiveness. In Proceedings of the Fifth Naval Training Device Center and Industry Conference. Naval Training Equipment Center Report IH-206, Orlando, FL, 1972.